Humus formation as a business model? Analysis of farmers' perceptions on carbon sequestration programmes

Abstract

Mitigating climate change by sequestering carbon in agricultural soils through humus formation is a crucial component of sustainable agriculture. This study examines the uptake of non-governmental humus programmes to promote carbon sequestration by analysing, for the first time, farmers' intentions and factors influencing participation. Humus programmes are still recent innovations, so current knowledge about farmers' motivation to participate is limited. We specifically investigate behavioural factors underlying farmers' adoption of humus programmes using the Theory of Planned Behaviour. To this end, we collected data using an online survey with 190 German farmers and applied partial least squares structural equation modelling. Results show that perceived economic benefits, fellow group norm and moral norm have a statistically significant influence on farmers' intention to participate in a humus programme. In contrast, perceived ecological benefits, political group norm as well as perceived arable and regulatory behavioural control have no considerable influence. Furthermore, there are deficits in knowledge among farmers about registration and the general functioning of humus programmes. These findings, which could also be an interesting starting point for European agriculture as a whole, suggest that emphasizing the financial benefits of humus programmes, combined with the use of community expectations and moral considerations, can increase participation in such initiatives.

Keywords: agricultural soil, carbon sequestration, farmer, humus, Theory of Planned Behaviour

1 Introduction

Agriculture might hold the key to successful climate change mitigation, particularly through the formation of humus in agricultural soils. Humus consists of plant residues and other organic material that stores carbon dioxide from the atmosphere in soil (Chenu et al., 2019). Carbon farming measures such as intercropping, no-tillage and agroforestry systems enable farmers to increase the humus content of their soils and thus sequester carbon dioxide (Sharma et al., 2021). Carbon dioxide is one of the greenhouse gases (GHGs) that is mainly responsible for global warming and the resulting climate change (IPCC, 2022; Ramanathan and Feng, 2009). The carbon storage capacity of soils is promising, as it is three times greater than the carbon pool of the atmosphere (Lal, 2004). The annual carbon storage potential of agricultural soils is estimated to be 1.5-15% of global anthropogenic carbon emissions (Janzen et al., 2022; Lal, 2004).

In addition to carbon sequestration, humus formation has numerous other benefits. An increase in humus content leads to better soil fertility, higher nutrient storage, better soil structure, improved water availability and better erosion control. Farmers benefit from these properties in land management, especially with rising temperatures and increasing frequency of extreme weather events (Lal, 2004;

Sharma et al., 2021). These soil-ecological advantages of an increased humus content can lead to higher and more stable yields and thus to economic advantages at farm level.

In response to both the increasing importance of strategies to avoid and remove greenhouse gases, and to the pricing of carbon emissions, 'humus programmes' have emerged (European Commission, 2021b; Oldfield et al., 2022). With humus programmes, non-governmental organizations link humus formation and humus certificates. In this way, farmers receive a payment for building up humus, which is linked to the final increase in humus or the application of a humus-building measure. The payment is funded by the sale of humus certificates to companies or private households that want to offset their carbon emissions.

Although the potential of carbon storage in the soil for climate protection is increasingly recognized, farmers' awareness and adoption of humus programmes is still limited. So far, there are only a few humus programmes worldwide, which are almost exclusively managed by non-governmental organizations (CarboCert, 2022; Ökoregion Kaindorf, 2022; Positerra, 2022). In addition to the humus programmes, there are more general (non-governmental) carbon farming initiatives in several countries that take a slightly different approach (Climate-KIC, 2022; Greening Australia, 2023; Life Carbon Farming, 2021). The world's leading platform for carbon storage in soils is 'AgreenaCarbon', which uses satellite technology to determine e.g. the type of tillage, cover crops or crop rotation and issues carbon dioxide certificates to farmers in 17 European markets (Agreena, 2023). In Australia, there is already one governmental carbon farming project (Australian Government Clean Energy Regulator, 2023). In Europe, governmental pilot projects for carbon farming are underway, e.g. Interreg North Sea Region Carbon Farming (European Union, 2023), and the European Commission (2021a) is increasing support for carbon farming and associated business models.

To support an effective design of humus programmes and increase their scope, it is essential to understand farmers' decision-making. The decision to change land management practice and to participate in Agri-Environmental-Schemes (AES) is driven by financial incentives (Bartkowski and Bartke, 2018), but not exclusively. Numerous studies have shown that behavioural factors – including cognitive, emotional, personal, and social aspects – play a crucial role in farmers' decisions to adopt sustainable practices (e.g. Dessart et al., 2019; Läpple and Kelley, 2015; Mzoughi, 2011; Tran-Nam and Tiet, 2022; Willock et al., 1999). In addition, the relationships between behavioural factors and, for example, participation in AES are often case- and context-specific, i.e. heterogenous (Schaub et al., 2023). Insights in the influence of behavioural factors are important for the voluntary adoption of sustainable land use practices and help guide Agri-environmental policy (Dessart et al., 2019). Hou and Hou (2019) investigated the decision-making process of Chinese farmers regarding the adoption of low-carbon production, but there is no study on the adoption of carbon sequestration programmes and the relationships to behavioural factors. However, with the rising demand of GHG reduction and increasing government interest in carbon farming business models, it is important to identify behavioural factors that influence farmers' willingness to participate in humus programmes.

The aim of this study is to identify and analyse how various behavioural factors influence farmers' intention to adopt a humus programme. To our knowledge, this is the first study that aims to gain a deeper understanding of farmers' motivation to participate in humus programmes by applying the conceptual framework of the Theory of Planned Behaviour (TPB). We have extended the original framework first introduced by Ajzen (1985) to complement existing constructs and to include a new construct: the moral norm. The moral norm has not yet been integrated as a construct in the TPB, but has already been considered in other studies on the adoption of sustainable practices by farmers (Johansson et al., 2013). Although our study is based on a sample of German farmers, our results could be partially transferable to other countries where a sensitivity for climate change mitigation exists. Our research provides valuable insights into the mechanisms that can drive participation in carbon sequestration initiatives and thereby advance carbon farming globally. Our findings are of interest to policy makers, programme providers and researchers as they help them develop effective strategies to increase carbon stocks, recruit farmers and guide the direction of research.

The remainder of this study is structured as follows: section 2 contains the theoretical framework as well as the data collection and the econometric modelling. Section 3 presents and discusses the results, followed by our conclusions and perspectives for further research in section 4.

2 Material and methods

Section 2.1 describes the conceptual framework and the associated hypotheses. Section 2.2 clarifies the data collection as well as the structure of the questionnaire and section 2.3 presents the econometric modelling.

