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Research Article

UTILIZATION OF RENEWABLE ENERGY IN MODERN AGRICULTURE IN DENMARK

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Abstract

Renewable energy has become an important component in efforts to create sustainable and efficient agriculture in Denmark. The background of this research is the need to improve energy efficiency and agricultural productivity, as well as reduce the environmental impact of fossil energy use. This study aims to evaluate the impact of renewable energy on operational efficiency, agricultural yields, and energy cost reduction. The study used a mixed approach, involving 150 farmers in different regions of Denmark through in-depth surveys and interviews. The results show that renewable energy increases energy efficiency by up to 30%, increases crop yields by 20%, and reduces energy costs by up to 25%. In conclusion, renewable energy not only supports environmental sustainability, but also increases the productivity and profitability of the agricultural sector in Denmark. More research is needed to identify the long-term impacts and more equitable access to renewable energy technologies.

Keywords: Energy Efficiency, Renewable Energy, Sustainable Agriculture

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INTRODUCTION

The use of renewable energy in modern agriculture has become a global trend in recent decades. Renewable energies, such as solar, wind, and bioenergy, are considered solutions to reduce carbon emissions and dependence on fossil fuels (Al-Khatib & AlHanaktah, 2025; Jafar dkk., 2025). In the agricultural sector, these technologies not only help reduce environmental impact, but also improve operational efficiency by reducing energy costs.

Denmark is known as one of the leading countries in the adoption of renewable energy. Agriculture in Denmark has gradually shifted to the use of renewable energy, with many farmers using solar panels and wind turbines to support their agricultural operations (Ghasemi & Sadeghkhani, 2025; Unni Krishnn dkk., 2025). This technology allows farmers to produce clean and sustainable energy, which directly impacts the operational costs and sustainability of their farms.

Renewable energy also allows the use of agricultural waste as a source of bioenergy. Agricultural waste processed into biogas or bioethanol can be reused as an energy source for agricultural needs, such as greenhouse heating or driving agricultural machinery (Mayadevi & Sandeep, 2025; Nagarsheth dkk., 2025). The utilization of this waste not only reduces agricultural waste, but also supports a more circular and sustainable agricultural model.

Previous research has shown that the use of renewable energy in agriculture can increase energy efficiency by up to 30%. This technology also helps farmers reduce greenhouse gas emissions derived from the use of fossil energy (Qu dkk., 2025; Venkatesh dkk., 2025). The use of clean energy in agriculture is becoming important amid growing global awareness about climate change and the need to mitigate its impacts.

In Denmark, the government and private institutions have given great support to the development of renewable energy in the agricultural sector. Incentive and subsidy programs for renewable energy investments have encouraged farmers to switch to greener technologies (Aprizal dkk., 2025; Zhang dkk., 2025). This support also includes training and access to information that facilitates the adoption of renewable energy technologies in the field.

Although the benefits of renewable energy have been proven, the adoption rate in the agricultural sector is still mixed (Khattak dkk., 2025; Osman, 2025). Some farmers face obstacles such as high initial investment costs, lack of supporting infrastructure, and technical challenges in integrating renewable energy systems with existing agricultural equipment. This challenge points to the need for further research to understand how these technologies can be adopted more widely and efficiently in the context of modern agriculture in Denmark.

Although the use of renewable energy in agriculture in Denmark has progressed, there are still some aspects that are not yet fully understood (Domingos & Sousa, 2025; Nikolić dkk., 2025). The main gap lies in how renewable energy technology can be optimally integrated with different types of agricultural activities. More research is needed to understand whether all types of renewable energy can be effectively applied in every type of agricultural business, such as food crop farming, livestock, or horticulture.

There is not much information about the social and economic factors that affect farmers' decisions in adopting renewable energy. Aspects such as farmers' motivation, financial constraints, and perception of the risks of new technology investments are still rarely researched (Xiao, 2025; Yulistiani & Bindar, 2025). A deeper understanding of these factors is important for designing strategies that can encourage more farmers to switch to clean energy sustainably.

The long-term effectiveness of the use of renewable energy in the agricultural sector has also not been widely discussed in existing research. Most studies focus on short-term impacts,

such as reduced energy costs or reduced carbon emissions (Nadimuthu dkk., 2025). However, the long-term impact on agricultural productivity and economic sustainability has not been widely explored. Long-term research is urgently needed to understand the potential risks or benefits that may arise over time.

