Farming for a Greener Future: The Behavioural Drive Behind German Farmers' Alternative Fuel Machinery Purchase Intentions

Marius Michels*, [a], Vanessa Bonke[b], Hendrik Wever[a], and Oliver Musshoff[a]

[a]Department of Agricultural Economics and Rural Development, Georg-August-Universität Göttingen, Platz der Göttinger Sieben 5, D-37073 Göttingen, Germany

[b]Department of Agricultural Economics, Humboldt-Universität zu Berlin, Philippstraße 13, D-10115 Berlin, Germany

***Corresponding author: marius.michels@agr.uni-goettingen.de**

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Abstract.

Climate change due to greenhouse gas emissions, e.g. anthropogenic carbon dioxide (CO_2), in the atmosphere will lead to damages caused by global warming, increases in heavy rainfall, flooding as well as permafrost melt. One of the main issues for reducing greenhouse gas emissions is the dependence on oil for fueling transportation and other sectors. Accordingly, policy makers aim to reduce dependency on fossil fuels with the accelerated roll-out of renewable energy. Among others, the increased focus on reducing greenhouse gas emissions and decreasing dependence on fossil fuels has led to a heightened interest in alternative fuels, particularly in the agricultural sector. Farmers have a special role to play in the production of some alternative fuels. On the one hand, farmers need large amounts of fuel to produce agricultural goods, making them potential consumers. On the other hand, farmers can act as suppliers by producing raw materials used for alternative fuels. As such, the opinions of farmers are of great importance in the successful establishment of alternative fuel concepts in agriculture, especially due to the dual nature of their role. However, few studies have explored farmers' perceptions of alternative fuel use for agricultural purposes. In light of this, the present study aims to identify constructs (latent factors) that influence farmers' intentions to purchase alternative fuel tractors, based on the Unified Theory of Acceptance and Use of Technology (UTAUT) framework. To achieve this, an online survey was conducted in 2022, yielding 141 usable responses. The UTAUT model was estimated using partial least squares structural equation modelling. Descriptive findings reveal that farmers perceive alternative fuel tractors as particularly suitable for low-energy farm and field work, but lower ranges relative to conventional diesel tractors are *the main barrier to adoption. The estimated model shows that general performance expectancy and social influence are the most potent drivers of farmers' intentions to purchase alternative fuel tractors among the model's constructs. Finally, this study offers numerous avenues for further research and has important implications for policy-makers, agricultural machinery manufacturers, practitioners, and scholars. Firstly, the results of the model demonstrate that farmers expect alternative fuel tractors to perform comparably to diesel engines. As such, manufacturers should ensure that their alternative fuel tractors meet these expectations and emphasize this in their marketing activities. In addition, manufacturers and extension services should also emphasize the environmental benefits of alternative fuel production and consumption in agriculture through their marketing efforts. Secondly, policy makers should consider the importance of a reliable legal framework to regulate adoption and use of alternative fuels in agriculture. Lastly, this study provides a useful foundation for future research. For example, the study could be replicated in other countries to enable cross-country comparisons. Additionally, hydrogen-powered tractors could be an interesting subject for future research inquiries.*

Keywords.
Unified Theory of Acceptance and Use of Technology; Partial Least Squares Structural Equation Modelling; Alternative Fuels; Technology Adoption; Agricultural Machinery

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Introduction

In agriculture, diesel fuel is mainly used to power tractors and agricultural machinery. However, achieving larger reductions of diesel fuel consumption in agriculture requires the development and diffusion of new environmentally friendly technologies such as powering agricultural machinery with alternative fuels (Lombardi and Berni 2021; Bagagiolo et al. 2022). Alternative fuels may vary by production process and origin, but what they all have in common is that they are produced from renewable energy sources, thus alleviating concerns surroundings limited fossil fuel energy.

Farmers have a special role to play in the production and consumption of some alternative fuels. On the one hand, farmers need large amounts of fuel to produce agricultural goods, making them potential consumers (e.g. Eckel et al., 2020). On the other hand, farmers can act as suppliers by producing raw materials used for alternative fuels (e.g. Cherubini, 2010). As such, the opinions of farmers are of great importance in the successful establishment of alternative fuel concepts in agriculture, especially due to the dual nature of their role (Holst et al., 2020). This is particularly pertinent given the need for alternative fuels to meet the demands of the European Green Deal (European Commission, 2021).