2.1 Conceptual framework

The TPB is based on the Theory of Reasoned Action (TRA) (Ajzen and Fishbein, 1980; Fishbein and Ajzen, 1977) and predicts human behaviour by analysing individual's intention to perform a certain behaviour. Intentions are assumed to capture motivating factors that affects behaviour and indicate people's efforts to perform the behaviour (Ajzen, 1991). Both theories (TPB and TRA) assume that intention is influenced by the 'attitude towards behaviour' and the 'subjective norm'. The TPB goes beyond purely volitional behaviours by adding 'perceived behavioural control' as a third latent construct that influences intention (Ajzen, 1991, 1985). In general, the more positive the attitude and subjective norm toward a behaviour and the greater the perceived behavioural control, the stronger a person's intention to display the respective behaviour. The relative importance of all three constructs in predicting intention depends on the behaviour and the situation, i.e. it is context dependent (Ajzen, 1991).

We use the TPB to assess farmers' intention to participate in a humus programme. Accordingly, the behaviour in our case is participation in humus programmes, which is associated with the adoption of carbon farming measures and possibly a change in land use. The TPB has already been applied to gain insights into farmers' decisions to participate in biodiversity conservation contracts (Greiner, 2015), to choose mixed cropping systems (Bonke and Musshoff, 2020), or to adopt low-carbon agriculture (Hou and Hou, 2019). Based on the TPB, we investigate the influence of attitude, social norm and perceived behavioural control on the intention to participate in humus programmes. In doing so, we have extended the TPB by going beyond existing constructs and adding a new construct (moral norm). The extension of the core construct of TPB to include, for example, personal and group norms, self-identity and perceived ecological/economic benefits is not uncommon (Bonke and Musshoff, 2020; Lokhorst et al., 2011; Michels et al., 2022). Extensions and adaptations of the constructs to the research context lead to a deeper understanding of farmers' decision-making. The constructs and the associated hypotheses that we used in this study are shown in Figure 1 and are explained in more detail below.

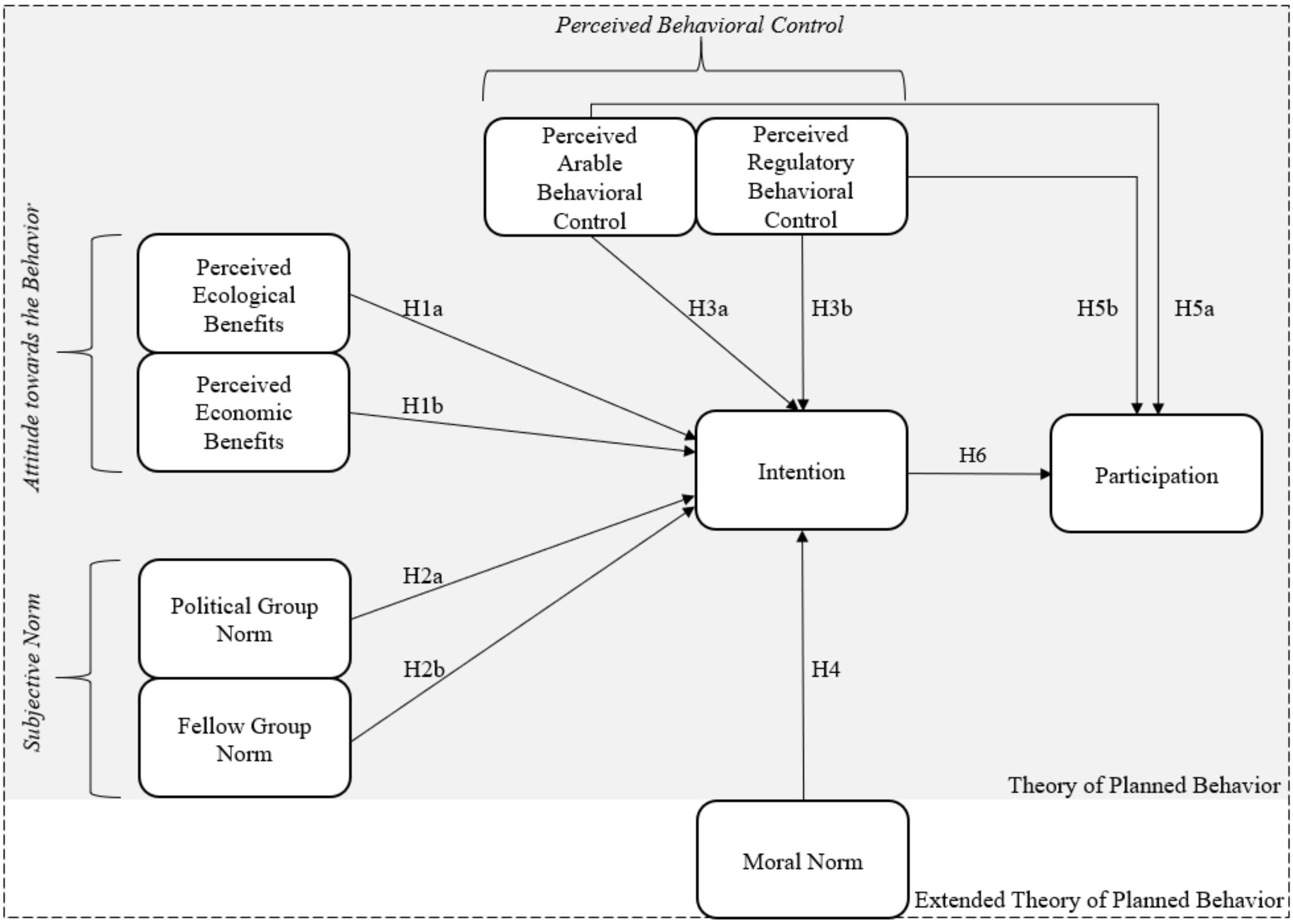

Figure 1: Extended Theory of Planned Behaviour, which is used in this study and is based on Ajzen (1991, 1985)

Attitude towards the behaviour is a latent construct that captures a person's favourable or unfavourable evaluation of the behaviour in question (Ajzen, 1985). Humus programmes touch two areas of a farmer's mindset. On the one hand, the attitude towards the ecological aspects of humus formation, meaning the reduction of carbon dioxide in the atmosphere and the improvement of soil fertility, is important. On the other hand, the attitude towards economic aspects of the humus programme is addressed by the payment for carbon sequestration. A positive influence of perceived ecological benefits and perceived economic benefits on farmers' attitudes, e.g. towards the use of herbicide resistance tests, is confirmed (Michels et al., 2022). Bonke and Musshoff (2020) found that ecological benefits lead to a higher attitude, which in turn leads to a higher intention to adopt mixed cropping. Furthermore, perceived (environmental) benefits influence the adoption of cover crops and conservation practices (Arbuckle and Roesch-McNally, 2015; Reimer et al., 2012). Economic benefits are the most important drivers for farmers' participation in AES (Lastra-Bravo et al., 2015; Wąs et al., 2021). Dessart et al. (2019) summarizes several studies that demonstrate a positive effect of perceived environmental and financial benefits on participation in agricultural payment-for-environmental-services programmes and the adoption of organic farming practices (e.g. Läpple and Kelley, 2015; Ma et al., 2012). With this in mind, we divided the attitudinal construct into perceived ecological and economic benefits of humus formation and humus programmes and derived the following hypotheses:

H1a: The perceived ecological benefits have a positive and statistically significant influence on farmers' intention to participate in a humus programme.

