Public acceptance of feed additives for methane emission reduction in dairy production

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Abstract

The reduction of methane emissions from livestock production is a prime issue on policy agendas worldwide. Methane from dairy cows accounts for about 50% of the climate emissions from dairy farms, and 1-2% of greenhouse gas emissions in the EU. Hence, governments are looking for solutions to reduce emissions without reducing food production. Understanding how the public views the adoption of natural and chemical feed additives for methane emission reduction is crucial for the acceptance of new feeding management practices. To this end, the European public response to novel feeding strategies (1) natural: supplementing the feed with algae or seaweed extracts, or plant-based oils or fats and 2) chemical: using 3-NOP feed additive) intended to reduce methane emissions from dairy cows were investigated. The analysis was based on econometric models and survey data with 3,220 participants from four EU member states (Finland, France, Poland and Ireland). The results indicated a significant difference in the acceptance between practices that use natural and chemical feed additives, with European citizens generally being more reluctant to use the latter. Additionally, the analysis showed a negative link between additional information and chemical feed additives. The findings have implications for encouraging broad acceptance of production schemes.

Keywords: Methane emissions, Dairy production, Feeding, Public perception, European Union

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Introduction

Enteric fermentation in ruminants is a major contributor to greenhouse gas emissions from agriculture, particularly methane. Methane from dairy cows accounts for about 50% of the climate emissions from dairy farms, and 1-2% of greenhouse gas emissions in the EU (Ritchie, 2020). Given the significant global demand for ruminant products such as meat and milk, reducing methane emissions is crucial. Various strategies, including the use of new feed additives, have been proposed to address the issue of methane emission reduction in dairy production (e.g. Hristov et al., 2022). For example, incorporating dietary fats, oils, or algae to dairy cows rations has demonstrated effectiveness in reducing methane emissions in numerous studies (e.g. De Bhowmick & Hayes, 2023; Kliem et al., 2019). Furthermore, chemical additives, such as the recently approved 3-NOP (3-Nitrooxypropanol) in European Union (EU) member states, offer additional options to curb methane release from dairy cows' husbandry (Van Wesemael et al., 2019).

Agricultural innovations are critical for enhancing livestock productivity and environmental sustainability. Yet, their successful integration into practice is dependent on public support, driven by concerns over food safety, environmental impact, and animal welfare. While regulatory bodies such as the European Food Safety Authority (EFSA) have established rigorous guidelines to assess the efficacy and safety of agricultural inputs like feed additives (Rychen et al., 2018), research consistently underscores the necessity of addressing public concerns and regulatory landscapes to leverage agricultural innovations effectively. This approach highlights the growing awareness that innovation in agriculture extends beyond technological advancements. It also involves engaging with the public, complying with regulations, and fostering positive views to guarantee that new agricultural methods are accepted and utilized effectively (Meynard et al., 2017).

In modern agriculture, the interplay between public perception and policy formulation, especially regarding agricultural practices and environmental protection, has become increasingly evident. The importance of public concerns and opinions in policy formulation and development is underscored by the evidence that public perceptions can significantly influence the direction and focus of policies, as demonstrated by the evolution of the Common Agricultural Policy (CAP) in the European Union. For instance, the decline in public support for the CAP, as highlighted by the Special Eurobarometer 440 (European Commission, 2016), suggests that when policies fail to align with public expectations—particularly regarding environmental commitment, administrative burdens, and priorities such as food quality over quantity—there is a tangible erosion of trust and acceptance (Pe'er et al., 2017). This oversight can affect policy success, acceptance, and long-term sustainability. Thus, integrating public opinion into policy-making is crucial for ensuring policies are relevant, effective, and supported, making ongoing dialogue between the public and policymakers essential for creating responsive and responsible policies.

This study aims to examine public perceptions of innovative dairy cattle feeding practices. More specifically, we focus on the association between the provision of additional information and European citizens' willingness to accept innovative feeding practices for methane reduction in dairy cows. Despite the current limited understanding among many European citizens of modern dairy farming techniques (Boogaard et al., 2011), there is an obvious increase in awareness. This increase is partly fueled by concerns about climate change and its link to methane emissions from livestock (Ilea, 2009). Moreover, adopting strategies that focus on communication and the sharing of information stands as an effective way to garner public support. Therefore, our study aims to explore the degree to which the provision of additional information influences the willingness of European citizens to embrace and support these innovative practices.

