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Survey analysis on the market potential of an agricultural energy management system

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The increasing demand for renewable energy and the associated reduction in the use of fossil fuels is becoming a key challenge for politics, society and science worldwide, especially in Germany. This development offers the agricultural sector the opportunity to use the energy generated itself by operating photovoltaic systems on existing agricultural buildings, wind turbines or biogas plants, regardless of the production processes used, and to supply the surplus electricity directly to the public grid as a market participant. However, intelligent electricity storage concepts and a corresponding energy management system are necessary to be able to use the existing potential at all, both to optimize internal production processes and to coordinate the varying energy demand and supply in the electricity grid. Agriculture could become an energy service provider in rural areas. The "Stable 4.0" research initiative of the Technical University of Munich and Weihenstephan-Triesdorf University of Applied Sciences has been working on the practice-oriented development of system-specific principles for the implementation of an on-farm energy management system (EMS) since 2013. Agricultural operations differ greatly from region to region, but also within their production processes, and can be expected to have varying requirements and usage profiles for the system. It is therefore of interest to what extent the industrial prototype can be used and further developed within the agricultural sector. The dissemination and use of new innovations on the market is largely determined by the users. Based on a project study with 1.057 completed online responses, the current interest of practitioners in a customized EMS can be derived. It shows that economic aspects, but also efficient self-consumption of electricity and the self-sufficiency rate are particularly important to farmers. The study also looks at the use of information channels for innovations in the field of energy and is intended to serve as the basis for a marketing concept. The influence of various production processes was also examined in the survey. Initial findings already indicate multiple potential benefits for the use of the EMS and a clear added value for the entire agricultural sector.

KEYWORDS

energy management systems, market potential, agriculture, innovation, energy efficiency, renewable energies, self-sufficiency

1 Introduction

The possibilities developed in recent years for the digitalization of production processes in agriculture, especially in livestock farming, have led to an increase in performance and improved husbandry conditions. New developments in husbandry technology and anticipated research findings on human-animal-technology interactions will lead to further optimized husbandry systems (Stumpenhausen and Bernhardt, 2019). In addition to the traditional production of milk and meat, a dairy farm also has the potential for a further operational main-stay, energy production, and thus could further optimize the "milk" value chain. Thanks to the existing buildings (stables and storage buildings) that are necessary for animal husbandry, the farmer also can generate energy independently on site. Especially in the case of a holistic system view, there is a realistic approach to an (even) more efficient utilization of existing resources in the field of renewable energies (Barckhausen et al., 2020).

The additional increase in the use of renewable energy sources and the resulting reduction in the use of fossil fuels has become a central challenge for politics, society and science worldwide, explicitly in Germany (Brodny and Tutak, 2023; Gawel et al., 2017). The growing demand for primary energy, the high inflation rate and increasing credit costs in times of armed conflict are leading to a tense and particularly volatile energy market (Europäischer Rat, 2024). The study on the energy consumption trend of Polish households (2006–2021) for hard coal, electricity and natural gas also confirms this described dynamic of the energy market and also forecasts the future increase in electricity demand (Gajdzik et al., 2023). As a result, energy as a resource is becoming a cross-sector cost driver (Statistisches Bundesamt, 2022). Because of the energy transition (IEA, 2023), the focus is shifting from ecological and socio-economic aspects to unused (economic) synergies (Bundesamt für Naturschutz, 2020). The increased provision of renewable energy sources (photovoltaics, biogas, wind power) poses additional economic challenges for rural areas and the agricultural sector, especially energy-intensive livestock farming. In addition to sustainable energy production, the discussion about grid stability, electricity tariffs and electricity storage and their more efficient use are also increasingly coming into focus (Gawel et al., 2017). By operating photovoltaic systems on existing farm buildings or utilizing the liquid manure and other byproducts from livestock farming in biogas plants, farmers can generate another source of income (energy) in addition to the production of milk, meat and grain (Hartmann, 2011). A holistic view of the system shows that renewable energies offer a realistic opportunity for more efficient utilization of existing resources and thus the possibility of reducing production costs (Kuner, 2024). However, to be able to utilize the existing potential for renewable energy production at all, intelligent electricity storage concepts and a corresponding energy management system are necessary to coordinate both internal production processes and the varying energy demand and supply in the electricity grid (Stumpenhausen and Bernhardt, 2022). The farmer could thus act as an energy supplier and service provider for rural areas.

2 Background to the "CowEnergySystem" research project

Since 2013, the "Stable 4.0" research initiative has been working on the practice-oriented development of system-specific principles for the implementation of an on-farm energy management system (EMS) for agricultural dairy barns (Stumpenhausen and Bernhardt, 2016). In cooperation with three project partners from industry and with the support of the Federal Ministry of Food and Agriculture (BMEL), the group is working on a multistage research program with defined project phases and has already been able to gain meaningful insights into the necessary requirements for such an on-farm energy management system on two practical pilot farms. The EMS was implemented in a practical hardware and software solution (Höld et al., 2016) and has now reached market maturity. Parallel to the growing degree of automation in the form of autonomous agricultural machinery and field robots in agriculture and horticulture (Gaus et al., 2017), indoor farming is also developing towards integrated dairy and energy production (integrated dairy farming) with the highest degree of automation and sensor-controlled production control (Lokhorst, 2018; Tedeschi et al., 2021). Due to the cross-production requirements for human-animal technology interactions, further test farms will be included in the project program to gain additional scientific knowledge and new foundations for intelligent networking of relevant system elements and to develop a complex communication structure for farm-specific load management (Höld et al., 2015; Höhendinger et al., 2023) outside the production direction of milk production. The structural facilities required for animal husbandry (stables and storage buildings) offer the possibility of independent decentralized energy generation (photovoltaics, biogas, wind power) on site (Bernhardt et al., 2021). The holistic system view shows a realistic opportunity for a more efficient and sustainable utilization of existing resources in the field of renewable energies.

Figure 1 shows the complex structures of the integrated system with the most diverse areas of influence. In contrast to foreign trade, there are no standardized data interfaces for the EMS, such as the ISOBUS standard in agricultural machinery technology. For this reason, separate actuators had to be developed for each system element to ensure optimized internal network and communication technology. These actuators are electronic modules that interact as components of the technical barn system between the EMS and individual energy consumers, thus ensuring an adaptable system installation. This proprietary sensor network allows all important information to be stored via a cloud system and forwarded accordingly. With the help of the EMS, it is thus possible to flexibilize both the time of use and the duration of use of the individual units during the day, by balancing energy generation and energy consumption. The EMS uses other process relevant production data, such as milk yield, current weather forecasts and barn climate data, to generate real-time simulations (Höhendinger et al., 2018). From this, the EMS can draw conclusions about the future energy requirements of the existing barn components. For example, when animal activity is concentrated in the feeding area due to the use of the electric feed mixer wagon, there is a good time to start the