H1b: The perceived economic benefits have a positive and statistically significant influence on farmers' intention to participate in a humus programme.

The subjective norm is a latent construct that refers to the perceived social pressure to behave in a specific way (Ajzen, 1991). In relation to humus formation, social pressure arises, for example through political guidelines or through peers. Political requirements, especially with regard to environmental sustainability, are increasing in agriculture. Recently, the environmental conditions and standards for agricultural production in the European Union were tightened as part of the Common Agricultural Policy (CAP). At the same time, farmers now have a wider range of voluntary environmental measures at their disposal (European Commission, 2023). The constant reference to or emphasis on sustainability can lead to political pressure, so that farmers feel forced to participate in sustainable measures even without regulation. As there are areas in agriculture where emissions cannot be reduced as effectively, e.g. in livestock farming (Federal Environment Agency Germany, 2023), there may also be climate policy pressure to compensate for these unavoidable emissions elsewhere. In addition, the recommendation of peers, also known as the 'neighbour effect', often has an impact on the farmer's decision, e.g. regarding participation in AES (Villamayor-Tomas et al., 2021). The adoption of mixed cropping and other sustainable practices is more likely if neighbouring farmers have applied the practice (Bonke and Musshoff, 2020; Dessart et al., 2019). Consequently, we formulate the following hypotheses:

H2a: The perceived group norm by environmental policy (political group norm) has a positive and statistically significant influence on farmers' intention to participate in a humus programme.

H2b: The perceived group norm by fellow farmers participating in humus programmes (fellow group norm) has a positive and statistically significant influence on farmers' intention to participate in a humus programme.

Perceived behavioural control is a latent construct that refers to the perceived ease or difficulty in performing the behaviour. In this case, previous experiences, expected obstacles, access, and need for resources are considered (Ajzen, 1991, 1985). As far as humus programmes are concerned, behavioural control is two-sided: arable behavioural control and regulatory behavioural control. Farmers' arable farming skills are addressed, as humus build-up must be in line with the general arable management concept, farm procedures, and available agricultural equipment. Teff-Seker et al. (2022) stated that knowledge of how to implement agri-environmental practices according to farm-specific procedures and characteristics would increase the long-term use of agri-environmental measures. Morgan et al. (2015) found that farmers who have the appropriate knowledge and skill are more likely to adopt low emission agricultural practices. Furthermore, humus programmes are not easy to understand and are mainly conducted online, which requires regulatory skills, e.g. process knowledge and technical understanding. Previous experiences with environmental programmes are positively related to farmers' participation in AES (Breustedt et al., 2013; Gatto et al., 2019) and other environmental programmes (Ma et al., 2012). According to Lemken et al. (2017), the perception of technical barriers considerably hinders the adoption of mixed cropping. We therefore hypothesize the following:

H3a: The perceived arable behavioural control has a positive and statistically significant influence on farmers' intention to participate in a humus programme.

H3b: The perceived regulatory behavioural control has a positive and statistically significant influence on farmers' intention to participate in a humus programme.

In addition to the subjective norm, the moral norm can also influence farmers' behavioural decisions. The moral norm reflects the self-created pressure to do 'the right thing'. It is based on individual conscience, ethical principles and concern for the welfare of others (Cushman, 2015). Farmers who care deeply about others and have high empathy scores are more likely to use conservation tillage (Sheeder and Lynne, 2011) and participate in voluntary forest conservation or wetland restoration (Johansson et al., 2013). Mzoughi (2011) found that avoiding guilt is one reason why farmers adopt organic practices and that organic farmers are happier. The intrinsic urge to contribute to climate change mitigation by building up humus, which is only possible for farmers, could be an important reason for participating in humus programmes. Therefore, we hypothesize the following:

H4: The perceived moral norm in relation to climate protection has a positive and statistically significant influence on farmers' intention to participate in a humus programme.

According to the TPB framework, the perceived behavioural control and the intention to carry out a specific behaviour have a direct influence on the actual behaviour. Greater perceived behavioural control increases the likelihood that the behaviour will actually be carried out. In addition, the stronger the intention to behave in a certain way, the more likely it is that the behaviour will be performed (Ajzen, 1991). Both can be assumed for participation in humus programmes. From this we derive the following hypothesis:

H5a: The perceived arable behavioural control has a positive and statistically significant influence on farmers' participation in a humus programme.

H5b: The perceived regulatory behavioural control has a positive and statistically significant influence on farmers' participation in a humus programme.

H6: Farmers' intention to participate in a humus programme has a positive and statistically significant influence on farmers' participation in a humus programme.

2.2 Survey design and data collection

We collected primary data from German farmers in an anonymous online experiment in January and February 2023, after pre-testing the questionnaire to ensure unambiguous questions. Farmers were invited to voluntarily participate in the experiment via email and internet appeal. The e-mail addresses were taken from a mailing list that had been created as part of previous surveys and in which farmers had explicitly expressed their interest in receiving invitations to participate in further surveys. In addition, the Westphalian-Lippe Agricultural Association has launched an internet call for participation in our survey on its website. The ethics committee and the data protection commissioner of the University of Goettingen reviewed and approved the project and the questionnaire in advance. The questionnaire was divided into five parts: first, farmers were asked to provide information on their farm characteristics, e.g. farm size, livestock density and soil type. The farmers also had to answer whether they knew the humus content of their fields, were already using humus-forming measures and were currently participating in a humus programme. In a second part, a discrete-choice-experiment followed. Third, farmers' risk and time preferences were elicited using incentivized lottery choices. Choice experiment and preference measures are not part of this study. Fourth, the farmers responded to the statements on the TPB constructs listed in Table 2 (see section 3.2), on a Likert-scale from 1 for complete disagreement to 5 for complete agreement. Fifth, socio-demographic data such as age, college degree and gender were collected.