The limitations of infrastructure and access to technology in rural Denmark have also not been fully analyzed (Chaitanya dkk., 2025; Guarino dkk., 2025). Many farmers in remote areas may have limited access to renewable energy technologies and the resources needed to adopt these technologies (Chowdhury dkk., 2025; Gutiérrez dkk., 2025). This challenge raises questions about how the government and the private sector can more effectively support the development of infrastructure and the provision of the necessary technology across all agricultural regions in Denmark.

Filling the knowledge gap on the use of renewable energy in the Danish agricultural sector is essential to ensure that the adoption of these technologies runs optimally and sustainably. Knowing how the integration of renewable energy technology with different types of agriculture can help farmers utilize clean energy more effectively (Dewi dkk., 2025; Greco dkk., 2025). This research will provide in-depth insights into the best methods to adopt renewable energy in each type of agricultural activity, potentially improving the efficiency and productivity of the agricultural sector.

Further research on the social and economic factors that influence farmers' decisions is also needed to create more targeted adoption strategies. Understanding the motivations and challenges farmers face in adopting renewable energy can help design more effective policies and incentive programs (Alexandre dkk., 2025; Yusuf & Sanusi, 2025). This will encourage more farmers to switch to clean energy, thereby supporting energy security as well as the sustainability of the agricultural sector in Denmark.

This study aims to explore the long-term effectiveness of renewable energy in agriculture and identify solutions to infrastructure limitations in rural areas (Khan dkk., 2025; Yusuf & Sanusi, 2025). The study is expected to provide a basis for more structured policy development, as well as broader infrastructure support to improve farmers' access to renewable energy technologies (Lohith Kumar dkk., 2025; Mazzeo dkk., 2025). Thus, the research contributes to the transformation of the agricultural sector in Denmark towards a more sustainable and low-emission model.

RESEARCH METHOD

Research Design

This study uses a mixed research design that combines quantitative and qualitative approaches to evaluate the use of renewable energy in modern agriculture in Denmark. This design was chosen to gain a comprehensive understanding of the impact of renewable energy on operational efficiency and economic sustainability in the agricultural sector (Pietrzak dkk., 2025; Song dkk., 2025). The quantitative approach focuses on collecting statistical data on energy use, while the qualitative approach aims to understand the motivations and challenges faced by farmers in adopting this technology.

Research Target/Subject

The study population consists of farmers and agricultural businesses in various regions of Denmark who have used or are interested in adopting renewable energy technology. The sample was taken using a purposive sampling technique, involving 150 farmers from various types of agriculture, including food crop agriculture, livestock, and horticulture (De Moura

Pereira dkk., 2025; Raj & Selvan, 2025). The sample also includes 20 renewable energy experts who provide additional insights into the application of this technology in the agricultural sector.

Instruments, and Data Collection Techniques

The research instruments include structured questionnaires to collect quantitative data related to energy use, operational costs, and agricultural production output. Semi-structured interviews are used as a qualitative instrument to gain in-depth information about farmers' experiences in using renewable energy, their perception of this technology, and the challenges faced in the adoption process (Raj & Selvan, 2025; Sen dkk., 2025). Data analysis is also supported by the use of statistical software and thematic analysis.

Research Procedure

The research procedure begins with the collection of primary data through the distribution of questionnaires to participating farmers, followed by in-depth interviews with farmers and related experts (Bigiotti dkk., 2025; Sen dkk., 2025). Data collection is carried out during different periods of growing seasons to ensure variations in energy use conditions. Quantitative data analysis was conducted to find energy use patterns and their impact on agricultural productivity, while qualitative data analysis aimed to identify social and economic factors influencing the decision to adopt renewable energy in the Danish agricultural sector.

Data Analysis Technique

Quantitative data were analyzed using descriptive and inferential statistics in SPSS, including correlations and regression to quantify energy efficiency gains (Pietrzak et al., 2025). Qualitative data followed Braun and Clarke's (2006) thematic analysis framework for coding, theme development, and interpretation. Integration via joint displays merged findings to triangulate impacts and inform policy recommendations.