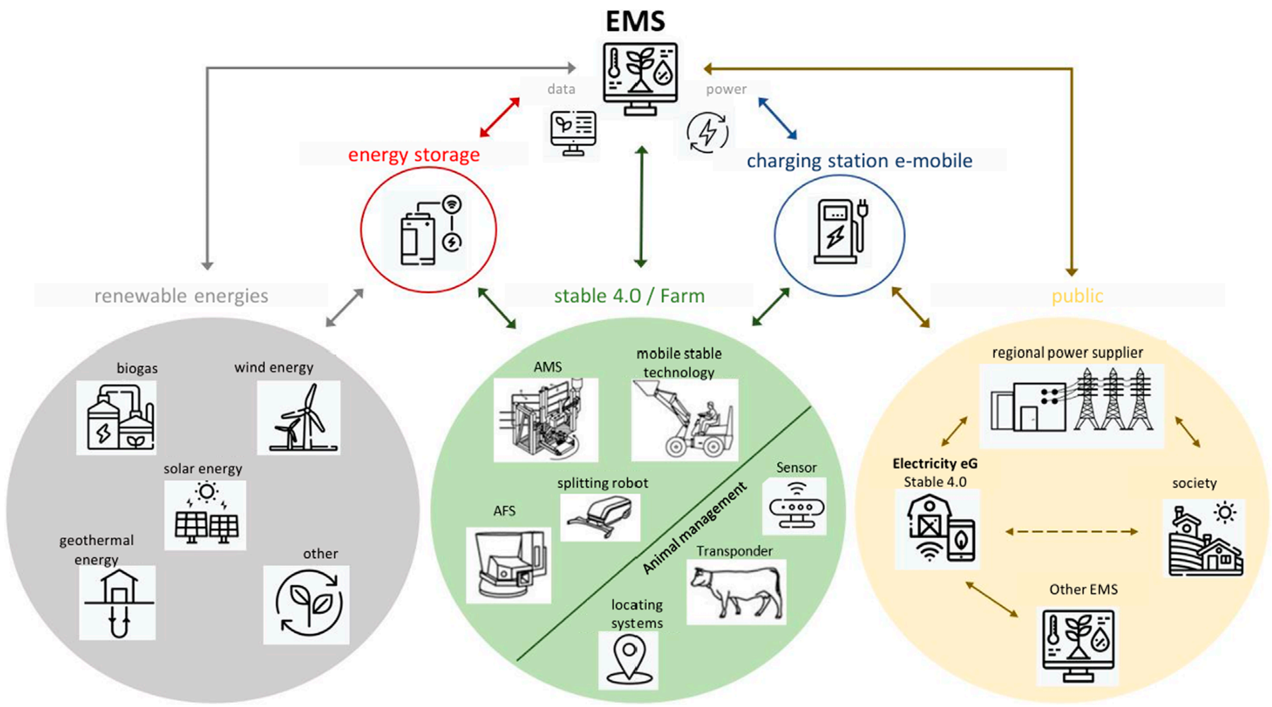

FIGURE 1
Integration of the on-farm energy management system into the production processes of an agricultural dairy farm (©TU Munich).

cleaning program of the automatic milking system (AMS). Logically, the energy required for cleaning must then also be available at this time via the current energy production or already stored energy. The storage concept must therefore include a diversification of power availability so that the EMS can manage the central control of energy flows according to supply and demand. Energy generation on a farm is usually characterized by the fact that on average more electricity is generated than can be consumed by internal processes (Hartwig-Kuhn, 2021). This means that the remaining surplus energy can be sold to the public grid for use. The farm therefore not only becomes energy self-sufficient, but also generates an additional source of income from existing resources and becomes a sustainable, decentralized energy service provider for rural areas (Bader et al., 2024).

2.1 Objectives of the "CowEnergySystem" research project

As farms differ greatly from region to region, but also within their production processes, the marketing success of the EMS is determined centrally by the expected added value for users (RQ2: Which factors are particularly influential in the decision for or against an EMS?). Therefore, in addition to the practical use of the prototype with different operational and technical equipment, the market potential (= number of potential buyers) was determined based on a comprehensive user survey (n = 1.057) and analyzed accordingly for a future marketing concept. In addition to the regional sales strategies to be developed, user potential, economic added value, internal drivers and the existing purchasing criteria of the agricultural sector are also addressed. The study also looks at the sector-specific information channels used by farmers and provides information on future product positioning. The market launch of the product in question should be started as soon as possible. However, it is important to know how well-known energy management systems already are in agriculture (RQ1: How well known are energy management systems in agriculture and how can the level of awareness be increased?), how this level of awareness can be increased, how great the interest in EMS is and how the interested groups can be described (RQ3: How great is the interest in EMS and how can the group of interested persons be described?). In addition, it is still partially unexplored which product characteristics and value drivers are decisive for success and where the farmers' willingness to pay for such an EMS lies (RQ4: Where is the willingness to pay for an EMS?). Furthermore, the market potential in the various target markets has not yet been determined with enough accuracy. These and other questions are to be answered in this study (Stumpenhausen and Bernhardt, 2022).

3 Materials and methods

As the EMS is an innovative, completely new development, a new market must also be tapped into. The primary target group for this is the future-oriented, entrepreneurial dairy farm that is looking for a flexibly structured, yet standardized overall solution that offers a high degree of automation, new ways of organizing working hours and an attractive combination of income through extensive use of the possibilities for generating renewable energy. The introduction of corresponding dairy barn

TABLE 1 Key research questions for the online survey.

RQ-number	Research question
RQ1	How well known are energy management systems in agriculture and how can the level of awareness be increased?
RQ2	Which factors are particularly influential in the decision for or against an EMS?
RQ3	How great is the interest in EMS and how can the group of interested persons be described?
RQ4	Where is the willingness to pay for an EMS?

energy concepts is associated with extensive changes for farms and their management. From the point of view of economics, we can therefore speak of innovations (Neumair, 2018). Experience in innovation research has shown that the success or failure of innovations is determined by their acceptance on the market. In many cases, however, there are subsequent problems associated with a specific innovation process, such as internal innovation barriers and/or general acceptance problems (Möhrle and Specht, 2018), which determine the spatial and temporal spread of an innovation (diffusion speed) (Kuehne et al., 2017). For these reasons, four research questions were previously defined for the project study, which served as the basis for the online survey (Table 1). The subsequent questionnaire construction was then based on these questions.

The standardized questionnaire consists of closed, open questions and mixed forms of both. The open text fields provided allow data to be collected individually for each company and then summarized into categories. In addition, different scales were included in the questionnaire. The questionnaire is divided into five subject areas.

3.1 Subject area “user group”

At the beginning of the survey, participants are asked questions about themselves. They are asked about their relationship to agriculture, origin and age.

3.2 Subject area “operational management”

This is followed by questions about the farm to which the interviewee has a closer relationship. In this section, information is collected on the type of farm, the respective form of production, the number of livestock units kept, and the area farmed, as well as the potential farm succession. In addition, the survey participants with dairy farming are asked about the size of the herd and the milking system used.

3.3 Subject area “energy management systems”

The third topic section briefly describes the EMS and then asks whether the survey participants have already heard of energy management systems in agriculture.

3.4 Subject area “technical equipment of the company”

The following section addresses questions about the equipment of the respective companies. The questions relate to the energy generation systems in the business, the amount of electrical energy generated, the amount of electricity required, the proportion of electricity consumed by the business itself, the (remaining) term of the subsidy under the EEG, the heating system installed and the number of buffer storage units at the respective business location. In addition, questions were asked about the purchase of a stationary battery storage system, possible obstacles in this regard and the ownership of electrical devices used on the farm.

3.5 Topic area “investment factors and internal drivers”

The fifth section deals with the topic of energy and energy systems. The focus here is on future investments, sources of information used in the energy sector, the importance of various factors in an EMS and the fundamental interest in an energy management system. In the final section, participants who have previously indicated that they are interested in an EMS for their company in principle, or are still unsure about this, are asked about the desired amortization period, the maximum conceivable initial investment and the potential cost of a service contract.