In total, 283 farmers started the survey and 93 withdrew during the survey, leaving 190 fully answered questionnaires for the econometric analysis. The average time to complete the survey was 31 minutes. Farmers who completed the questionnaire could choose between a petrol station voucher and a DIY voucher worth 15 € and had a 10% chance of winning a pay-out of up to 346.50 € in the lottery decisions (third part of the experiment).

2.3 Measurement model

Structural Equation Modelling (SEM) facilitates the estimation of causal relationships between independent (exogenous) and dependent (endogenous) latent variables or constructs. Since constructs are indirectly observable, they are measured and subsequently estimated using indicators. In the context of surveys, indicators are often statements that are evaluated by the participants (Sarstedt et al., 2014). SEM comprises two approaches: covariance-based SEM (CB-SEM) and variance-based SEM. CB-SEM minimizes the discrepancy between the estimated and sample covariance matrices. Conversely, Partial Least Squares SEM (PLS-SEM), a non-parametric variance-based SEM, maximizes the explained variance (R^2) of the endogenous constructs (Hair et al., 2014; Hair et al., 2011). This study uses PLS-SEM for two reasons: it has fewer limitations in terms of data structure than CB-SEM, which requires normally distributed data, and it permits the use of constructs with only one or two indicators (Hair et al., 2022; Hair et al., 2014).

The models estimated via PLS-SEM are evaluated in a two-step process according to Hair et al. (2022). First, the relationships between the indicators and constructs are evaluated. Each indicator is conceptualized as a linear function of the corresponding construct plus a residual term:

$$X_i = \Lambda_i \xi_i + \varepsilon \quad (1)$$

$$X_j = \Lambda_j \xi_j + \delta \quad (2)$$

where ξ_i is the vector of exogenous constructs and ξ_j is the vector of endogenous constructs. X_i and X_j characterize the associated vectors of the indicators $(x_1, \dots, x_i; x_1, \dots, x_j)$ of the exogenous construct ξ_i and endogenous construct ξ_j, respectively. In addition, Λ_i and Λ_j reflect the matrices of indicator loading $(\lambda_1, \dots, \lambda_k)$, where K is the number of indicators. ε and δ are the vectors of the measurement errors for the indicators (Chin, 1998).

Indicator reliability, internal consistency, convergent validity, and discriminant validity are essential metrics for the evaluation of the outer model in PLS-SEM (Hair et al., 2022). To establish indicator reliability, the standardized loadings of an indicator λ should be above 0.7, which means that the construct explains more than 50% of the indicator's variance. Internal consistency is given if the composite reliability (CR; ρ_c) is above 0.7, meaning that all indicators actually measure the same construct. The CR for a construct ξ_j is estimated as follows:

$$CR\xi_j = \frac{\left(\sum_{k=1}^{k_j} \lambda_{jk}\right)^2}{\left(\sum_{k=1}^{k_j} \lambda_{jk}\right)^2 + \Theta_{jk}} \quad (3)$$

where λ_{jk} is the indicator loading and Θ_{jk} is the error variance of the k^{th} $\left(k = 1, \dots, K_j\right)$ indicator for the construct ξ_j. The Average Variance Extracted (AVE) serves as a critical criterion for the assessment of convergent validity and should be above 0.5. This threshold value implies that the construct explains more than half of the variance observed in the indicator. The AVE for a latent construct ξ_j can be estimated as follows (Hair et al., 2022):

$$AVE\xi_j = \frac{\sum_{k=1}^{k_j} \lambda_{jk}^2}{\sum_{k=1}^{k_j} \lambda_{jk}^2 + \Theta_{jk}} \tag{4}$$

Discriminant validity can be established by calculating the Heterotrait-Monotrait (HTMT) correlations between the constructs to ensure that the constructs are distinguishable and that each indicator uniquely represents a construct. The HTMT ratios should be kept below 0.9 to confirm this validity (Hair et al., 2022; Henseler et al., 2015) and can be estimated for two constructs ξ_i and ξ_j with the indicators K_i and K_j as follows (Henseler et al., 2015):

$$HTMT_{ij} = \frac{\frac{1}{k_i k_j} \sum_{g=1}^{k_i} \sum_{h=1}^{k_j} r_{ig,jh}}{\left(\frac{2}{k_i(k_i-1)} \sum_{g=1}^{k_{i-1}} \sum_{h=g+1}^{k_i} r_{ig,ih} \frac{2}{k_j(k_j-1)} \sum_{g=1}^{k_{j-1}} \sum_{h=g+1}^{k_j} r_{jg,jh}\right)^{\frac{1}{2}}} \tag{5}$$

where r_{ij} is the coefficient for the correlation between two constructs ξ_i and ξ_j.

Next, the inner model representing the relationships between exogenous and endogenous constructs is estimated with standardized path coefficients, denoted as β. These β coefficients, also referred to as direct effects, establish the linkage between the endogenous and exogenous constructs as follows:

$$\xi_j = B\xi_j + \Gamma\xi_i + \zeta \tag{6}$$

B and Γ represent path coefficient matrices, where B is the matrix of coefficients for causal effects between endogenous constructs and Γ is the matrix of coefficients for the causal effects of the exogenous constructs ξ_i on the endogenous construct ξ_j. In PLS-SEM, a latent endogenous construct can also serve as an exogenous construct for another endogenous construct. Consequently, one endogenous construct ξ_j also explains another endogenous construct ξ_j, as expressed in equation (6). Finally, ζ is the residual vector indicating that the exogenous constructs do not comprehensively explain the variance in the latent endogenous construct (Chin, 1998; Hair et al., 2022).

The *t*-statistics used to verify the statistical significance of the β coefficients are calculated using a bootstrapping procedure involving 10,000 subsamples. In addition, the R^2 value of the endogenous construct is evaluated as a quality criterion (Hair et al., 2022). The software *SmartPLS 4* was used to estimate the PLS-SEM model (Ringle et al., 2022).