Despite the growing interest in alternative fuels in the agricultural industry, only a limited number of studies have focused exclusively on farmers and their attitudes towards these fuels as both suppliers and consumers. Lombardi and Berni (2021) have analyzed Italian farmers' willingness to pay for a multi-functional full electric battery tractor. They showed that, besides socio-demographic and farm characteristics, increasing investment and maintenance costs decrease farmers' willingness to pay. Most importantly, they showed that engine power is a major determinant of farmers' willingness to adopt an electric fuel tractor. More recently, Bagagiolo et al. (2022) showed that Italian farmers have a higher interest in using biomethane and e-fuel than in hydrogen. Furthermore, costs and refueling were perceived as the main technical barriers for the adoption. Bessette et al. (2022) showed that organic small-scale vegetable and fruit growers in the USA would prefer a battery electric tractor over a diesel tractor as they perceive them as being more environmentally friendly, while expressing concerns regarding performance, costs and maintenance. Most recently, Sok and Hoestra (2023) showed that working time and range as well as operational and purchase costs are the most important attributes of an electric tractor for Dutch farmers, while emissions is the least important of the barriers presented for selection in the survey. Furthermore, they showed that negative feelings concerning (environmental) policies may hinder the potential widespread adoption in the near future. The research question emerged from the recognition of a gap in the existing literature regarding the adoption of alternative fuel technologies in agriculture. Previous studies, such as those by Lombardi and Berni (2021), Bessette et al. (2022), and Sok and Hoestra (2023), have explored specific aspects of this issue by focusing on electric tractors. Bagagiolo et al. (2022) is the only study focusing on more than one alternative fuel by asking for a ranking of these and of barriers to adoption. Still, an overarching study focusing on farmers' perceptions of alternative fuels in general and the factors influencing their intentions to buy alternative fuel tractors, has been lacking. As most alternative fuel tractors are still in development, initial perceptions and attitudes, even regarding potential costs, are of great importance for an effective dissemination in the future. Hence, the overall research question arises: What are the key latent factors that influence farmers' intentions to purchase alternative fuel tractors?

To the best of the authors' knowledge, there is no overarching study to answer the research questions of how farmers perceive alternative fuels in general and specifically, what drives their intention to buy tractors using such fuels. Furthermore, literature about potential barriers and on-farm application of alternative fuel tractors is scarce. Therefore, this study aims to fill these research gaps by pursuing the objective of understanding the causal relationship between constructs based on the Unified Theory of Acceptance and Use of Technology (UTAUT)

(Venkatesh et al., 2003) framework and farmers' intention to buy an alternative fuel tractor. Hence, the problem being addressed is the limited understanding of the factors influencing farmers' intentions to purchase alternative fuel tractors. Despite the growing interest in alternative fuels in agriculture, few studies have focused on farmers' perceptions and attitudes towards alternatives fuels in a holistic manner. This problem is important due to the dual role of farmers as both potential consumers and suppliers in the alternative fuel market. With agriculture accounting for a notable percentage of greenhouse gas emissions, understanding farmers' intentions is crucial for the successful adoption of environmentally friendly technologies like alternative fuel tractors. Evaluating and understanding the causal relationship between the constructs of the UTAUT and farmers' intention to buy an alternative fuel tractor therefore allows us to identify levers that will facilitate adoption and improve marketing activities.

Thus, this article adds the following to the literature: this is the first article focusing on the general adoption of alternative fuels in agriculture. To be specific, perceived barriers to the use of alternative fuels in agriculture are assessed. Furthermore, areas of farm work were recorded, which, from the farmers' point of view, are particularly suitable for the practical use of alternative fuel tractors. Moreover, this is the first study to identify constructs influencing farmers' intention to buy alternative fuel tractors. In this study, the UTAUT framework was adapted and extended to this context.

Hypotheses Generation

The development of our hypotheses under the UTAUT framework is informed by the intersection of innovation and sustainability. We hypothesize that the attributes of alternative fuel tractors, such as their environmental benefits and innovative features, play a crucial role in shaping farmers' purchase intentions, which are conceptualized in the statements of our UTAUT adaption. The corresponding statements to the derived constructs and the broader associated literature are shown in Table 1.

Performance expectancy (PE) refers to the extent to which potential users of a new technology or practice believe that their job performance is enhanced, which positively influences the intention to use the technology or practice (Venkatesh et al., 2003). Given that alternative fuels are not a direct improvement on diesel engines, but rather a substitute, it is reasonable to expect that potential users will anticipate comparable or superior performance. Moreover, for alternative fuels to be widely accepted among potential users, their costs should be lower or on par with those of diesel fuel. Additionally, the driving experience, including factors such as steering, acceleration, and comfort, should be similar to, or better than, that of diesel fuel tractors. Hence, the following hypothesis is generated:

H1: General Performance Expectancy (GPE) has a statistically significant positive effect on the Intention to Buy an Alternative Fuel Tractor (INT)

Alternative fuels also promise to be an environmentally friendly alternative to fossil fuels. Moreover, there is a special connection with regard to the production of some alternative fuels and agriculture, as farmers can be producer and consumer of the final product and by-products. Agricultural by-products can be utilized in the production of alternative fuels, which facilitates sustainable value creation. Conversely, by-products generated during fuel production can also be repurposed for agricultural production such as fertilizer or animal feed, thereby representing a more sustainable and efficient use of existing resources. Therefore, expectations concerning the ecological performance of alternative fuels, in addition to their general performance, may play a distinct role in the decision to purchase an alternative fuel tractor. Accordingly, the following hypothesis will be tested:

H2: Ecological Performance Expectancy (EPE) has a statistically significant positive effect on the Intention to Buy an Alternative Fuel Tractor (INT)

Effort Expectancy (EE) is defined by Venkatesh et al. (2003) as the degree of ease potential users associate with using a new technology or practice. EE positively impacts a users' intention to use a new technology or practice (Venkatesh et al., 2003). Alternative fuel tractors should be as easily refueled and maintained as diesel fueled tractors. Otherwise, farmers would have serious disadvantages switching to alternative fuels. Hence, expectations regarding refueling and service costs might influence the willingness to buy alternative fuel tractors which is reflected in the following hypothesis:

H3: Effort Expectancy (EE) has a statistically significant positive effect on the Intention to Buy an Alternative Fuel Tractor (INT)

The extent to which potential users of a new technology or practice believe that important people think that they should use a new technology or practice, is defined as social influence (SI) in the UTAUT model by Venkatesh et al. (2003). SI positively influences the intention to use a new technology or practice. Likewise, it can be expected that positive attitudes towards alternative fuel tractors of colleagues or experts also increase farmers' intention to buy an alternative fuel tractor. This relationship is presented in the following hypothesis:

H4: Social Influence (SI) has a statistically significant positive effect on the Intention to Buy an Alternative Fuel Tractor (INT)

Facilitating conditions (FC) can be characterized as the degree potential users perceive the present infrastructure supports the adoption of a new technology or practice (Venkatesh et al., 2003). Alternative fuels are relatively new to the market, which is why political planning certainty with regard to the legal framework can influence the decision to invest in a tractor with an alternative fuel system. Likewise, a sufficient infrastructure to refuel the tractor is needed to trigger the purchase intention. Hence, the following hypothesis is tested in the model:

H5: Facilitating Conditions (FC) has a statistically significant positive effect on the Intention to Buy an Alternative Fuel Tractor (INT)

Table 1: Constructs, indicators and corresponding statements

Construct **Indicator**	**Statement**
General Performance Expectancy	
gpe1	I think that by using alternative fuel tractors I can achieve identical daily outputs (e.g. ha/h) as with diesel fuel
gpe2	The fuel costs per hour of operation or area worked are lower than those of a tractor powered by a diesel engine
gpe3	The driving experience and comfort of tractors with alternative fuels during use are comparable to the characteristics of a diesel tractor.
Ecological Performance Expectancy	
epe1	I think that the use of alternative fuels can reduce the greenhouse gas emissions of my farm and thus have a positive environmental impact
epe2	Regionally renewable resources, such as rapeseed oil or biomass, can be used to produce alternative fuels, allowing energy to be produced in a more environmentally friendly manner
epe3	By using alternative fuels, resources can be used more efficiently, as secondary products from the production of alternative fuels can also be used as e.g. animal feed or farm fertilizer
Effort Expectancy	
ee1	Refueling of alternative fuel tractors is similarly fast as for diesel tractors
ee2	The use of alternative fuels is associated with increased service costs (e.g. maintenance of fuel lines or tank cleaning)
Social Influence	
si1	According to agricultural media reports, which I trust, alternative fuels are a serious alternative for diesel fuels
si2	People in my private environment are of the opinion that I should use alternative fuel tractors
si3	According to expert opinions, which I trust, alternative fuels are a good, serious alternative to diesel fuels
Facilitating Conditions	
fc1	The existing regulatory framework (e.g. fuel tax or driving bans) gives me sufficient planning security to invest in alternative fuel technologies in the long term
fc2	The subsidy programs available on the market create sufficient incentive for me to invest in alternative fuel systems in the long term
fc3	I consider the existing refueling infrastructure for alternative drives to be insufficient and should therefore be expanded
Intention to Buy an Alternative Fuel Tractor	
int1	I am planning to buy a tractor with alternative fuel in the near future
int2	I already have concrete plans to purchase a tractor with an alternative fuel concept

Sources: Venkatesh et al. (2003); Bagagiolo et al. (2022); Bessette et al. (2022); Frenzel et al. (2021); Sok and Hoestra (2023); Lombardi and Berni (2021)

Material and Methods

Structure of the Questionnaire and Data Acquisition

An online survey was conducted in the second quarter of 2022. Participation of farmers was voluntary and participating farmers agreed that their data would be processed anonymously[1]. Farmers were invited to participate through personal contact. Additionally, the survey link was shared in social media groups dedicated to agricultural discussions. The link was also emailed to agricultural training farms, whose addresses were available online. Upon receiving the link, farmers were encouraged to participate in the survey. The initial page of the survey provided detailed information about the study's objectives.