Before the questionnaire was released on the survey platform, it was reviewed by five people familiar with the topic. The questionnaire was then modified based on their comments and submitted to seven people for an official pretest, which included checking comprehensibility, grammar and filtering. To gain as much benefit as possible and to test various aspects, a targeted selection was made of farm owners, farm successors, people with agricultural training but without their own farm and a consumer with no close connection to agriculture. Based on the feedback from these pretesters, final modifications were made to the questionnaire. At the same time, the time required to answer the questionnaire was recorded to indicate the time frame (from 8 to 10 min) for the survey in the introductory text to the survey. The survey and distribution of the survey link were then started on 27.03.2023. The link could be accessed via www.umfrageonline.com/c/twreqxid for 5 weeks. The survey link was advertised via the network of colleges and universities, as well as all project partners and their customers, to training companies, agricultural offices and ministries by email, and distributed via LinkedIn and Instagram on social media. The questionnaire could be completed online on the platform. To answer the research questions, farm managers, farm successors, elderly farm owners and family members of agricultural businesses were surveyed. The reason for choosing this target group is the person's current or future decision-making power when purchasing an energy management system for the farm. Only these groups of people can be regarded as future purchasers of an EMS. Other survey participants, such as agriculturally trained persons without a farm and pure consumers, were passed on to the end of the survey after the question on their relationship to agriculture. In addition, people under the age of 18 were not included in the desired target group for data protection reasons and their survey was also terminated after they indicated their age.

Data collection was stopped at 9.30 a.m. on 2 May 2023, meaning that the survey period covered 37 days. According to the survey platform, the trimmed average participation time was 8.22 min. A total of 1.485 responses were collected. Of these, 74.6% of the surveys were completed in full, meaning that 1.108 completed questionnaires were collected during this period. Of these, 1.057 people corresponded to the target group described in the survey. The data from the incomplete questionnaires and the data from people who did not belong to the desired target group were excluded from the analysis. The results of the survey were exported from the survey platform to Excel. The open and partially open questions were then evaluated in Excel and the data processed and analyzed. The answers were summarized in categories. Version 2,111 Microsoft 365 MSO of the Excel program from 2016 was used for the entire data preparation. Responses that are to be regarded as future investments or plans were not included in the preparation, as the study was intended to shed light on the status in 2023. In addition to descriptive evaluations, chi^2 tests were also carried out. The SPSS platform was used and a significance level α of 0,05 was applied. This is often the case with statistical evaluations (Frost, 2017).

4 Results

The following presentation of the results is again based on the subject areas used in the structure of the questionnaire and was summarized in the following three areas (user group, operational structure, energy management system).

4.1 Overall evaluation of potential user group

The origin of the survey participants is shown in Figure 2, stratified by federal state.

38.51% of the participants or 407 respondents come from Bavaria (Figure 2), just under 9% come from Baden-Württemberg (9.18%). More than 50 respondents each came from the federal states of Hesse (6.53%), North Rhine-Westphalia (7.00%) and Schleswig-Holstein (6.53%). Lower Saxony participated in the survey with 4.35%. Just over 3% of the respondents stated that they came from Saxony-Anhalt, Saxony or Thuringia. Outside Germany, 142 people responded to the questionnaire, 93.66% of whom came from German-speaking Switzerland, just under 5% from Austria (4.93%) and one respondent each from France and Liechtenstein.

In addition to their origin, the survey participants were also asked about their age. The distribution (Figure 3) shows that more than 20% of the respondents were in each of the age groups 35–44 years (21.19%), 45–54 years (22.14%) and 55–65 years (23.27%). The proportion of 25 to 34-year-olds corresponds to 18.83%; 11.92% of respondents were 18–24 years old. Over 65 s accounted for 2.65% of survey participants.

In addition, the survey participants were also asked about their connection to agriculture. Almost 80% of respondents are farm managers and around 11% are farm successors (Figure 4).

4.2 Overall evaluation of operating structures

Of interest were the different types of farming operations of the survey participants. The relative frequencies of the respective farm types are illustrated in Figure 5.

Figure 5 shows that almost four-fifths of the survey participants run an arable farm. In addition, a good one in two keep dairy cattle. 38.22% fatten and/or rear cattle and 15.52% fatten and/or breed pigs. Extensive livestock farming is practiced by 12.11% of farms, while 11.54% of respondents are involved in special crops. It was also possible to specify other types of farming. There was a total of 296 responses in this regard, which were grouped into categories where possible. A total of 81 people operates a biogas plant. 24 survey participants named direct marketing as another mainstay of their business, and 21 named forestry. In addition, the participants were asked to classify the associated branches of business according to their individual importance, which was done by 1.030 people. For a better evaluation, the classification of the individual participants was converted into a point system, whereby the most important branch received more points than the branch that was considered less important. The most important branch overall was dairy farming with 1.598 points, followed by arable farming (1.416 points) and cattle fattening/rearing (701 points). The category "Other types of farming" came fourth with 494 points, followed by pig fattening/breeding in fifth place with 353 points and poultry fattening and/or laying hen farming with 233 points. Extensive livestock farming came last (229 points). In the next step, the type of production used on the respective farm was surveyed. Here, 77.39% of the 1.057 participants stated that they use conventional production methods on their farm. Only 21.10% of farms farm organically and 3.31% according to other forms of production. A total of 19 people stated that they used two different forms of production on their farm.

In addition to the basic production direction, the respondents were also asked about the more specific operational equipment, with energy generation systems being of interest. Figure 6 illustrates the respective proportions. Around 80% of respondents operate one (or more) photovoltaic systems, 26% produce biogas. A proportion of 15.7% do not operate a system for decentralized energy supply.

In equipment for businesses, participants who use at least one energy generation system were asked whether they had already considered purchasing a stationary storage system (batteries) (Figure 7).

Around 27% of respondents stated that they had not yet thought about purchasing a stationary battery. Accordingly, 72.95% have