Theoretical background

The theoretical model underpinning the empirical strategy to explore the relationship between the provision of additional information and European citizens' willingness to accept innovative feeding practices for methane reduction in dairy cows incorporates insights from several psychological and communication theories. At its core, the Theory of Planned Behavior (TPB) provides a robust framework for understanding how information might influence public acceptance. According to TPB, an individual's intention to support or adopt innovative environmental practices is influenced by their attitudes towards the behavior, the perceived social norms surrounding it, and their perceived control over performing the behavior (Ajzen, 1991). In this context, providing detailed information about natural and chemical feed additives could positively influence public attitudes by enhancing knowledge, adjusting perceived norms, and increasing perceived behavioral control by elucidating the practicality and benefits of these practices (Sánchez-Medina et al., 2014).

Furthermore, the Information Deficit Model and the Elaboration Likelihood Model (ELM) offer additional perspectives on how information dissemination can affect public acceptance. The Information Deficit Model suggests that skepticism or resistance towards scientific innovations often stems from a lack of understanding. Thus, by bridging this information gap, it is presumed that the public will be more inclined to accept and support the innovative feeding practices. On the other hand, the ELM highlights the importance of how information is processed, suggesting that the impact of additional information on acceptance may vary depending on whether individuals engage with the information through a central route (focusing on the content) or a peripheral route (influenced by external cues) (Petty & Cacioppo, 1986). This dual-process theory underscores the need for carefully designed communication strategies that not only provide factual information but also engage individuals in meaningful processing of the benefits and safety of the feeding practices (Greaves et al., 2013).

Lastly, Cognitive Dissonance Theory and Risk Perception Theory provide insights into the psychological mechanisms that might mediate the relationship between information provision and public acceptance. Cognitive Dissonance Theory suggests that individuals seek for consistency in their beliefs and attitudes. When presented with information that conflicts with pre-existing beliefs, individuals may experience dissonance, leading to a potential shift in attitudes to reduce discomfort (Festinger, 1957). Risk Perception Theory further elucidates that public acceptance is also shaped by individuals' assessments of the risks and benefits associated with innovative practices (Slovic, 1987), which can be significantly influenced by the nature and framing of the information provided. Together, these theories form a comprehensive theoretical model that captures the multifaceted ways in which information can sway public attitudes and acceptance toward innovative agricultural practices aimed at mitigating environmental impacts. This model serves as the foundation for the empirical strategy, guiding the analysis of how information influences public willingness to support sustainable farming innovations.

Empirical strategy

The main goal of our analysis was to explore the relationship between providing additional information to European citizens and their willingness to accept the following innovative feeding practices: i) the use of natural feed additives (i.e. supplementing the feed with algae or seaweed extracts, or plant-based oils or fats) to decrease methane emissions, and ii) the use of chemical feed additives (3-NOP) for the same purpose. The acceptance levels were evaluated in the survey through a 5-point Likert scale. Regression analysis was employed to control for covariates. The complete specification of estimated model is outlined below:

$$Public\ acceptance\ of\ innovative\ practices = \alpha_0 + \alpha_1 Level\ of\ information + \beta X + \varepsilon, \qquad (1)$$

where the observed public acceptance of three different innovative practices involving the use of feed additives to reduce methane emissions is the dependent variable and α_1 is the main coefficient of interest, while X represents the control variables. These control variables comprised of socio-demographic characteristics of the participants and their perceptions and preferences that might be associated with the decision to support the use of innovative feeding practices.

We estimate the model outlined in Equation (1) both with and without the inclusion of control variables. Our primary findings are based on a linear probability model via Ordinary Least Squares (OLS) regression. To ensure the robustness of our results, we further explore nonlinear probability models, including ordinal probit models. Following Angrist & Pischke (2009), we favor the linear probability model as our principal approach due to its advantages in the straightforward interpretation of the coefficients and the challenges presented by alternative models (see Breen et al. (2018)). Additionally, we adjust our standard errors to account for heteroscedasticity.

A series of robustness checks to validate the stability of findings were conducted. We transform the variables capturing public's perception into binary variables to check for the robustness of our measurement approach. More specifically, we identify those individuals who have a highly positive perception (rating 4 and 5 on a 5-point Likert scale) of the utilization of algae or seaweed extracts, plant-based oils or fats, and chemical feed additives in the diet of dairy cows. This robustness check evaluates if the way we define our variables affects our main results, while simultaneously simplifying their interpretation.