The questionnaire was divided into four parts. In the first part, the farmers received a short explanation about alternative fuels, to ensure a comparable knowledge of participants, which

[1] The survey was deemed unobjectionable by the Ethics Committee as well as the University's Data Protection Representative.

reads as follows: “Currently, the market for agricultural machinery is dominated by diesel-powered vehicles. However, agriculture already produces raw materials for fuel production (e.g. vegetable oils, sugar and starch) as well as fuels (e.g. biodiesel, rapeseed oil fuels, ethanol or biomethane) or electricity (from e.g. photovoltaics, wind power, biogas) on a large scale. These energy sources and the associated drive systems for mobile machinery are referred in the survey as so-called alternative fuels or alternative fuel tractors”.

In the second part, perceived barriers and potential areas of alternative fuel tractor application were queried. In the third part, the 16 statements (see Table 1) for the UTAUT model (see Figure 1) had to be evaluated by each farmer using an equally-spaced 5-point Likert scale (1 = high disagreement; 5 = high agreement). In the last part, socio-demographic and farm related characteristics were assessed. Purposive sampling or judgment sampling for full-time farmers was applied since full-time farmers, only relying on income from agricultural production, are the most likely group of farmers to first invest in alternative fuel tractors in the future.

Partial Least Squares Structural Equation Modelling

Structural equation modelling (SEM) allows one to estimate cause-effect relationships between independent (exogenous) and dependent (endogenous) constructs. Constructs cannot be observed directly, but must be measured by indicators and then estimated. The indicators are the statements evaluated by the participants in the survey (Table 1). PLS-SEM aims to maximize the explained variance (R^2) of the target construct (e. g. intention to buy an alternative fuel tractor). PLS-SEM is used in this study for the following reasons:

1. PLS-SEM better performs if the sample size is small
2. PLS-SEM allows the use of constructs with only one or two indicators

PLS-SEM models are evaluated in two steps. In the first step, the relationship between indicators and constructs (outer model) are assessed. For the evaluation of the outer model indicator reliability, internal consistency, convergent validity and discriminant validity are estimated (Hair et al., 2022). Standardized loadings of an indicator should exceed $\lambda = 0.7$ to establish indicator reliability. Loadings above 0.7 mean that 50 % of the indicators’ variance is explained by its associated construct. If composite reliability (CR) surpasses a value of 0.7, internal consistency is established in the outer model. This means that all indicators measure the same construct. Average variance extracted (AVE) is the quality criteria for convergent validity and should exceed 0.5. A value above 0.5 for AVE means that the construct explains more than half of the indicators’ variance. Discriminant validity can be established by estimating Heterotrait-Monotrait ($HTMT$) correlations between the constructs. Discriminant validity ensures that the constructs are separable from each other and one indicator only represents one construct. $HTMT$ ratios should not exceed 0.9 (Hair et al., 2022). Variance inflation factors (VIFs) are estimated to control for issues with multicollinearity.

In the second step, the inner model is estimated which represents the relationships between exogenous and endogenous constructs with standardized path coefficients β. *t*-statistics to check for statistical significance of the β coefficients are estimated by applying a bootstrapping procedure with 10,000 subsamples. Values for R^2 of the target construct are also estimated as a quality criterion. For this study, SmartPLS 3.2.7 was used to estimate the model (Ringle et al., 2022).

Results

Descriptive Results

Table 2 shows the descriptive results for the sample. 141 usable records were used. All in all, the sample is slightly biased towards younger, relatively better educated farmers from larger farms with livestock (German Farmers' Federation, 2022). With respect to the bias towards larger farms, this was expected as we purposely sampled for full-time farmers only. However, the sample is still valid for the research purpose as full-time farmers from larger farms are most likely the first ones to adopt new technologies and also display the highest interest in new machinery and technologies in agriculture (Michels et al., 2020). Furthermore, most farmers in the sample have already heard about alternative fuels for agriculture and a larger share of the sampled farmers is also engaged in renewable energy production.

Table 1: Descriptive statistics of the sample (N = 141)