The target variable in the model is a binary variable with the specification to participate (= 1) or not to participate (= 0) in a humus programme, which is why PLS-SEM is not suitable in this context as it would raise biased standard errors (Hair et al., 2012). Accordingly, we estimated a logistic regression for the binary participation variable, assuming a logistic distribution of the error term ε. The independent explanatory variables are presented by the factor scores for the arable and regulatory perceived behavioural control ($\xi_{ArablePBC_j}$, $\xi_{RegulatoryPBC_j}$) as well as the intention to participate in a humus programme ($\xi_{Intention_j}$) extracted from the PLS-SEM. Formally, the participation decision is specified as:

$$Participation_j = \beta_0 + \beta_1\xi_{ArablePBC_j} + \beta_2\xi_{RegulatoryPBC_j} + \beta_3\xi_{Intention_j} + \varepsilon_j \quad (7)$$

where j represents the individual respondent and ε_j is assumed to be a random error term. The logistic regression was conducted with the software *Stata 17*.

3 Results and discussion

Section 3.1 illustrates the descriptive statistics of the sample. Section 3.2 and section 3.3 present the results of the outer and inner model of the PLS-SEM. Section 3.4 discusses practical and scientific implications.

3.1 Sample

The farmers in our sample differ from the average German farmer population (published by the German Farmers Association, 2022) primarily in terms of age, education, farm size and full-time farming (see Table 1). As the farmers surveyed are on average younger, better educated, and tend to run larger full-time farms, the sample is not representative for the German agricultural sector. However, it could characterize a future sample against the background of increasingly comprehensive entrepreneurial decisions and structural change. It was also expected that an online survey would have a higher response rate among younger people (Wu et al., 2022). There are minor differences in the regional distribution of farms and the proportion of rented land. While eastern and western Germany are well represented in our study, there are around twice as many farms in northern Germany in our sample compared to the average German distribution. The proportion of rented land in our sample is around 12%-points lower than the German average. In terms of gender and livestock density, however, our sample corresponds to the German average. About every second farmer in our sample cultivates loamy and/or sandy soils and about every sixth farmer cultivates clayey and/or silty soils.

Knowledge about humus and the willingness to build up humus is available, but could be improved. Around three quarters of the farmers surveyed already use targeted humus-building measures, but not all of them know the humus content of their soil. Thus, there is an opportunity to make farmers even more aware of objective criteria such as the actual measured humus content in order to make humus formation more targeted and effective. Furthermore, only 8% of farmers in our sample stated that they are currently participating or have participated in a humus programme, while 11% stated they did not know what a humus programme is.

Table 1: Descriptive sample statistics (N=190)

Variable		Mean/Share	SD	German Average [a)]
Age (in years)	<25	2.1%		10.6%
	25-34	24.2%		14.9%
	35-44	27.9%		15.3%
	45-54	21.6%		22.2%
	>54	24.2%		36.9%
College degree (1 = yes)		70.0%		14.0%
Farm size (hectares of total land)		249.5	476.4	64.1
Full-time farming (1 = yes)		77.4%		43.5%
Gender (% of farmers are male)		91.1%		89.0%
Humus content knowledge (1 = yes)		53.7%		n.a.
Humus measure application (1 = yes)		76.3%		n.a.
Humus programme participation (1 = yes)		7.9%		n.a.
Livestock density (in livestock units per hectare)		1.0	1.4	1.1
Region (% of farms in … states)	North	41.1%		20.3%
	East	9.5%		7.8%
	West	26.8%		24.8%
	South	21.1%		47.1%
	Outside Germany	1.6%		n.a.
Rented land (% rented land of total land managed)		48.1%	27.1	60.0%
Soil type (multiple answers possible)	Clay	17.4%		n.a.
	Loam	54.2%		n.a.
	Sand	42.1%		n.a.
	Silt	14.2%		n.a.
	Do not know.	2.6%		n.a.

SD = Standard deviation; n.a. = not available

[a)] German Average published by German Farmers Association (2022)

3.2 Evaluation of the outer model and descriptive indicator results

The results derived from the outer model (see Table 2) were carefully analysed according to the methodology described in Section 2.3. To ensure the quality of the measurement model, we considered various reliability and validity metrics: indicator reliability, composite reliability, convergent validity, and discriminant validity. Indicator loadings predominantly surpass the widely accepted threshold value of 0.7 (Hair et al., 2022), albeit with one exception in the case of the second indicator of the perceived economic benefits construct, which has a loading of $\lambda = 0.667$. However, one assertion of Chin (1998) is that indicators should only be excluded from the model if the loadings are below 0.5. In addition, Hair et al. (2022) suggest that indicators can be considered in the model if their omission has a negative impact on subsequent model results and validity. The bootstrapping results confirm that the loading of the aforementioned indicator is statistically significant, with a $p < 0.01$. Composite reliability was also demonstrated, with all CR values exceeding the benchmark value of 0.7 and the lowest observed value being 0.800. At the same time, convergent validity is confirmed, with all AVE values above the threshold of 0.5 and the lowest value being 0.573. Discriminant validity is also demonstrated, with the highest HTMT value attributed to the correlation between the constructs perceived economic benefits and intention, yielding a value of 0.751 [0.630:0.865] (HTMT values are not listed in Table 2 for reasons of space). According to the reliability and validity metrics, the measurement model is of good quality. The descriptive results for the indicators used to form the constructs, also listed in Table 2, offer some interesting insights, which is why they are discussed below.

Table 2: Descriptive and outer model results (N = 190)

Construct	Statement	Mean (SD)	Outer loading
Attitude towards humus/humus programmes			
Perceived ecological benefits (AVE = 0.590; CR = 0.851)			
	Humus can help maintain and improve soil and water quality.	4.53 (0.66)	0.709***
	Humus build-up promotes biodiversity.	4.34 (0.84)	0.735***
	Measures to increase humus content lead to a reduction in carbon dioxide levels in the atmosphere.	3.84 (0.93)	0.837***
	Humus build-up offers enormous potential for mitigating climate change.	3.08 (1.08)	0.785***
Perceived economic benefits (AVE = 0.573; CR = 0.800)			
	Participation in a humus programme has many advantages.	3.45 (0.91)	0.833***
	The additional expenditure for the application of humus-building measures is sufficiently covered by the humus premium.	2.51 (0.78)	0.667***
	Humus programmes will bring economic benefits in the future.	3.18 (0.87)	0.762***
Subjective norm			
Political group norm (AVE = 0.745; CR = 0.852)			
	Strategies for carbon dioxide reduction, e.g. humus formation, are increasingly coming into political focus.	4.02 (0.89)	0.953***
	Political demands are increasingly taking environmental aspects into account.	3.77 (1.06)	0.763***
Fellow group norm (AVE = 0.732; CR = 0.845)			
	My colleagues, who are friends of mine, think humus programmes are useful.	2.69 (0.87)	0.862***
	Colleagues, who are friends of mine, already participate in humus programmes.	1.98 (0.94)	0.849***
Perceived behavioural control			
Perceived arable behavioural control (AVE = 0.859; CR = 0.924)			
	I have the possibility to integrate humus-building measures into my farm business.	4.11 (0.78)	0.951***
	I have the technical equipment to build up humus.	3.88 (0.91)	0.902***
Perceived regulatory behavioural control (AVE = 0.620; CR = 0.829)			
	I know where to register for a humus programme.	2.45 (1.18)	0.744***
	I am familiar with the basic procedure of a humus programme.	2.72 (1.02)	0.887***
	I understand the principle of a humus programme.	3.77 (0.82)	0.722**
Moral norm (AVE = 0.655; CR = 0.850)			
	It is my responsibility to use the carbon storage in my soils to counteract climate change.	3.56 (1.06)	0.832***
	It is important that all farmers make the best use of their opportunities to contribute to climate change mitigation.	3.71 (0.99)	0.870***
	Building up humus is not a long-term solution to climate change. [a)]	2.73 (1.25)	0.718***
Intention to participate in humus programmes (AVE = 0.897; CR = 0.946)			
	In intend to participate in a humus programme.	3.27 (1.03)	0.959***
	I will not participate in a humus programme in the future. [a)]	2.42 (1.14)	0.935***