Secondly, we employ a methodology to assess potential selection bias by calculating the extent of selection on unobservables that would negate the statistical significance of our observed relationships (Oster, 2019). This involves an examination of how observable factors might influence our key findings, suggesting that a greater emphasis on observables raises concerns about overall selection bias, including from unobservable factors. Oster's (2019) framework facilitates an estimation of the necessary degree of selection on unobservables that could nullify our initial findings. This process is twofold: first, determining the relative strength of selection on unobservables versus observables needed to challenge our primary estimates; and second, analyzing how equal levels of selection on both unobservables and observables would alter our main findings, specifically the impact of additional information on public perception. This analysis underscores the potential impact of unobserved variables relative to included control variables on our outcomes. Such a robustness check is crucial for assessing the influence of factors not included in our model on our overall conclusions. See Oster (2019) for a comprehensive review of this methodology, while Oster (2016) offers guidance on its implementation using Stata.

Lastly, we use an ordinal probit model rather than a linear approach to examine the relationship depicted in Equation (1) and its variations, and we report the corresponding marginal effects.

Data

We conducted an online survey to collect data among citizens in four EU member states (Finland, France, Ireland and Poland). Data collection took place in July 2023, conducted by the market research firm Taloustutkimus through an online panel, with the survey being available in French, Finnish, English, and Polish. A total of 3 220 respondents completed ed the survey. In our survey invitation, we made it explicit to the participants about the survey's purpose and its association with the HoloRuminant research project, which is supported by funding from the European Union's Horizon 2020 program. We also explicitly requested their consent to participate.

The structure of the survey was divided into three main parts. The first section aimed to evaluate the novel interventions, the second to assess associated attitudinal variables and third to provide basic socio-demographic information. More specifically, in the first part, we asked participants to indicate their level of acceptance of three interventions on a standardised scale ranging from 1 to 5, with 1 indicating "strongly agree" and 5 indicating "strongly disagree". There was also an option for responders who were unsure could choose to answer "I do not know". In order to assess the relationship between providing additional information and public's perception, 50% of sample in each country were randomly selected to receive additional information about possible impact of the intervention on calf health and welfare, the quality of milk and meat products, environmental effects, effect on production and costs of milk and dairy products for citizens (for details, please see Figure 1 in Appendix). In the second part of the survey, we asked participants questions regarding their understanding of various aspects related to dairy production. This included their knowledge of farming systems, awareness of food safety, environmental considerations, animal welfare, cost considerations, and cultural views on dairy product consumption, among other general concerns associated with dairy production. Finally, in the third part of the survey, we focused on participants' characteristics, such as gender, age, education, income levels, and consumption preferences. Table 1 presents summary statistics and a detailed description of variables.

Table 1. Data overview and summary statistics of variables used in the analysis.

Name	Unit	Description	Mean	S.d.
Public's Perception of the use of algae or seaweed extracts	Scale 1–5	Perception of the public towards the utilization of the additive, rated from 1 (strongly disagree) to 5 (strongly agree).	3.10	1.57
Public's Perception of the use of plant-based oils or fats	Scale 1–5	Perception of the public towards the utilization of the additive, rated from 1 (strongly disagree) to 5 (strongly agree).	2.98	1.56
Public's Perception of the use of chemical feed additives	Scale 1–5	Perception of the public towards the utilization of the additive, rated from 1 (strongly disagree) to 5 (strongly agree).	2.18	1.41
Degree of Information Detail	Binary	Half of the participants were randomly selected to receive extra information on the intervention's potential impact on calf welfare, product quality, environmental effects, production, and consumer costs.	0.50	0.50
Age	Number of years	Participants age in years.	41.65	13.08
Gender	Binary	The gender of each participant is coded as binary: 1 for male and 2 for female.	1.54	0.51
Education	Scale 1–5	Indicates the participant's level of education, ranging from 1 (Less than primary education) to 5 (University education).	4.16	0.94
Income	Scale 1–8	Indicates the participant's annual income range, from 1 (€0-€10,000) to 8 (€150,001 or more).	3.54	1.71
Meat consumption	Binary	Indicates whether the participant consumes meat, with a dummy variable: 1 for yes and 0 for no.	0.89	0.31
Dairy consumption	Binary	Indicates whether the participant consumes dairy products, with a dummy variable: 1 for yes and 0 for no.	0.90	0.30
Residence area	Binary	Indicates the participant's living area with a binary variable: 1 for rural and 0 for urban.	0.25	0.43
Familiarity with farming	Aggregated score*	Evaluates participants' knowledge and exposure to farming, understanding of microbiomes, and awareness of food production.	11.38	2.56