Variable	Description	Mean	SD	Min	Max	German Average [a]
aware	1, if the farmer has heard of alternative fuel tractors	0.90	-	0	1	-
Socio-demographic and farm characteristics						
age	Farmers' age in years	44.87	13.43	21	71	-
	< 25 years	0.09	-	0	1	0.08
	≥ 25 and ≤ 35 years	0.20	-	0	1	0.15
	> 35 and ≤ 45 years	0.17	-	0	1	0.14
	> 45 and ≤ 55 years	0.16	-	0	1	0.24
	> 55 years	0.36	-	0	1	0.36
arableland	Hectares of arable land managed by the farmer	602.56	783.47	10	3900	-
	< 20 hectares	0.02	-	0	1	0.07
	≥ 20 and ≤ 50 hectares	0.06	-	0	1	0.12
	> 50 and ≤ 100 hectares	0.16	-	0	1	0.19
	> 100 and ≤ 200 hectares	0.21	-	0	1	0.21
	> 200 and ≤ 500 hectares	0.17	-	0	1	0.16
	> 500 hectares	0.45	-	0	1	0.25
Farm_Gas	1, if the farm has its own diesel gas station	0.90	-	0	1	-
Field_Farm_Dist	Field to farm distance in km	4.51	3.26	1	17	-
Gender	1, if the farmer is male	0.89				0.90
Higheredu	1, if the farmer holds a university degree	0.31	-	0	1	0.14
Livestock	1, if the farmer is active in livestock farming besides arable farming	0.78	-	0	1	0.69
East	1, if the farm is located in Brandenburg, Saxony, Saxony-Anhalt or Thuringia; 0, other	0.25	-	0	1	0.07
Plough	1, if the farmer uses a plough	0.73	-	0	1	0.57
Tractor	The farmer uses a tractor with…[b]					
	< 100 HP	0.75	-	0	1	-
	≥ 100 and ≤ 250 HP	0.97	-	0	1	-
	> 250 HP	0.50	-	0	1	-
Renewable energy use and production						
Biogas	1, if the farmer is engaged in biogas production	0.31	-	0	1	-
Photovoltaics	1, if the farmer is engaged in photovoltaics	0.79	-	0	1	-
Wind_Energy	1, if the farmer is engaged in wind energy	0.17	-	0	1	-
Thermal_Power	1, if the farmer is engaged in a cogeneration plant	0.14	-	0	1	-
Biofuel	1, if the farmer is engaged in biofuel production	0.03	-	0	1	-
Other	1, if the farmer is engaged in other renewable energy production	0.02	-	0	1	-

[a] German Farmers' Federation (2022)

[b] Multiple answers possible

[c] Mean shown for farmers with variable *electric_car*=1 (N = 23)

SD = Standard deviation, HP = Horse power

Figure 1 shows various potential areas of farm work for alternative fuel tractors from farmers point of view. Tractors with alternative fuels are considered practical primarily for non-energy-intensive light farm work (90 %) and for transportation over short distances (54 %). In contrast, only a small share of farmers perceives tractors with alternative fuels as being potentially suitable for energy-intensive field work (14 %) and long-distance transportation (16 %). The results could be explained by looking at Figure 2 showing barriers for the adoption of alternative fuel tractors. The majority of farmers (70 %) think that tractors with alternative fuels have relatively lower driving ranges than diesel powered tractors. Further barriers mentioned are high investment costs (60 %) and a lack of sufficient infrastructure for alternative fuels (50 %). The results resemble Sok and Hoestra (2023), who showed that working time and range as well as operational and purchase costs are the most important attributes of an electric tractor for farmers. Contrasting results are presented by Bagagiolo et al. (2023) who showed that refueling and costs are the most important barriers.

Figure 1: Potential areas of farm work for alternative fuel tractors from farmers' point of view. Multiple answers possible. (N = 141)