AVE = Average variance extracted (Cut-off level >0.5); CR = Composite reliability ρ_c (Cut-off level >0.7); SD = Standard deviation. Asterisks indicate different levels of statistical significance (***p<0.01; **p<0.05; *p<0.1).
[a)] Numerical coding for negatively formulated statements was reserved to establish equal coding for estimation.

Farmers are aware of the benefits of humus build-up and the responsibility to counteract climate change, but there are some uncertainties regarding humus programmes. The mean values for the perceived ecological benefits tend towards agreement, with the highest mean value for the positive effect of humus on soil fertility and water availability. This indicates that farmers have largely recognized the ecological benefits of humus. Farmers' thoughts are more ambiguous when it comes to the perceived economic benefits of humus programmes. They value the payment itself but do not believe that the humus premium adequately covers the additional costs of applying humus-building measures, indicating a lack of clarity among farmers about the economic benefits of humus programmes. The political group norm shows mean values tending towards agreement, suggesting that farmers are aware that carbon sequestration is becoming more valuable to policy and that environmental considerations are increasingly tackled by policy measures. In contrast, the fellow group norm shows mean values that tend towards disagreement, which indicates that most peers do not participate in a humus programme. The low pressure from farmers to participate in humus programmes indicates a possible lack of awareness or popularity of these programmes in farming communities. The mean scores of the perceived arable behavioural control tend towards agreement, i.e. farmers agree that they have the ability and equipment to build humus, so are fairly confident that they can control humus build-up in their soil. However, farmers do not feel that they are familiar with the registration and procedures of humus programmes, indicating a lack of regulatory control, although they tend to agree that they understand the principle of a humus programme. The indicators for the moral norm, i.e. self-imposed pressure, tend towards agreement. This indicates that farmers actually have a sense of duty and strive to meet their own demands as well as feel an obligation to contribute to climate change mitigation by building humus.

In summary, the descriptive indicator results suggest that several approaches are needed to increase participation in humus programmes. This includes providing clear economic incentives and information, simplifying regulatory procedures, improving the visibility and perceived value of these programmes, and harnessing farmers' intrinsic motivation to contribute to environmental sustainability.

3.3 Evaluation of the inner model

The latent constructs we have shown in Figure 1 explain 40% of the variation (R^2) in farmers' intention to participate in a humus programme. The results of the inner model of the PLS-SEM show that perceived economic benefits, fellow group norm and moral norm have a positive and statistically significant influence on farmers' intention to participate (see Figure 2). Consequently, hypotheses H1b, H2b and H4 are confirmed by the model. A higher perceived economic benefit of humus programmes as well as the perceived pressure from other farmers and themselves therefore lead to a higher intention to participate in a humus programme. Perceived economic benefits has the largest path coefficient on intention, which is about three to four times higher than the other coefficients. In contrast to the previous results, hypotheses H1a, H2a, H3a, and H3b are not supported, as the associated path coefficients do not reach statistical significance and have small effect sizes as well. The path coefficient which represents the effect of perceived ecological benefits on intention (H1a) does not even correspond to the expected positive sign. Due to the small effect size and lack of statistical significance of these four constructs, we focus on the other constructs (perceived economic benefits, fellow group norm, moral norm) when developing effective strategies to increase participation in humus programmes.

The relationship between actual participation decision of farmers and the latent constructs arable and regulatory perceived behavioural control (H5a, H5b) as well as intention (H6) is examined using a logistic regression. The goodness-of-fit characteristics for the logit model are reported beneath Figure 2, e.g. the McFadden Pseudo R^2 (between 0.2 and 0.4) and the Hosmer-Lemeshow test (not statistically significant) indicate a (very) good fit of the model. As a robustness check, we tested for multicollinearity and no violation was found (variance inflation factors < 5, tolerances > 0.1) (Curto and Pinto, 2011). The results show that the actual participation in humus programmes is positively and statistically significantly influenced by farmers' regulatory behavioural control (odds ratio (OR) = 1.531) and intention (OR = 2.423). Thus, H5b and H6 are supported by the model. Since the odds ratio for intention is considerably greater than 1, the positive effect of intention on the decision to participate can be described as substantial. In contrast, H5a is not supported, as the perceived arable behavioural control has no statistically significant influence on actual participation and even shows a negative tendency (OR = 0.841). The logit model formally completes the analysis of the TPB and shows that there is no intention-behaviour gap. Therefore, participation in humus programmes can be predicted using the TPB framework.