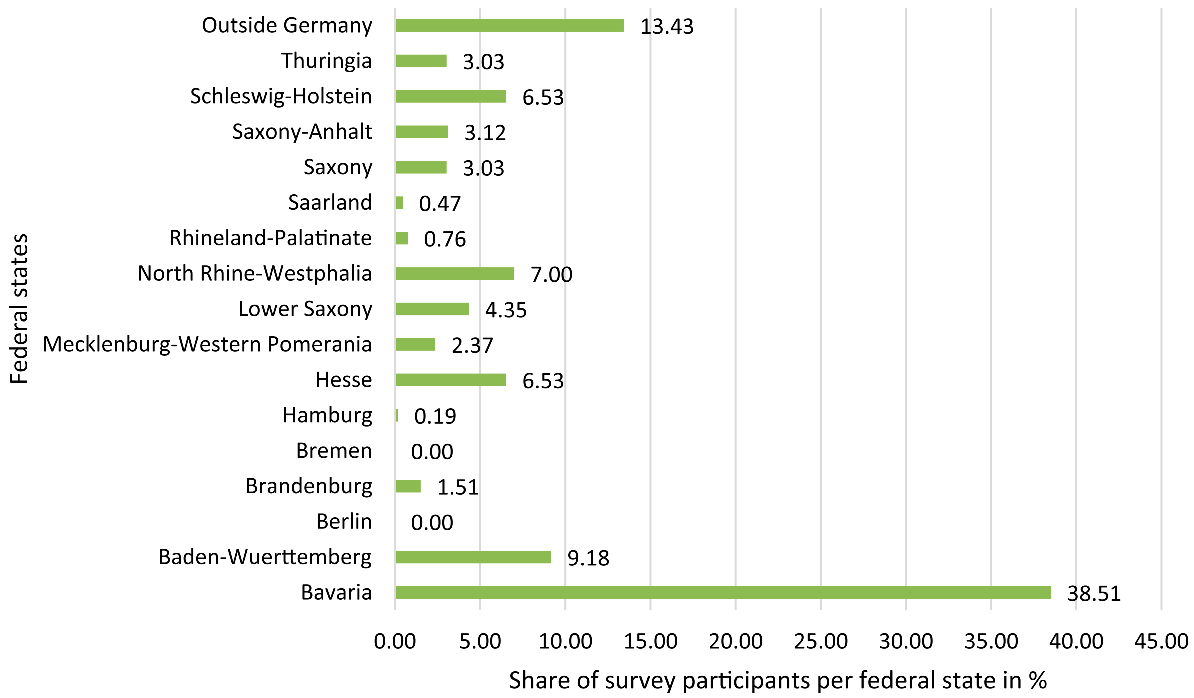

FIGURE 2
Origin of survey participants by federal state (n = 1.057).

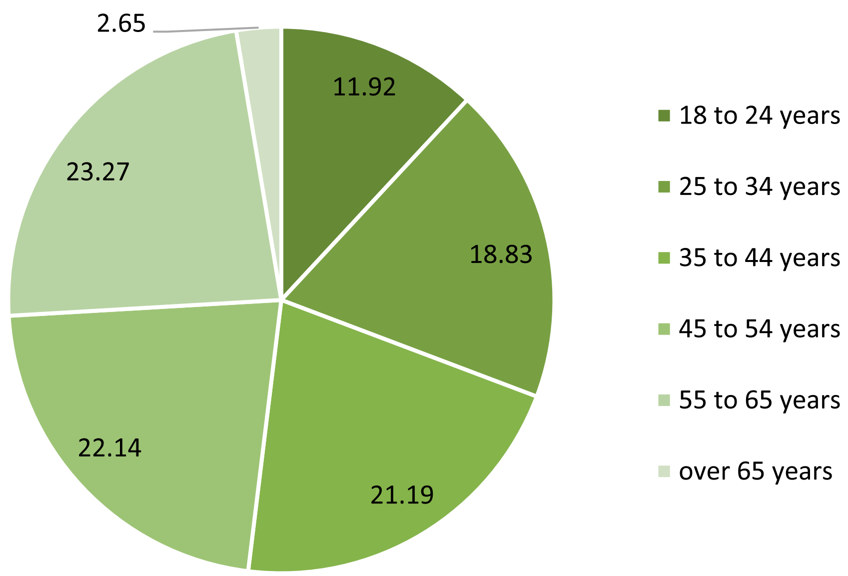

FIGURE 3
Age structures of survey participants (n = 1.057).

already considered purchasing such a storage battery. 10.10% already have a stationary battery on their farm, 4.49% of those surveyed have decided to purchase a stationary battery; however, this is not yet available to the farm. 43.88% of survey participants have already considered a stationary battery but have not yet decided. Despite preliminary considerations, 14.48% of respondents have decided against purchasing a rechargeable battery. The reasons given for hesitating or refusing to buy a rechargeable battery were doubts about its cost-effectiveness (around 71%), but also reluctance to make the investment itself (47%) (Figure 8).

More than 20.00% of respondents cited inadequate support (25.96%) and insufficient knowledge (23.85%) as reasons. To record the reasons for their skepticism in as much detail as possible, this question gave respondents the opportunity to note

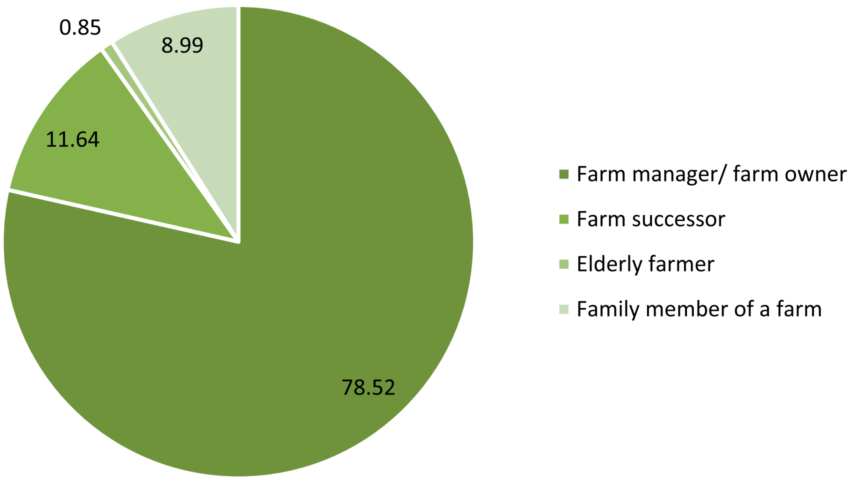

FIGURE 4
Survey participants' relationship to agriculture (n = 1.107) in %.

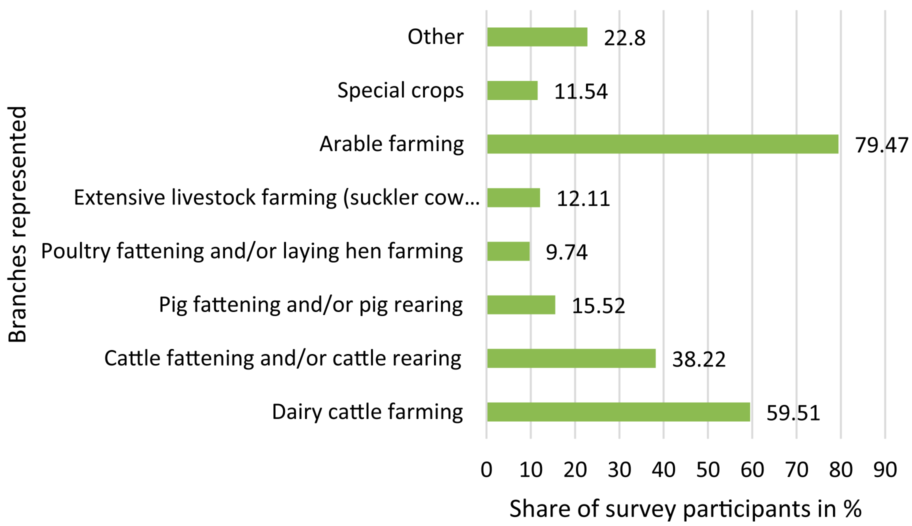

FIGURE 5
Branches of business of the survey participants (n = 1.057).

other aspects that would hinder their decision to purchase a stationary battery. Concerns about the technology were expressed by 2.12% of respondents, and thus most frequently, on the one hand about the uncertain service life, but also about the current state of development of the battery. 1.92% of respondents had concerns about the manufacture and/or disposal of the battery.

The last question on farm equipment asked about the electrical equipment currently available to farms, with multiple answers possible. The results are shown in the following bar chart.

Figure 9 shows that, at 51.37%, more than half of the survey participants do not currently own any of the electric devices listed. Electric feed pushers (16.75%), electric/hybrid cars (16.46%) and slat robots (16.08%) are widespread. Around one in ten survey participants uses a milk tank with ice water storage on the farm, while only a few have an electric loader (4.82%) or an electric feed mixer (2.65%) in use.