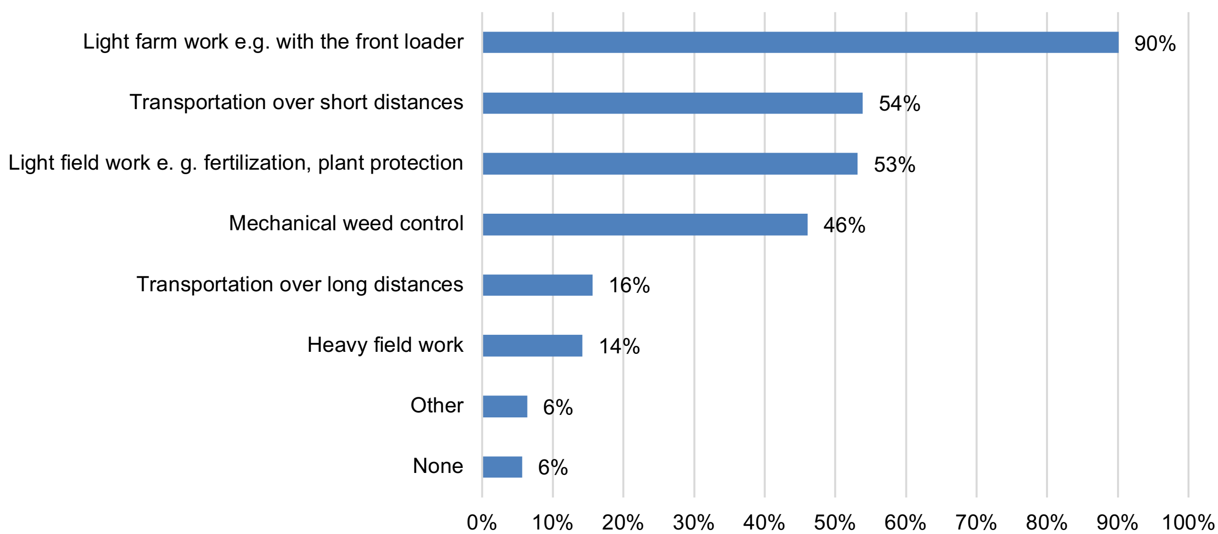
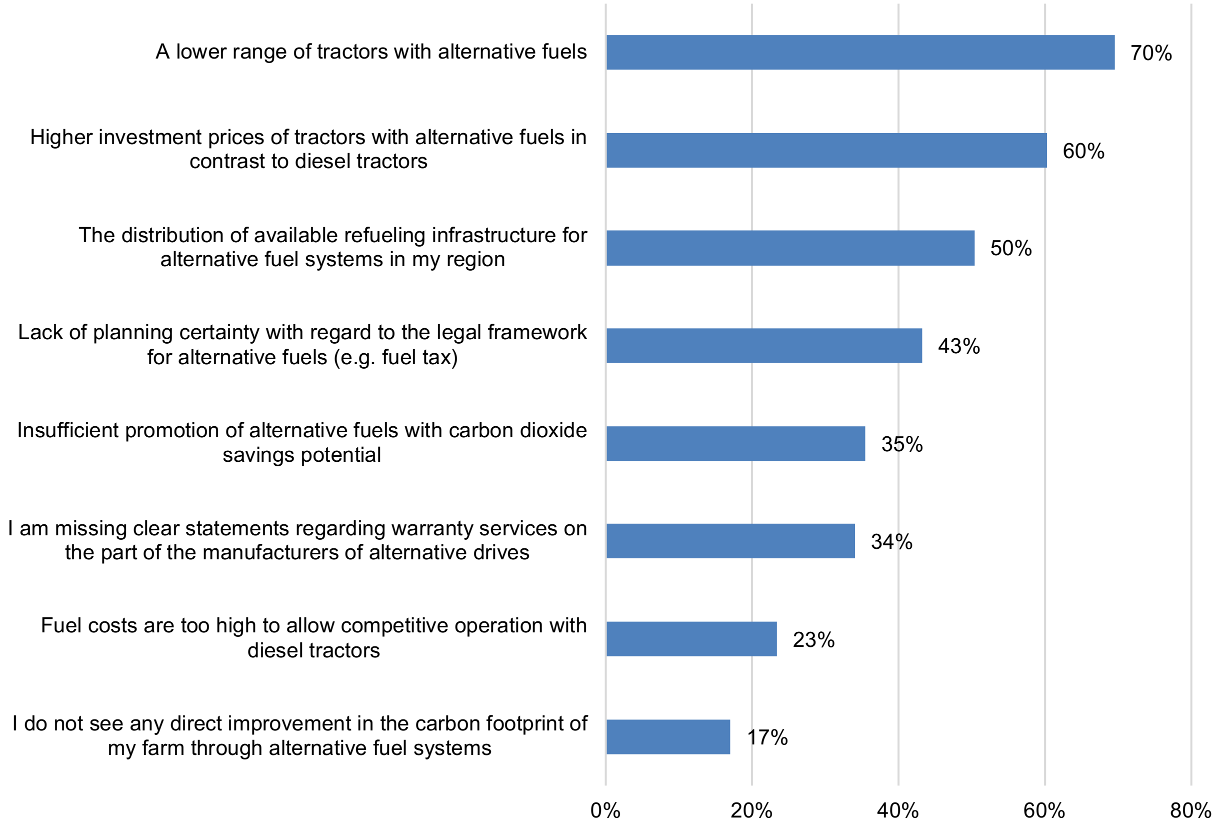


Figure 2: Barriers to the adoption of alternative fuel tractors. Multiple answers possible. (N = 141)