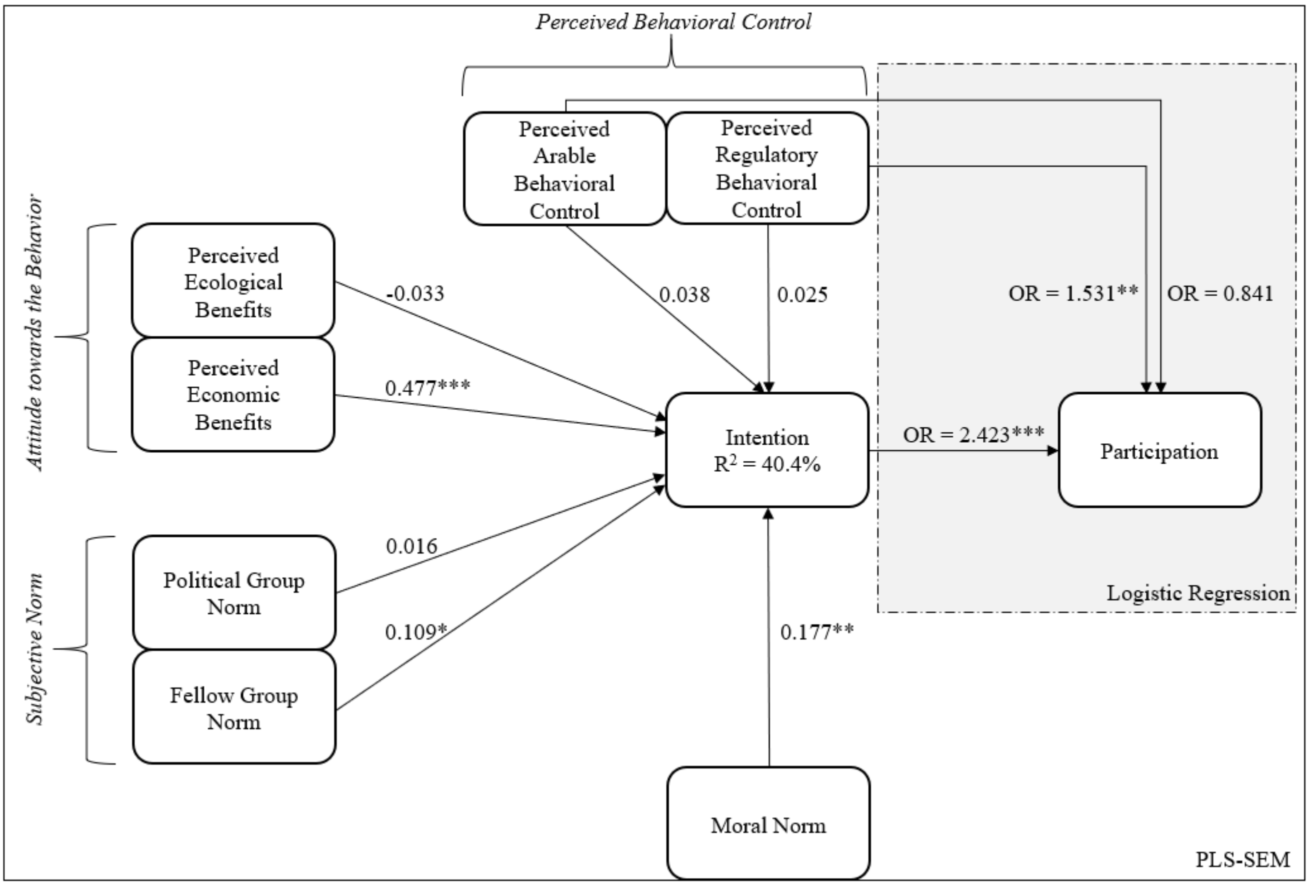

Figure 2: PLS-SEM inner model results for the intention to participate in a humus programme (N = 190)

Notes: Asterisks indicate different levels of statistical significance for t tests based on bootstrapping with 10,000 runs (***$p < 0.01$; **$p < 0.05$; *$p < 0.1$). OR = odds ratio, OR > 1 indicates a positive effect, OR < 1 indicates a negative effect. Goodness-of-fit characteristics for the logistic regression: log-likelihood = -29.61, LR chi^2 (3) = 24.82***, McFadden Pseudo R^2 = 0.295, McKelvey & Zavoina Pseudo R^2 = 0.542, Nagelkerke Pseudo R^2 = 0.343, Pearson Chi^2 (159) = 152.77 (p = 0.62), Hosmer-Lemeshow Chi^2 (8) = 11.18 (p = 0.19), Area under ROC curve = 85.73%, Correctly classified = 95.79%. Test for multicollinearity: variance inflation factors = 1.06 – 1.12, tolerances = 0.89 – 0.95.

3.4 Practical and scientific implications

If farmers only see ecological benefits in humus programmes, they tend not to participate. The construct perceived ecological benefits shows an unexpected negative influence on the intention to participate in a humus programme, but with a small effect size and without statistical significance (see Figure 2). The negative effect contradicts the literature, which states that farmers who perceive higher ecological benefits are more likely to adopt sustainable methods, like mixed cropping, cover crops and other conservation practices (Arbuckle and Roesch-McNally, 2015; Bonke and Musshoff, 2020; Reimer et al., 2012). Since the farmers in our study definitely see the ecological benefits of humus build-up (see Table 2), this result indicates that the ecological benefits alone are not sufficient to directly stimulate farmers' decision to participate. Farmers already derive an ecological benefit from humus without humus programmes, which at least 68% of the farmers surveyed already do, and see no further ecological benefits in participating in a humus programme.

Although farmers do not see any additional ecological benefits from participating in humus programmes, they do recognize the economic benefits. The construct perceived economic benefits has the highest effect on the farmers' intention to participate in a humus programme and also shows statistical significance (see Figure 2). This result is consistent with previous findings showing that economic benefits have a positive effect on participation in AES (Lastra-Bravo et al., 2015; Wąs et al., 2021). Similar to our results, Michels et al. (2022) found that perceived economic benefits have a high effect on farmers' intention to use herbicide resistance tests, while perceived ecological benefits have a low effect. To increase farmer interest in humus programmes, it is advisable to focus on promoting the economic benefits of humus programmes rather than the ecological benefits of humus enrichment. In particular, financial incentives and cost-effectiveness of humus programmes need to be improved and clearly communicated, as the farmers in our sample do not yet consider the humus premium to be cost-covering (see Table 2).

The fellow group norm has a positive and statistically significant influence on farmers' intention to participate in a humus programme (see Figure 2). This is consistent with Perry and Davenport (2020), who found that neighbouring farmers are the most important reference group to farmers. What other farmers do is important for farmer decision making, e.g. regarding participation in AES (Villamayor-Tomas et al., 2021), adoption of mixed cropping (Bonke and Musshoff, 2020), and other sustainable practices (Dessart et al., 2019). Dessart et al. (2019) suggest that this is based on insider information from farmers who have already implemented the practice. Therefore, building informal networks for direct communication between farmers and encouraging early adopters to act as role models and share their knowledge and experience with other farmers may be key to increasing participation rates in humus programmes. There seems to be great potential to increase the awareness and perceived social value of participation in humus programmes, as the popularity of humus programmes and the pressure to participate among farmers are low (see Table 2). Kuhfuss et al. (2016) showed that additional information about other farmers' participation in AES can be a successful social nudge. It could therefore be of interest to test the effectiveness of social nudges in the context of humus programmes in further studies.