4.3 Overall evaluation of the energy management system

To determine the importance of different factors for the (future) use of an energy management system, the survey participants were able to give a weighting between none (1), low (2), high (3) and very high importance (4). The average weighting was then calculated and a ranking compiled (Table 2).

As can be seen from the ranking in Table 2, economic efficiency is the most important factor in energy management systems for the respondents. More than half (56.86%) stated that economic

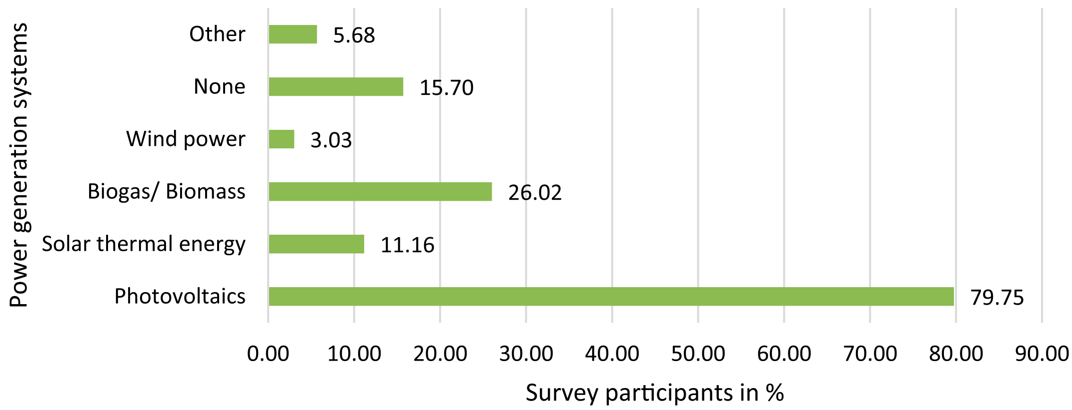

FIGURE 6
Installed energy generation systems among the survey participants (n = 1.057).

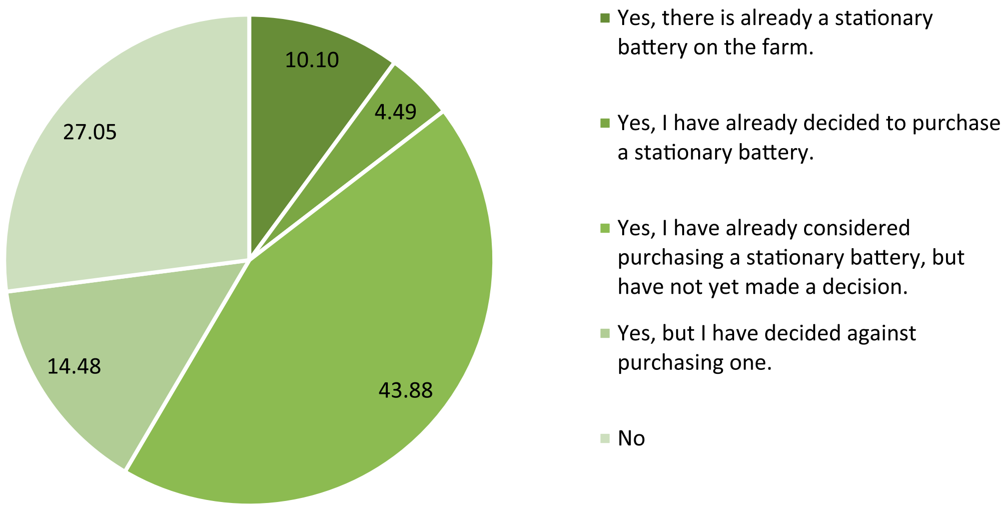

FIGURE 7
Realized or planned electricity storage concepts on the survey farms (n = 891) in %.

efficiency was very important or at least very important (38.86%); only 4.54% attributed little or no importance to it. In second place is better use of the electricity produced on the farm or control of energy flows (41.63% very high, 44.65% high weighting). According to the respondents, potential energy savings through the EMS is the third most important factor. For over a third (35.76%), this aspect is very important and for 51.18% it is very important. In contrast, energy savings are of little or no importance for 13%. In fourth place was the factor of profit maximization through demand-oriented feed-in. According to the survey participants, the importance of self-sufficient energy supply with the EMS is in the middle range (fifth place), followed by the aspect that the EMS represents a personal contribution to a more environmentally friendly energy supply. Other factors cited were preparation for the time after the EEG subsidy and, finally, the potential time savings offered by an automated energy management system.

The scientific data collection should then also be transferred into practice in order to serve as a basis for a future marketing and sales concept. The survey therefore deals with the type and frequency of use of information channels on technical innovations in the energy sector. For this purpose, the response variants were assigned the number (4) for frequently, (3) for sometimes, (2) for rarely and the number (1) for not at all. The average weighting of the respective information channel was then calculated (analogous to Table 2) and presented in the corresponding order (Table 3).

The ranking shown in Table 3 shows that the Internet is the most frequently used information channel for technical innovations in the energy sector, with just under half of the respondents (49.86%) using this medium frequently and a further 38.60% using it at least sometimes to obtain information. 9.27% rarely use this information channel and 2.27% never use it. The second most important source of information is specialist journals, which are used frequently or at least sometimes (42.76%) by around a third of participants (33.96%). Rarely, 17.31% or 5.96% do not use this source of information at all. In third place are friends and acquaintances as a source of information: 16.18% use them frequently, over half (52.89%)

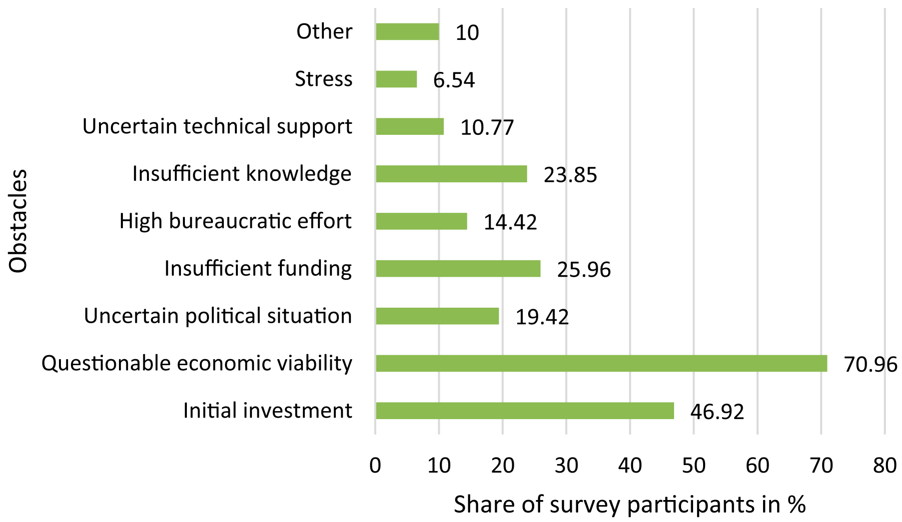

FIGURE 8
Reasons for barriers to buying a stationary battery (n = 520).