Estimation results of the UTAUT model

Tables 3, 4 and 5 show the estimation results for the outer model. Three results in Table 3 merit particular attention and are mentioned first. First of all, the construct “Effort Expectancy” did not meet necessary quality criteria. Hence, we decided to split the construct up into two single-item constructs “Effort Expectancy – Refueling” (H3a) and “Effort Expectancy – Service” (H3b) which is still in line with Hair et al. (2022) who pointed out that the use of single-item constructs is possible in PLS-SEM. The same holds for the construct “Facilitating Conditions” which we split up into the constructs “Facilitating Conditions – Market” (H5a) and “Facilitating Conditions – Infrastructure” (H5b). Second, the indicator loadings of “epe2” and “epe3” for the construct “Ecological Performance Expectancy” are below the common cut-off level of $\lambda = 0.7$ (Hair et al., 2022). However, Hulland (1999) reasoned that only indicators with a loading less than 0.5 should be dropped. Hair et al. (2022) proposed that indicators should be retained in the model if their drop would negatively affect further model results and validity. Furthermore, bootstrapping results show that both indicator loadings are statistically significant at the 5% significance level. Hence, the indicators were kept in the model. Third, the indicator “gpe3” is also below the common cut-off level of $\lambda = 0.7$ (Hair et al., 2022). We use the above explanation to clarify why the indicator remains in the model. However, the AVE value for the construct “General Performance Expectancy” amounts to 0.496, which is close to the threshold of 0.5 but still below it. Fornell and Larcker (1981, p. 46) argued that if the estimated CR for the associated construct is above the recommended threshold, the “[…] construct is adequate, even though more than 50% of the variance is due to error”. Hence, internal consistency is established for the construct “General Performance Expectancy”. All other indicator loadings exceed the common threshold of 0.7. Furthermore, all values for CR and AVE exceed the recommended quality criteria thresholds establishing internal consistency and convergent validity. Values for the outer and inner VIFs (max. value of inner VIF = 1.53) indicate that multicollinearity is not at a critical level as no VIF exceeds the threshold of 5. Lastly, the results for HTMT (max. HTMT value = 0.739) do not exceed the threshold 0.9 which establish sufficient discriminant validity for the outer model.

Table 2: Outer model results (N = 141)

Construct					***CR***	***AVE***
Indicator	**Factor Loadings λ**	**Mean**	**SD**	**OVIF**		
General Performance Expectancy					*0.742*	*0.496*
gpe1	0.803***	2.772	1.238	1.081		
gpe2	0.793***	2.772	0.997	1.081		
gpe3	0.586***	3.577	1.076	1.121		
Ecological Performance Expectancy					*0.747*	*0.512*
epe1	0.947***	3.570	1.125	1.201		
epe2	0.550**	3.503	1.121	1.391		
epe3	0.582**	3.611	1.091	1.550		
Effort Expectancy – Refueling					-	-
ee1	-	2.752	1.135	1.000		
Effort Expectancy – Service					-	-
ee2	-	3.309	0.941	1.000		
Social Influence					*0.816*	*0.596*
si1	0.789***	2.819	1.056	1.561		
si2	0.753***	2.268	1.072	1.142		
si3	0.774***	2.711	0.964	1.633		
Facilitating Conditions - Market					*0.831*	*0.711*
fc1	0.887***	1.879	0.889	1.224		
fc2	0.797***	1.739	0.870	1.224		
Facilitating Conditions – Infrastructure					-	-
fc3	-	3.839	1.118	1.000		
Intention to Buy an Alternative Fuel Tractor					*0.806*	*0.678*
int1	0.907***	1.899	1.047	1.162		
int2	0.730***	1.550	0.930	1.162		

SD = Standard deviation, OVIF = Outer variance inflation factors, CR = Composite reliability, AVE = Average variance extracted
***p<0.01; **p<0.05; *p<0.1

Table 4 shows the results of the inner model. Explained variance (R^2) of the target constructs amounts to 23.1%. Most of the hypotheses derived in section 2 are supported by the model, with the exception of H3a and H3b, for which the path coefficients are not statistically significant.

Table 3: Results of the inner model (N = 141)

Path	H	Path coefficient β	t-value [a]	p-value	Support H?
GPE → INT	H1	0.195**	2.315	0.010	Yes
EPE → INT	H2	0.171**	1.815	0.037	Yes
EE – Refueling → INT	H3a	-0.060	0.627	0.265	No
EE – Service → INT	H3b	0.027	0.360	0.363	No
SI → INT	H4	0.210**	2.200	0.014	Yes
FC – Market → INT	H5a	0.131**	1.678	0.045	Yes
FC – Infrastructure → INT	H5b	0.091*	1.322	0.093	Yes

EE – Refueling = Effort Expectancy – Refueling, EPE = Ecological Performance Expectancy, FC – Market = Facilitating Conditions – Market, FC – Infrastructure = Facilitating Conditions – Infrastructure, INT = Intention to Buy an Alternative Fuel Tractor, GPE = General Performance Expectancy, EE – Service = Effort Expectancy – Service, SI = Social Influence

***p<0.01; **p<0.05; *p<0.1

R^2(INT) = 0.231, Q^2(INT) = 0.094

[a] Bootstrapping result with 10,000 sub-samples

Practical implications, limitations and conclusions

According to the inner model results, increasing the perceived general performance of alternative fuel tractors also statistically significantly increases farmers' intention to buy them (H1, Table 4). Furthermore, the construct is the second strongest predictor[2] of farmers' intention to buy alternative fuel tractors. This aligns with Lombardi and Berni's (2021) findings, where engine power was a major determinant in adopting electric fuel tractors. The notion that farmers expect alternative fuel tractors to perform similarly to diesel tractors resonates with the studies by Sok and Hoestra (2023) and Frenzel et al. (2021), underscoring the importance of meeting these performance expectations. These findings have important implications. Firstly, they suggest that farmers expect alternative fuel tractors to perform at a level comparable to that of diesel-powered tractors. For manufacturers, this implies that the efficiency of alternative fuel tractors must be correspondingly high to stimulate purchase intention. Secondly, the comparable performance of alternative fuel tractors could be utilized for marketing purposes, given the results of the perceived barriers to the use of alternative fuel tractors (Figure 2). Furthermore, this could potentially reduce farmers' perception that alternative fuel tractors are only suitable for low-energy tasks on the farm or field (Figure 1).