Table 1 *(continued)*

Name	Unit	Description	Mean	S.d.
Food safety	Aggregated score*	Measures participants' emphasis on food safety through label reading and expectations of producer responsibility.	12.55	1.93
Environmental awareness	Aggregated score*	Assesses commitment to eco-friendly behaviors and sustainable practices.	15.17	3.04
Animal welfare	Aggregated score*	Indicates concern for animal welfare, ethical purchasing, and support for animal rights organizations.	9.87	2.92
Conscientious consumption preferences	Aggregated score*	Reflects a preference for ethical, organic, and high-quality food choices, even at higher costs.	13.81	3.63
Cultural view on dairy consumption	Aggregated score*	Captures attitudes towards dairy's nutritional value, support for local dairy industries, and its cultural significance.	11.33	2.86

*Note: A principal component analysis (PCA) is performed on 34 attitudinal variables measured on a Likert scale from 1 to 5, This method allows to objectively extract relevant information and enables a dimensional reduction. The PCA revealed that the underlying structure of the attitudinal variables can be largely explained by six independent components: familiarity with farming practices, food safety, environmental awareness, animal welfare, cost-conscious preferences, and social norms. Only the items with a significant loading were retained for the analysis (see Supplementary Table A1). Each component was quantified by aggregating the score points of the corresponding items to obtain six continuous variables.

Results and discussion

Participants were asked to assess the inclusion of three feed additives designed to reduce methane emissions, namely supplementing the feed with: (1) algae or seaweed extracts; (2) plant-based oils or fats; or (3) chemical additives to reduce dairy cow methane emissions. Public acceptance of these feeding practices was elicited using a 5-point Likert scale (from 1 = strongly disagree to 5 = strongly agree). On average, the public's acceptance of incorporating algae or seaweed extracts (mean of index = 3.09, sd = 1.57) was significantly higher (using a t-test) than the acceptance of adding plant-based oils or fats (mean = 2.98, sd = 1.55). In addition, the value of index measuring the public's acceptance of using chemical feed additive was significantly lower than that of both algae or seaweed extracts and plant-based oils or fats (mean = 2.17, sd = 1.41).

Regression analysis was used to examine the relationship between providing additional information to European citizens and their willingness to accept novel livestock practices. Results are shown in Table 2. Six models are included in the analysis, each focusing on different intervention strategies and the inclusion or exclusion of control variables. In Models 1, 2, and 4, 5, which explore the public's perception of the use of algae or seaweed extracts and plant-based oils or fats in dairy cow feed, the degree of information detail is significantly and negatively associated with perception. It appears from this that the public's perception of these innovative interventions tends to be more critical or circumspect the more detail there is available. However, when it comes to the use of chemical feed additives, Models 3 and 6 demonstrate a positive link between the level of information detail and public impression (coefficients: 0.139 and 0.125, statistically significant at the 1% level). It is suggested that more specific information may help people acquire a more positive opinion of chemical feed additives. The consistency of the results between the models, with and without the control variables, emphasizes how robust the findings are. This consistency supports the study's findings, which show that the level of information detail has a considerable impact on public perception and is independent of other underlying factors.

Table 2. Relationship between public's perception of innovative interventions to reduce dairy cow methane emissions and the provision of information

	Model 1 (Public's Perception of the use of algae or seaweed extracts in dairy cows' feed with no control variables)	Model 2 (Public's Perception of the use of plant based oils or fats in dairy cows' with no control variables)	Model 3 (Public's Perception of the use of chemical feed additives in dairy cows' feed with no control variables)	Model 4 (Public's Perception of the use of algae or seaweed extracts in dairy cows' feed with control variables)	Model 5 (Public's Perception of the use of plant based oils or fats in dairy cows' with control variables)	Model 6 (Public's Perception of the use of chemical feed additives in dairy cows' feed with control variables)
Degree of Information Detail (dummy)	-0.320*** (0.043)	-0.240*** (0.044)	0.139*** (0.047)	-0.315*** (0.041)	-0.235*** (0.042)	0.125*** (0.045)
Controls included in the model (see additional details in A3–5)	Control variables are not included.	Control variables are not included.	Control variables are not included.	Control variables are included.	Control variables are included.	Control variables are included.
Number of Obs.	2836	2835	2881	2828	2829	2873

Note: We present coefficient estimates (standard errors) from an OLS regression with heteroscedasticity robust standard errors. *, **, *** indicate statistical significance at the 10%, 5%, 1% levels, respectively.

Table 3. Detailed results of regression analysis including control variables.