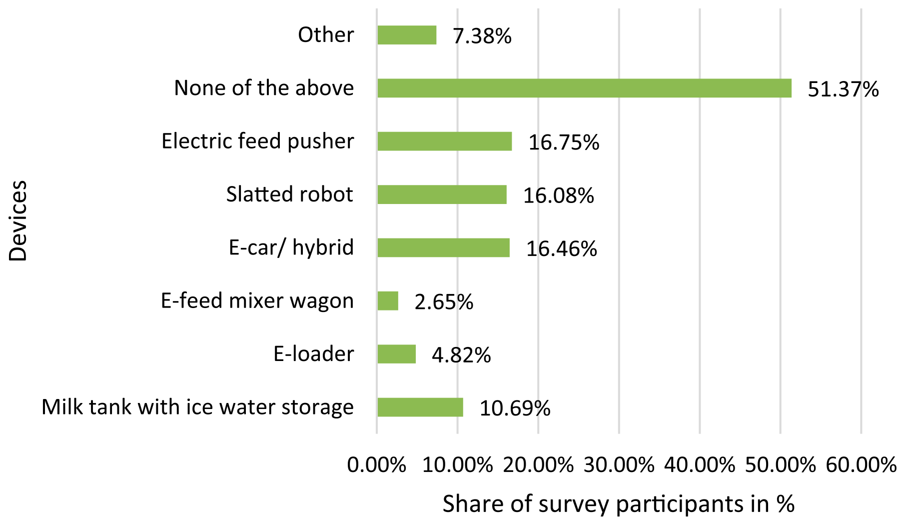

FIGURE 9
Electrical appliances already present on the farm (n = 1.057).

sometimes, a quarter (25.17%) rarely and 5.77% not at all. The use of information from electricians and agricultural fairs is even lower. Information from social media such as Instagram or Facebook is used least frequently.

After the presentation of the possibilities of energy management systems and their advantages, the focus was on the fundamental interest in an energy management system. Figure 10 clearly shows that of the 1.057 usable participant responses, 80.61% showed a fundamental interest in an energy management system, while a further 5.49% were still unsure. Only 13.91% were not interested in using an EMS in their company.

The next step was to determine the willingness to pay of the interested parties surveyed or the participants who were not averse but still uncertain, whereby the amortization period (Figure 11), the maximum amount of the initial investment (Figure 12) and the maximum costs of a service contract (Figure 13) were of interest.

19.10% of respondents did not answer this question (Figure 11). Most survey participants prefer an amortization period of five (22.17%) or 10 years (24.70%). A period of less than 5 years was stated by a total of 8.02%, while a further 19.10% would like the EMS to have a payback period of six to 9 years for their business. A total of 6.92% of survey participants expects more than 10 years. The average return on investment was 6.28 years. In addition to the payback period, participants were asked what maximum initial investment they could imagine within the next 5 years. The respondents were able to choose between various specified initial investment amounts. The results are summarized in Figure 12.

TABLE 2 Importance of selected factors in the use of an energy management system (n = 1.057).

Ranking	Factors	Weighting
1	Economic efficiency	3.51
2	Better utilization of the electricity produced on the farm, control of energy flows	3.24
3	Energy saving	3.21
4	Profit maximization through demand-based feed-in	3.12
5	Self-sufficient energy supply	2.91
6	Personal contribution to a more environmentally friendly energy supply	2.82
7	Improving the image of agriculture	2.64
8	Preparing for the time after the EEG subsidy	2.57
9	Time savings thanks to an automated energy management system	2.49

TABLE 3 Importance of selected information channels about technical innovations in the energy sector (n = 1.057).

Ranking	Information channel	Weighting
1	Internet	3.36
2	Trade journals	3.05
3	Friends/acquaintances	2.79
4	Electrician	2.62
5	Agricultural fairs	2.53
6	Agricultural advice centers	2.18
7	Energy advice centers	1.87
8	Instagram	1.38
9	Facebook	1.37
10	LinkedIn	1.12

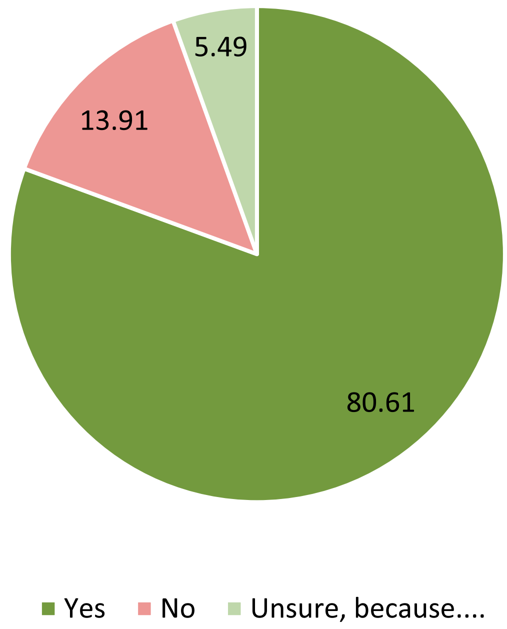

FIGURE 10
Question about basic interest in an energy management system (n = 1.057) in %.

Most survey participants (26.26%) would be prepared to make an initial investment of between 10.000€ - 24.999€. The second most common range was 25.000€ - 100.000€, cited by 21.54% of respondents; a further 19.23% would pay 5.000€ - 9.999€. The willingness to spend over 100.000€ on an energy management system was declared by 10.99% of the group of people mentioned. 6.92% of survey participants did not provide any information.

In addition to the possible initial investment, the survey participants were also asked about their willingness to pay monthly or annual contributions for a service con-tract as part of an energy management system. A service contract is understood here as a support and maintenance contract. The service contract also includes the use of the platform provided (Figure 13).

Of the 910 survey participants who answered this question, a range of 40€ - 69€ per year was most frequently stated. A further 14.51% would be prepared to spend 30 € - 69 € per month (i.e. 360€ - 828€ per year) on a corresponding service contract; 14.07% would only spend 10€ –39 € per year or 5€ - 29€ per month (60€ - 348€ per year). No information was provided by 18.02%.

5 Discussion

This study provides comprehensive approaches for analyzing the market potential of an energy management system for the German agricultural sector. For a future marketing concept, however, it

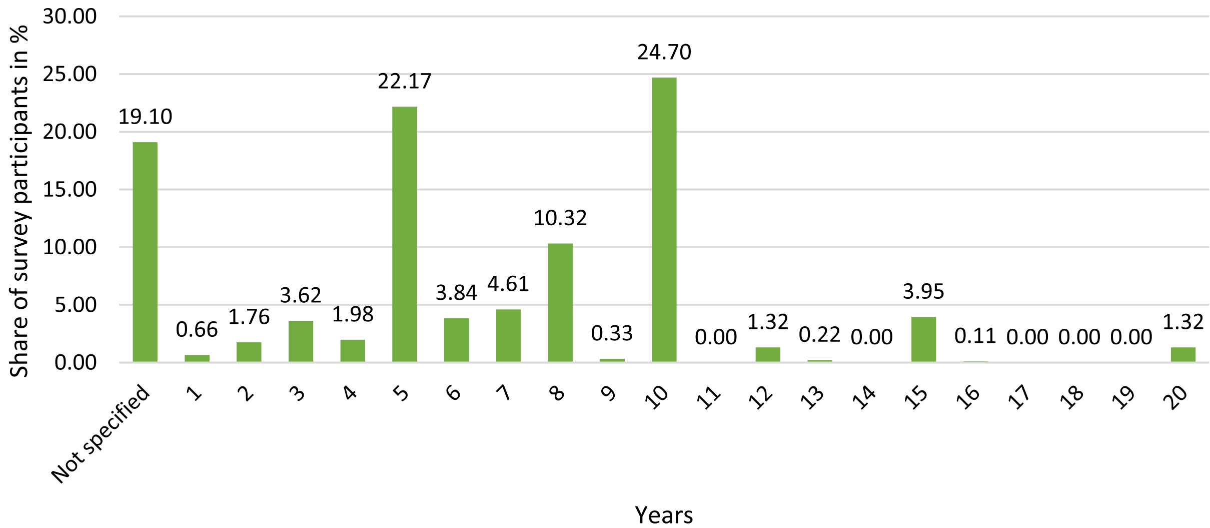

FIGURE 11
Potential target amortization period in years (n = 911).