Ecological performance expectancy encompasses the reduction of greenhouse gas emissions and the effective utilization of agricultural or fuel-production by-products associated with alternative fuel tractors, statistically significantly increases farmers' intention to buy them (H2, Table 4). This also corresponds to the highest approval regarding the associated indicators for the construct "Ecological Performance Expectancy" in Table 3, mirroring sentiments observed by Bessette et al. (2022) among small-scale growers. The results of Sok and Hoestra (2023) are however in contrast. Based on our results, it can be expected that farmers are very willing to buy tractors that use alternative fuels to help protect the environment. This environmental consciousness should be addressed by marketing activities. Furthermore, it can be assumed according to the results in Table 3 that they also could be willing to engage in raw material production for alternative fuel production or use the by-products of alternative fuel production. These results have implications for extension services, as they can assist in elucidating the economic benefits of alternative fuel use and making them more appealing to farmers. Nevertheless, it could be worthwhile to investigate the reason for our contrasting results with Sok and Hoestra (2023). One potential explanation could be the ongoing "nitrogen crisis" in the

[2] As path coefficients in PLS-SEM are standardized, they allow a comparison in their magnitude.

Netherlands mentioned by Sok and Hoestra (2023) which could cause general reluctance by the farmers to environmental issues and regulations. A direct country-comparison could shed more light on these contrasting results.

The non-statistically significant impact of both “Effort Expectancy” constructs on farmers' intention to purchase an alternative fuel tractor (H3a and H3b, Table 4) raises suspicions. Two possible explanations may be put forward to account for these findings. Firstly, farmers may not be sufficiently familiar with the diverse refueling methods and necessary repair and maintenance procedures for new alternative fuel systems as indicated by the studies of Bagagiolo et al. (2022). Secondly, it is more probable that the refueling and maintenance systems differ too much for various alternative fuels. For instance, loading an electric tractor is simpler than refueling a biomethane tractor. Although the effect was not statistically significant, farmers may still benefit from receiving information about refueling and maintenance procedures through marketing activities conducted by manufacturers.

Social influence is the strongest statistically significant predictor for farmers’ intention to buy an alternative fuel tractor (H4, Table 4). This result implies that agricultural machinery manufactures could use agricultural magazines or testimonials for marketing purposes and to disseminate knowledge about alternative fuels. Likewise, agricultural professional meetings could be used for marketing activities as they can also stimulate the exchange of experience and knowledge among farmers on the topic.

Perceived favorable facilitating conditions are statistically significantly positively associated with farmers willingness to buy an alternative tractor in the future (H5a, Table 4). Hence, planning certainty regarding the legal framework can stimulate farmers’ intention to buy an alternative fuel tractor. This result is also supported by the results in Figure 2. Regarding political implications, farmers express the need for certainty regarding the legal framework surrounding alternative fuels (H5a, Table 4) as noted in the works of Sok and Hoestra (2023). Likewise, the expansion of infrastructure for the supply of alternative fuels must be politically supported (H5b, Table 4).

However, it is important to acknowledge the limitations of our research. The focus on German full-time farmers may not fully capture the diverse agricultural contexts across different regions and farming scales. To be specific, the use of this sample could introduce biases, affecting the generalizability of our findings. This limitation opens avenues for future research, highlighting the need for comparative studies across various cultural and farming contexts and suggesting the potential value of longitudinal studies to track the evolving perceptions of farmers as alternative fuel technologies advance. Additionally, hydrogen-powered tractors could be an interesting subject for future research inquiries. By continuing to explore these crucial themes, one can better support the agricultural sector's journey towards a more sustainable and environmentally responsible future.

In summary, for agricultural machinery manufacturers, our findings underscore the importance of aligning tractor performance with farmers' expectations. Demonstrating that alternative fuel tractors can perform comparably to diesel counterparts is crucial. Professional magazines and testimonials could effectively be used for this. Policymakers can leverage the study’s insights to formulate policies that support the adoption of alternative fuel technologies in agriculture. Incentives and infrastructure development could accelerate the shift towards more sustainable agricultural practices. Lastly, for farmers, the insights into factors that drive adoption decisions can inform their choices and open avenues for more sustainable farming practices.

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