	Public's Perception of the use of algae or seaweed extracts	Public's Perception of the use of plant based oils or fat	Public's Perception of the use of chemical feed additives
Degree of Information Detail	-0.315*** (0.041)	-0.235*** (0.042)	0.125*** (0.045)
Familiarity with farming	0.043*** (0.011)	0.023** (0.011)	0.032*** (0.011)
Food safety	-0.033** (0.015)	-0.031** (0.015)	-0.121*** (0.015)
Environmental awareness	0.048*** (0.012)	0.059*** (0.012)	0.017 (0.011)
Animal welfare	0.024* (0.012)	0.011 (0.012)	0.058*** (0.013)
Conscientious consumption preferences	0.027*** (0.010)	0.032*** (0.010)	0.012 (0.010)
Cultural view on dairy consumption	-0.021** (0.009)	0.002 (0.009)	0.002 (0.010)
Age	-0.002 (0.002)	-0.006*** (0.002)	-0.013*** (0.002)
Gender	-0.127*** (0.042)	-0.130*** (0.043)	-0.279*** (0.046)
Education	0.006 (0.023)	-0.018 (0.023)	-0.009 (0.026)
Income	0.007 (0.013)	0.009 (0.014)	-0.004 (0.016)
Meat consumption	0.065 (0.076)	0.034 (0.077)	0.126 (0.087)
Dairy consumption	-0.014 (0.079)	-0.114 (0.079)	-0.208** (0.089)
Residence area	-0.087* (0.047)	0.024 (0.048)	-0.172*** (0.052)
Finland	0.044 (0.068)	0.320*** (0.069)	0.163** (0.068)
Ireland	0.417*** (0.060)	0.434*** (0.063)	0.305*** (0.066)
Poland	0.170*** (0.059)	0.325*** (0.061)	0.179*** (0.064)
Intercept	2.409*** (0.209)	2.303*** (0.218)	3.214*** (0.225)
Number of Obs.	2828	2829	2873

Note: We present coefficient estimates (standard errors) from an OLS regression with heteroscedasticity robust standard errors. *, **, *** indicate statistical significance at the 10%, 5%, 1% levels, respectively.

The notion of exposing people to scientific information (e.g., novel feed additives or new technology) is associated with the accessibility of scientific knowledge on the topic and the comprehension of the individual (Allum et al., 2008). For example, research suggests that the reason people are reluctant to support sustainable and alternative practices is a lack of knowledge about the causes and effects of emissions (Drummond et al., 2018; Poortinga et al., 2019). Our results present a nuanced viewpoint challenging this hypothesis, indicating that the impact of information provision on public acceptance is influenced by the nature of the intervention, resulting in both negative and positive effects. It's worth noting that the manner in which information is presented, or "framed," can impact how individuals perceive it and their willingness to support these new practices, programs, policies, or technologies Dearing & Lapinski, 2020).

Turning now to the results of the association between the control variables that could potentially be correlated with the public's perception, some interesting results are observed. Familiarity with the farming system positively influences the perception of all three interventions. While concerns about food safety negatively influence the public's perception of all three interventions, the use of chemical feed additives is the most adversely affected. Not surprisingly, environmental awareness positively impacts the perception of algae/seaweed extracts and plant-based oils/fats. However, the association is not significant for chemical feed additives. One might speculate that using chemical feed additives may introduce complexity and uncertainty into respondents' decision-making. Chemical feed additives, even if intended to reduce methane emissions, could trigger concerns about potential risks to animal health, humans, and ecosystem integrity.

In our analysis, we also account for socio-demographic characteristics. We found that age and gender show a significant correlation with the public's perception. While previous studies suggested a positive association between females and support for environmentally friendly practices (Glass et al., 2016; Hunter et al., 2004), our results show that women generally have a more negative perception of these interventions. Additionally, older respondents, who may lean towards more traditional or conservative viewpoints, are linked with a negative perception of these environmental strategies.

Robustness checks

We perform a series of robustness checks to validate the reliability of our results. First, we transform variables related to the public's perception into binary form. In particular, we categorize individuals who express a highly favorable view (rating 4 and 5 on a 5-point Likert scale) of the utilization of algae or seaweed extracts (representing 48% of the total sample), plant-based oils or fats (accounting for 45% of the total sample), and chemical feed additives (19% of the total sample) in the diet of dairy cows. Using these binary variables instead of the 5-point Likert scale responses does not alter our findings. Our results remain robust, meaning that the provision of additional information is strongly associated with a lower perception of the use of algae or seaweed extracts and plant-based oils or fats, while this extra information is positively linked to the public's perception of chemical additives. (see Table 4 for details).