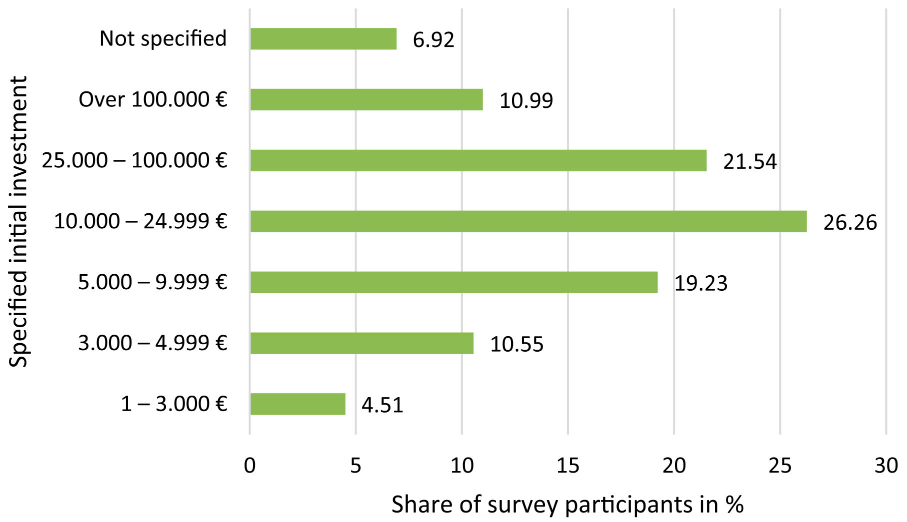

FIGURE 12
Willingness to pay for an initial investment (n = 910) in %.

is necessary to consider the corresponding results of the online survey in detail and in relation to the factors analyzed, as a one-dimensional evaluation of the areas presented (potential users, farm structures and the energy management system) does not lead to enough and/or sufficiently robust findings. As agricultural operations differ significantly from one another in terms of their production processes, management, region, electricity production, storage and equipment, the results must be assessed in the three categories presented and then across the board.

5.1 Discussion on the topic of potential user groups

The individual partial results initially show a high market potential for the EMS presented, which proves the fundamental interest of over 80% of the potential user group in such a system. It is important to note here that 75% of those surveyed see themselves in the role of operations manager. This group also represents the potential decision-makers who determine whether such investments

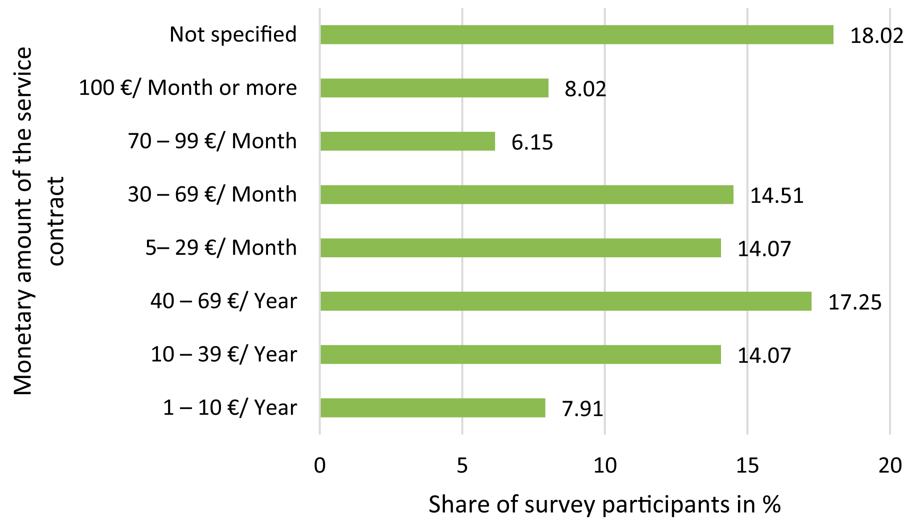

FIGURE 13
Willingness to pay for a service contract (n = 910).

will be made on the farm in the future. Furthermore, the age structure of the participants is evenly distributed from the age of 18 to the statutory retirement age of 65. This means that the available data is reliable regardless of the age of the farm managers, as the topic of energy management systems is not a new trend that is currently occurring within the younger, middle or older generation, but is being addressed equally across all age groups. However, the situation is different regarding the location of the companies. As both the current test company and the research initiators are in Bavaria, almost 40% of the survey participants come from this federal state, followed by Baden-Württemberg (9.18%) and North Rhine-Westphalia (7%). The participation rate outside Germany is also interesting at 13.43%. This shows that the industry is currently also very concerned with this topic outside Germany. The distribution of companies is therefore also strongly related to the type of company and production process, which in turn suggests that certain individual results of the survey should also be considered in combination at the end.

5.2 Discussion on the topic of operating structures

The dominant production methods among the farmers surveyed were dairy cattle (59.51%) and beef fattening/rearing (38.22%). The greatest positive response from this cluster was therefore to be expected, as the pilot farm works in the same production process and the scientific implementation of the EMS is most advanced in this area. In addition, the target group of dairy farmers was the first to be dated in the future marketing concept. However, as the EMS will now be implemented on a further ten test farms with different types of operation, further marketing strategies and promotional activities can soon be based on an even broader experience base in animal husbandry. It is to be expected that the times of use of devices, the resulting electricity demand and corresponding energy flows within different production processes vary greatly compared to the current test farm with dairy cattle farming. Therefore, the implementation of further test farms should generate more data on the required functionality and equipment of the EMS to prove a practical functionality within the entire agricultural sector. Furthermore, the survey provides an additional insight into the entire external economy, as around 80% of the responses indicated arable farming as a (further) common focus. It remains to be scientifically determined which synergy effects result from this across farms. A further aspect must be mentioned, because for the meaningful use of an EMS, in addition to the corresponding electricity production, there must also be enough internal electricity consumers or electricity storage on the farm. Otherwise, further investments will have to be made in advance, which could lead to a loss of willingness to innovate for some of the companies. According to the study, almost 80% of the target group already have a PV system on their premises. However, it remains questionable that around 50% do not yet have a mobile storage system (in the form of an e-charger, e-feed mixer wagon, etc.) and only just under 15% already have a stationary storage system, which is due to the prevailing skepticism regarding the purchase of a stationary battery storage system. This critical assessment is underpinned by the fact that over 70% of respondents put the question of cost-effectiveness first and the importance of the initial investment (46.92%) second. On the other hand, this can also be a signal for the use of an intelligent EMS, because only then can such storage concepts be operated economically on an individual basis. After all, around 15% of those surveyed have already decided to purchase an electricity storage system and a further 43.88% are still undecided about purchasing one. From this, it can be concluded that as soon as the question of economic efficiency continues to develop in a positive direction, there will also be the potential to invest in a storage medium and a corresponding EMS.