In contrast to the fellow group norm, the political group norm has a negligible and statistically non-significant influence on farmers' intention (see Figure 2), although the increasing political environmental requirements and standards are present for the farmers (see Table 2). From this result, we can conclude that the current policy to enforce sustainable farm management does not put pressure on farmers to participate in a humus programme. It could therefore make sense to expand and support the existing policies through social nudges. With the fellow group norm in mind, policy makers can use 'testimonials', i.e. giving targeted space to pioneer farmers participating in carbon sequestration programmes to report on their (positive) experiences.

Farmers feel that they have arable control over humus formation (see Table 2), but the construct perceived arable behavioural control has no statistically significant influence on intention to participate in a humus programme or on actual participation (see Figure 2). This could be related to the fact that 76% of farmers already carry out humus-forming measures and at least 90% of them do not participate in a humus programme. Carbon farming and humus formation are therefore not uncommon and meeting the agronomic requirements for this is not enough to participate in a humus programme.

The construct perceived regulatory behavioural control has a slightly positive but not statistically significant influence on intention to participate in a humus programme (see Figure 2). Furthermore, the descriptive indicator results show that farmers have a lack in knowledge about the registration and programme process (see Table 2), indicating missing regulatory control. Improving regulatory control could be another approach to increasing participation rates. This is supported by the fact that regulatory behavioural control indeed has a positive and statistically significant impact on actual behaviour (see Figure 2). Other studies have already shown that technical barriers prevent farmers from adopting sustainable practices and therefore need to be addressed (Lemken et al., 2017). Hence, programme providers, experts and other authorized persons need to educate farmers more about organizational and regulatory aspects of humus programmes. The first step might be to expand and communicate the financial benefits of humus programmes. This is because farmers tend to believe that the current premium is not sufficient to cover the costs of humus building (see Table 2) and therefore it is currently not worth learning more about how humus programmes work.

The moral norm has the expected positive sign with a statistically significant effect that has the second largest impact on farmers' intention to participate in a humus programme (see Figure 2). This is in line with some studies stating that farmers' altruistic thoughts or feelings of guilt actually influence the adoption of more sustainable farming practices (Johansson et al., 2013; Mzoughi, 2011; Sheeder and Lynne, 2011). The farmers in our study indeed feel responsible for using the existing potential to combat climate change (see Table 2), and this feeling seems to influence their intention to participate in humus programmes. An appeal to farmers' moral norm could therefore actually lead to a higher participation rate in humus programmes.

In summary, policy-makers, programme providers, and researchers should focus on the monetary added value of humus programmes in order to increase farmers' willingness to participate in such programmes. Due to the increasing demand for GHG storage, GHG emissions will become more and more expensive, so that more money will be available to offset carbon sequestration (IETA, 2023). To mitigate monetary incentives, an appeal can be made to farmers' moral norms and social networks. The self-generated pressure to counteract climate change and the orientation towards the actions of other farmers are the main drivers for the decision to participate in humus programmes, in addition to the financial benefits.

4 Conclusions

The sequestration of carbon in agricultural soils through humus enrichment represents a great opportunity for farmers to counteract climate change. The carbon storage capacity in soils is promising worldwide and has attracted a lot of attention in recent years. Therefore, non-governmental organizations have developed humus programmes that combine the potential of farmers to build humus (= sequester carbon) with the willingness of companies and households to pay for offsetting their carbon emissions. However, humus programmes are relatively new and are constantly evolving. To support effective programme design, an understanding of farmer decision making is needed. To our knowledge, there has been no research that addresses farmers' perceptions on carbon sequestration programmes in general or humus programmes in particular. We are therefore the first to analyse which behavioural factors influence farmers' intention to participate in a humus programme and to what extent. To this end, we implemented an extended framework of the TPB in an online survey with 190 German farmers.

The core finding of our study is that participation in humus programmes can be predicted using the TPB framework (no intention-behaviour gap), with perceived economic benefits, fellow group norm, and moral norm being the key motivators for farmers' participation. Among these, the economic benefit is the biggest motivation for participation. The opinion and actions of other farmers (fellow group norm) are also relevant for decision-making, suggesting that information on peer experience is valued. The moral norm, i.e. the self-generated pressure to do the right thing, also influences farmers' intention to participate. Farmers thus seem to have high expectations of themselves, which influences their actions in terms of climate-friendly land use.

Further results show that the perceived ecological benefits, the political group norm and the perceived behavioural control do not statistically significantly motivate farmers to participate in humus programmes. Clearly, farmers do not need a humus programme to reap the ecological benefits of humus. Many farmers (about two thirds of the farmers in our study) already carry out humus-forming measures due to the ecological benefits without participating in a humus programme. Furthermore, the current political approaches are not suitable for motivating farmers to participate in a humus programme. The arable control of humus build-up is also not sufficient motivation to participate in a humus programme. There is a lack of knowledge about the registration and functioning of humus programmes, resulting in an average low level of regulatory control. Although perceived regulatory behavioural control does not have a statistically significant influence on intention to participate, it does have a statistically significant influence on actual participation, suggesting that it may play an important role when it is present.

As we provide initial insights into the drivers influencing farmers' willingness to participate in carbon sequestration programmes, particularly humus programmes, the results of the study are of interest for policy makers, private certifiers and researchers. We contribute to the literature by identifying the behavioural factors that influence farmers' decision to participate. This is necessary to develop efficient carbon sequestration programmes and increase their acceptance. In order to increase the participation of farmers in humus programmes, the following should be considered: (i) The potential financial benefits of humus programmes and the fact that the financial perspective is dynamic, i.e. increasing, should be better publicized. (ii) More networks for direct dialog between farmers should be created. In this context, pioneer farmers in particular should be given space to share their (positive) experiences. (iii) A stronger appeal can be made to farmers' intrinsic motivation, e.g. through nudging. (iv) The knowledge gap about how a humus programme works and how to sign up for such a programme needs to be tackled. (v) The current policy guidelines could be enhanced with social nudges to improve their effectiveness in terms of participation in humus programmes.

Future research could replicate this study with a larger, representative and multinational sample. It could be of great interest to investigate how farmers from other countries with less experience in carbon farming view humus programmes. Since our results suggest that the actions of other farmers and their own ethics influence the decision to participate, a targeted investigation of the effects of social nudges on farmers' decision to participate in a carbon sequestration programme would be worthwhile. This could offset the need for financial incentives for farmers in humus programmes. In summary, researchers should continue to focus on how to support farmers' efforts to build up humus and thus sequester carbon, as this can make an important contribution to mitigating climate change.

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