Second, we examined the possibility of selection bias influencing our findings by evaluating the extent to which unobserved factors would need to alter our results (Oster, 2019). Our analysis indicates that the established relationships are robust. Specifically, for the relationships to be negated, unobserved variables not included in our comprehensive regression model would need to have a significantly greater impact than the observed variables we did include. To quantify this, we looked at how much more influential unobserved variables would need to be compared to observed ones to invalidate our primary findings (measured by the Delta coefficient). Our findings suggest that unobserved factors would need to be disproportionately influential — by factors of 40.77, 55.37, and 30.68 — to nullify the observed effects of public perception on the use of algae or seaweed extracts, plant-based oils or fats, and chemical additives, respectively (refer to Table 2). Additionally, we assessed how our main findings (outlined in Table 2) might shift if the influence of unobserved factors equaled that of observed ones (measured by the Beta coefficient). This scenario indicated that even if unobserved factors were as influential as observed ones, the impact on our initial findings would be minimal, with a maximum change of only 0.004. For more detailed information, refer to Table 5.

Finally, we opted for an ordinal probit model over a linear one to analyze the models presented in Table 2. Results are shown in Table 6. We found that the direction and statistical significance of the results aligns perfectly with those from the OLS regression previously discussed. Moreover, the magnitude of the marginal effects derived from the probit model is very similar to those from the OLS regression.

Table 4. Robustness Check 1: Transformation of the variables capturing public' perception into binary variables.

	Model 1 (Public's Perception of the use of algae or seaweed extracts in dairy cows' feed with no control variables)	Model 2 (Public's Perception of the use of plant based oils or fats in dairy cows' with no control variables)	Model 3 (Public's Perception of the use of chemical feed additives in dairy cows' feed with no control variables)	Model 4 (Public's Perception of the use of algae or seaweed extracts in dairy cows' feed with control variables)	Model 5 (Public's Perception of the use of plant based oils or fats in dairy cows' with control variables)	Model 6 (Public's Perception of the use of chemical feed additives in dairy cows' feed with control variables)
Degree of Information Detail (dummy)	-0.141*** (0.018)	-0.113*** (0.020)	0.054*** (0.019)	-0.136*** (0.018)	-0.111*** (0.019)	0.047*** (0.018)
Controls included in the model (see additional details in A3–5)	Control variables are not included.	Control variables are not included.	Control variables are not included.	Control variables are included.	Control variables are included.	Control variables are included.
Number of Obs.	2050	2033	2243	2042	2028	2236

Note: We present coefficient estimates (standard errors) from an OLS regression with heteroscedasticity robust standard errors. *, **, *** indicate statistical significance at the 10%, 5%, 1% levels, respectively.

Table 5. Robustness Check 2: Selection on observables and unobservables using Oster (2019)'s bounds

	Public's perception of the use of algae or seaweed extracts in dairy cows' feed		Public's Perception of the use of plant based oils or fats in dairy cows' feed		Public's Perception of the use of Chemical Feed Additives in dairy cows' feed	
	(1)	(2)	(3)	(4)	(5)	(6)
Beta	0	-0.311	0	-0.232	0	0.121
Delta	40.768	1	55.373	1	30.681	1
R^2 max	0.133	0.133	0.120	0.120	0.126	0.126

Note: Following Oster (2019), we select the maximum R^2 (R^2 max) to be 1.3 times the R^2 value obtained from the regression that includes controls.

Table 6. Robustness Check 3: Probit estimates and marginal effects on association between public's perception of innovative interventions to reduce dairy cow methane emissions and the provision of information

	Model 1 (Public's Perception of the use of algae or seaweed extracts in dairy cows' feed with no control variables)	Model 2 (Public's Perception of the use of plant based oils or fats in dairy cows' with no control variables)	Model 3 (Public's Perception of the use of chemical feed additives in dairy cows' feed with no control variables)	Model 4 (Public's Perception of the use of algae or seaweed extracts in dairy cows' feed with control variables)	Model 5 (Public's Perception of the use of plant based oils or fats in dairy cows' with control variables)	Model 6 (Public's Perception of the use of chemical feed additives in dairy cows' feed with control variables)
Degree of Information Detail (dummy)	-0.293*** (0.040)	-0.211*** (0.039)	0.115*** (0.040)	-0.303*** (0.040)	-0.218*** (0.040)	0.107*** (0.040)
Controls included in the model (see additional details in A3–5)	Control variables are not included.	Control variables are not included.	Control variables are not included.	Control variables are included.	Control variables are included.	Control variables are included.
Number of Obs.	2836	2835	2881	2828	2829	2873

Note: *, **, *** indicate statistical significance at the 10%, 5%, 1% levels, respectively.