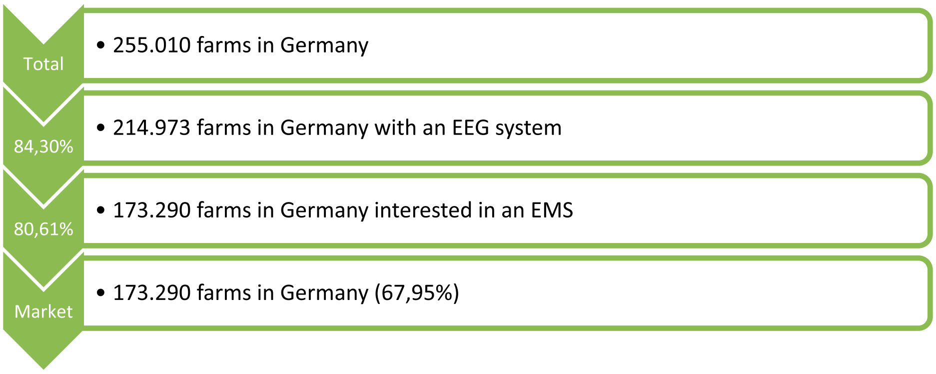

FIGURE 14
Estimation of the target market based on information from this project study.

5.3 Discussion on the topic of energy management systems

The positive assessment of the benefits of an EMS can be classified as very positive overall, with over 80% expressing interest, which can be attributed to the expected synergy effects and the increased additional benefits. Increased profitability, better utilization of the electricity produced on the farm and profit maximization through intelligent electricity purchase and sale were cited by the respondents as the most important reasons for investment. However, the actual benefits and the expected profit must be substantiated in the upcoming project phase by the planned installations in ten further test farms with correspondingly different conditions and conditions of use. The question of the media and information sources to be used is another key component for future product positioning among farmers. According to the available data, the Internet is the most frequently used medium, so that a corresponding (re)orientation of the marketing strategy must also take place here. The willingness of 45.49% to make an initial investment for an energy management system of between 5.000€ and 25.000€ (a further 21.54% even up to 100.000€) suggests positive impetus for the introduction, as does the willingness to pay for the necessary service and support contracts in maintenance. An expected amortization period of up to 10 years is also a realistic assessment of the respondents. In conclusion, it can be stated that the expectations of an EMS that can also be used on a broad scale in agricultural businesses can be classified as high.

5.4 Discussion of the overall survey

The implementation of an energy management system within the agricultural industry involves a comprehensive influence on existing structures and processes of the agricultural business. The survey made it clear that the installation of an EMS can lead to a considerable optimization of individual as well as overarching production processes and that this can be of benefit to the farm. The farmer has already recognized the possibility of leveraging previously unused synergy effects if the necessary foundations for the desired mode of operation of an EMS are in place or at least initially available. Making this potential usable for the agricultural sector in all its diversity requires reliable economic data from a wide variety of farm types, locations and production methods to be able to place a versatile product in practice. The results show both the soft and hard market factors and serve as a basis for the creation of a practice-oriented, science-based sales and marketing concept. Basically, the present study can be assessed as very comprehensive, positive and insightful, to serve as a basis for location- and company-specific market development.

According to the Federal Statistical Office, the Federal Republic of Germany has a total of 255.010 farms in 2023 (Statistisches Bundesamt DESTATIS, 2024) (Figure 14). Based on the restrictions and assumptions presented, it can therefore be deduced that the Federal Republic of Germany has a possible target market of 173.290 farms (or a market potential of 67.95%). The restriction of energy storage through mobile or stationary storage systems has not (yet) been considered.

6 Conclusion

The Weihenstephan-Triesdorf University of Applied Sciences, together with the Technical University of Munich and three project partners, is researching the development of an on-farm energy management system for combined milk and energy production on farms (Stumpenhausen and Bernhardt, 2022; Stumpenhausen and Bernhardt, 2016). The market launch of this technology is to be started as soon as possible. It is important to have knowledge of the target market of the innovation to ensure a successful market entry (Möhrle and Specht, 2018; Wübbenhorst, 2018). The primary aim of this work is to assess the starting points for the market potential and segmentation of energy management systems in agriculture. This assessment is an important part of the market analysis and describes a maximum possible sales volume with optimal market development (Wübbenhorst, 2018). In addition to the theoretical principles for determining market potential, key factors from the

"Stable 4.0" research initiative and the energy management system developed as part of the "CowEnergy" and "CowEnergySystem" collaborative research projects are also described.

Building on the findings of the research initiative launched in 2010, which has since developed its product to market maturity, this concept of an online survey within the industry was developed. Four research questions were answered. Firstly, the survey aimed to determine the level of awareness of the innovation and identify ways in which this can be increased. Secondly, the most important factors for the acquisition of an EMS were researched. In addition, the aim is to find out how great the interest in such an EMS is and how the group of interested parties can be characterized. The survey was answered in full by a total of 1.057 people. It was found that 53.83% of those surveyed had already heard of energy management systems in agriculture and that the Internet, trade journals and contact with friends and acquaintances were used to find out about technical innovations in the field of energy. Particularly important factors for the purchase of an EMS are economic efficiency, better use of the electricity produced on the farm or the control of energy flows and possible energy savings. Interest was expressed by 80.61% of respondents. A total of 314 people specifically requested further detailed information because of the survey. The survey results were used to quantify the basics for various target markets and their market potential. In addition to in-house electricity consumption by corresponding operational electricity consumers (milking plant, refrigeration, electric vehicles, etc.), electricity generation directly on site and the associated electricity storage are essential components for the commissioning of an energy management system. For this reason, farms that currently operate an EEG plant (plant that produces electricity from renewable energies such as solar, biomass, wind or water) are a target market (Federal Network Agency, 2023). The project study revealed that of the 1.057 successful respondents, only 15.70% do not have adequate equipment for generating energy on their farm.

In conclusion, it can be said that an update of economic data through the modeling of further test farms is of considerable advantage to refute the obstacles in questions of profitability for other types of farms beyond dairy farming and to confirm the already existing broad acceptance with corresponding results from practice. Both for agriculture and for decentralized energy production in rural areas, a more efficient use of resources across farms can bring benefits for society to achieve the desired reduction in fossil fuels. Furthermore, by establishing an intelligent communication structure between the EMS and the regional grid operators, a system can be created not only within the farm, but also outside it, which helps to better coordinate the varying energy demand and supply in the electricity grid (Forschungsstelle für Energiewirtschaft e. V., Consentec GmbH, 2024). However, the current market situation is very volatile, and a wide variety of factors are increasingly influencing price trends, sales markets and ultimately the economic situation of farms (Bundesministerium für Ernährung und Landwirtschaft, 2024). The German agricultural industry is characterized by its region-specific and diverse forms of farming and income generation within the sector (Weber et al., 2024). Accordingly, an intelligent energy management system must be just as versatile and practicable to achieve economic, ecological and social improvements.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

CB: Conceptualization, Investigation, Visualization, Writing – original draft, Writing – review and editing. EG: Conceptualization, Writing – review and editing. JS: Conceptualization, Funding acquisition, Project administration, Supervision, Writing – review and editing. CS: Data curation, Formal Analysis, Methodology, Validation, Writing – review and editing. HB: Conceptualization, Funding acquisition, Project administration, Supervision, Writing – review and editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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