Discussion and Conclusion

We study the European public's response to innovative feeding strategies aimed at lowering dairy cow methane emissions. The results revealed a contrast in the acceptance levels between natural and chemical feed additives, with Europeans showing greater reluctance towards the latter. Furthermore, we found that offering more detailed information to participants during the evaluation of practices involving algae or seaweed extracts and plant-based oils or fats significantly reduced their acceptance. By contrast, when participants were provided with more details regarding the use of chemical feed additive that aims to lower enteric methane emissions, their acceptance of it increased.

The observed negative relationship between disseminating extra information and the public's view of utilizing algae or seaweed extracts and plant-based oils or fats in dairy cow diets appears to contradict the "information deficit approach." This approach suggests that enhancing public understanding of agricultural practices should lead to greater acceptance of innovative methods (Bidwell, 2016; Simis et al., 2016). However, while both interventions aim at reducing methane emissions and have potential benefits, the negative association with public perception might stem from concerns about product quality (residues in milk), practicality and scalability of implementation (especially in pasture-based systems), increased production costs (feeding and possibly labor), and the direct impact on consumer prices. These factors might outweigh the environmental benefits in the public's perception, leading to a less favourable view of these interventions.

Based on these findings, it could be beneficial to introduce schemes providing subsidies or incentives to farmers. These can help mitigate the elevated expenses associated with feed additives, thereby enhancing the economic viability of the interventions and reducing the burden on consumer pricing. Moreover, the establishment of rigorous quality control and certification measures is essential. Such measures will ensure that any residual substances in milk or meat products remain within safe thresholds, addressing public worries about the safety and quality of the products. When it comes to communication strategies, it's important to acknowledge up front the concerns that the public has regarding the quality and price of products. This can be accomplished by providing clear, factual information about the steps taken to address these problems, such as through quality assurance initiatives and subsidy programs.

Despite initial skepticism, public acceptance of chemical feed additives for reducing enteric methane emissions improved with the provision of detailed, evidence-based information. As chemical substances can raise concerns, this result could be related to that respondents initially had negative perceptions about this intervention, and receiving more comprehensive information may have helped them to recognize the potential environmental benefits of reducing emissions, thus justifying the use of chemical feed additives. This emphasizes the importance of conveying messages to citizens in understandable, consistent and evidence-based manner. This finding holds significant implications for policy and industry sectors. Developing educational programs that present clear, precise, and extensive information about the advantages (notably the positive environmental impact of reducing methane emissions) and the safety of chemical feed additives is essential for positively shifting public perception. Additionally, proactively addressing and dispelling public doubts and misconceptions about chemical additives is fundamental in streamlining this process.

Further research should investigate the effectiveness of different communication strategies in enhancing public understanding and acceptance of sustainable alternatives. This could involve comparing the impact of various formats (e.g., digital media, brochures, interactive sessions) and messaging approaches. Moreover, it may be necessary to extend the analysis presented here to include social psychological factors that influence public acceptance of innovative agricultural practices. This could help in identifying underlying beliefs or misconceptions that impact acceptance levels and inform targeted educational interventions.

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Appendix

Figure A1. A comparative example of the information delivery Approach for the three evaluated interventions

Group A

A1. After reading the information, to what extent do you agree that the following intervention is <u>acceptable</u>?
Please select only one option.

Intervention 1	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	I don't know
Adding algae or seaweed extracts to the feed to reduce dairy cow methane emissions.	-	-	-	-	-	-
Using Algae and seaweed extracts as feed additives to reduce dairy cow methane emissions can help to mitigate the environmental impact of dairy farming. By including certain feed additives to the cow's diet, it is possible to alter the microorganisms in the cow's gut and reduce the amount of methane produced.						

Group B

B1. After reading the information on impacts, to what extent do you agree that the following intervention is <u>acceptable</u>?
Please select only one option.

Intervention 1	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	I don't know
Adding algae or seaweed extracts to the feed to reduce dairy cow methane emissions.	-	-	-	-	-	-
Using Algae and seaweed extracts as feed additives to reduce dairy cow methane emissions can help to mitigate the environmental impact of dairy farming. By including certain feed additives to the cow's diet, it is possible to alter the microorganisms in the cow's gut and reduce the amount of methane produced.						

Criteria	Possible impacts
Animal health and welfare	No significant effect
The quality of milk and meat products	Residues in milk, but at minimal levels.
Environmental effect	Reduction of methane emissions by 30 to 50%
Effect on production	Feeding cost increase, No impact on labour costs. Difficult to impossible in pasture-based systems.
Cost of milk and dairy products for consumers	The rise in feed costs increases milk prices.

Group A

A2. After reading the information, to what extent do you agree that the following intervention is acceptable?
Please select only one option.

Intervention 2	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	I don't know
Adding plant-based oils or fats to the feed to reduce dairy cow methane emissions	-	-	-	-	-	-
Using plan-based oils and fats as feed additives to reduce dairy cow methane emissions can help to mitigate the environmental impact of dairy farming. By including certain feed additives to the cow's diet, it is possible to alter the microorganisms in the cow's gut and reduce the amount of methane produced.						

Group B

B2. After reading the information on impacts, to what extent do you agree that the following intervention is acceptable?
Please select only one option.

Intervention 2	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	I don't know
Adding plant-based oils or fats to the feed to reduce dairy cow methane emissions	-	-	-	-	-	-
Using plan-based oils and fats as feed additives to reduce dairy cow methane emissions can help to mitigate the environmental impact of dairy farming. By including certain feed additives to the cow's diet, it is possible to alter the microorganisms in the cow's gut and reduce the amount of methane produced.						
Criteria	**Possible impacts**					
Animal health and welfare	No known negative effects if fats and oils are less than 5 % of cow's feed intake					
The quality of milk and meat products	May have small (positive) effects on human health					
Environmental effect	Reduction of methane emissions by 5 to 15%					
Effect on production	Feeding cost increase, May effect labour costs. Difficult to impossible in pasture-based systems.					
Cost of milk and dairy products for consumers	The rise in feed costs increases milk prices.					

Group A

A3. After reading the information, to what extent do you agree that the following intervention is <u>acceptable</u>? Please select only one option.

Intervention 3	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	I don't know
Adding chemical additives to reduce dairy cow methane emissions.	-	-	-	-	-	-
Using chemical additives, such as 3-nitrooxypropanol, as feed additives to reduce dairy cow methane emissions can help to mitigate the environmental impact of dairy farming. By including certain feed additives to the cow's diet, it is possible to alter the microorganisms in the cow's gut and reduce the amount of methane produced.						

Group B

B3. After reading the information on impacts, to what extent do you agree that the following intervention is <u>acceptable</u>? Please select only one option.

Intervention 3	Strongly Agree	Agree	Neither Agree nor Disagree	Disagree	Strongly Disagree	I don't know
Adding chemical additives to the feed to reduce dairy cow methane emissions.	-	-	-	-	-	-
Using chemical additives, such as 3-nitrooxypropanol, as feed additives to reduce dairy cow methane emissions can help to mitigate the environmental impact of dairy farming. By including certain feed additives to the cow's diet, it is possible to alter the microorganisms in the cow's gut and reduce the amount of methane produced.						

Criteria	Possible impacts
Animal health and welfare	No impact known to date.
The quality of milk and meat products	No known risk. Research is currently being carried out to identify possible effects.
Environmental effect	Reduction of methane emissions by around 33%
Effect on production	Feeding cost increase. May affect labour costs. Difficult to impossible in grass-based systems.
Cost of milk and dairy products for consumers	The rise in feed costs increases milk prices.

Table A1. Statements that were considered as part of citizens' attitude factors in this study.

Attitudes statements	Factor
I have visited a farm and seen first-hand how cattle are raised. I understand the role of microbiota in human health and well-being. I understand the benefits and challenges associated with the food production and sustainability in the livestock sector.	Familiarity with farming and microbiome
It is important for me to consume food products that are safe for me. I take the time to read the labels and packaging information (e.g. allergens) to ensure food I purchase is safe to consume. I believe that food producers have an ethical responsibility to provide safe food products to consumers.	Food safety
I consider the environmental impact of a product before making a purchase I frequently recycle and make an effort to reduce my waste I frequently buy products that are labelled as antibiotic-free I try to reduce my carbon footprint by walking, biking, or taking public transit when possible	Environmental awareness
I actively seek out information about animal welfare standards of companies before purchasing animal derived products. I am willing to pay more for products that are produced using high animal welfare practices. I support animal welfare organizations and donate to their causes.	Animal welfare
I prioritize buying organic food, even if it is more expensive. I am willing to pay more for products that are sustainably sourced and produced. I am willing to pay more for food produced using high animal welfare standards. I am willing to pay a premium price for food products that are guaranteed to be free from harmful contaminants and residues.	Conscientious consumption preferences
I feel that consuming dairy products is necessary for balanced nutrition and healthy life. I feel that it is important to purchase dairy products to support the dairy industry and local farmers. Consuming dairy products is a traditional and cultural practice that should be continued.	Cultural perspective of consuming dairy products