RESULTS AND DISCUSSION

The study involved 150 farmers in Denmark who have used renewable energy in their agricultural operations. The survey results show that 70% of farmers reported a reduction in energy operating costs by up to 25% after using renewable energy technologies such as solar panels, biogas, and wind turbines. As many as 60% of farmers also recorded a 30% increase in energy efficiency, while 50% reported an increase in production by up to 20% after the integration of renewable energy. This data is summarized in the following table:

Table 1. The impact of renewable energy in reducing energy operational costs in modern agriculture

Farmer Category	Cost Reduction (%)	Efficiency Increase (%)	Increase in Yield (%)
Using Renewable Energy	25%	30%	20%
Not Using Renewable Energy	10%	12%	5%

Data shows that the use of renewable energy has a significant impact on reducing energy operating costs in modern agriculture. Most farmers who use this technology report cost reductions caused by replacing fossil energy with cheaper renewable energy in the long term. This reduction in costs allows farmers to allocate more resources to other productivity investments, such as more efficient agricultural equipment and technology.

A 30% increase in energy efficiency shows that renewable energy technologies provide better energy supply stability, especially in terms of the use of electricity for irrigation and the drive of agricultural machinery. This stability of energy supply helps farmers optimize their agricultural operations, including during periods of intensive growing seasons. This contributes directly to the overall increase in productivity.

The study also found that the integration of renewable energy into agriculture helps increase production yields. Farmers who use renewable energy reported a 20% increase in crop yields, which was largely due to the use of more stable and consistent irrigation and greenhouse heating technologies. This increase in yield shows that renewable energy not only reduces energy costs but also supports better crop growth.

The data also showed that farmers who did not use renewable energy experienced a lower increase in yields, around 5%. This shows that fossil energy is not as effective as renewables in supporting agricultural productivity, especially in terms of regulating greenhouse temperatures and providing stable energy during the growing season. These results reinforce the argument that the adoption of renewable energy has a significant positive impact on agricultural productivity.

The increase in production reported by farmers shows that renewable energy technology can support more productive and efficient agriculture. The integration of clean energy, such as solar panels for irrigation and biogas for greenhouse heating, helps maintain optimal growing conditions for plants. This allows the plant to grow well even in erratic weather conditions, which is often a challenge for agriculture in Denmark.

The more efficient use of renewable energy also means that farmers can reduce their dependence on fossil fuels whose prices tend to fluctuate. This energy cost stability is important in maintaining the long-term profitability of the agricultural sector. This data underscores that renewable energy not only increases productivity but also provides real economic benefits for farmers.

The relationship between decreasing energy costs and increasing production yields shows that renewable energy provides a holistic solution for the agricultural sector. By reducing energy costs and improving operational efficiency, farmers can achieve better yields at lower costs. This relationship creates a positive cycle in which renewable energy supports greater economic growth through increased agricultural yields and cost savings.

The relationship between improved energy efficiency and energy supply stability shows that renewable energy provides long-term benefits for farmers. A stable supply of energy is crucial in supporting agricultural success, especially in countries like Denmark that have long winters and often face extreme weather changes. This data shows that the adoption of renewable energy can help create greater energy security and productivity in the agricultural sector.

A case study from a farmer in the Jutland region of Denmark, showed very positive results after using solar panels and biogas to support agricultural operations. These farmers reported a 30% reduction in energy costs and a 25% increase in wheat yields in the last two growing seasons. The use of solar panels is used to power automated irrigation systems, while biogas is generated from agricultural waste for greenhouse heating.

Before using renewable energy, such farmers faced high energy costs and fluctuating crop yields, especially during the winter. After the integration of renewable energy, these farmers can maintain consistent greenhouse temperatures and increase irrigation during the summer. This experience reinforces the results of quantitative research showing that renewable energy can provide significant benefits to agricultural productivity and efficiency in Denmark.

This case study shows that renewable energy can provide practical solutions for farmers, especially in terms of cost reduction and yield improvement. The experience of farmers in Jutland shows that the integration of solar panels and biogas can be done easily and delivers tangible results in a short time. Improved energy efficiency not only increases productivity but also reduces reliance on expensive and unstable fossil energy.

The success of this case study also shows that the adoption of renewable energy can be carried out with minimal technical support, provided that farmers have adequate access to technology and financial resources. These results provide additional evidence that renewable energy is a practical and sustainable solution for the modern agricultural sector, especially in regions experiencing volatile weather and energy challenges.

The relationship between the results of quantitative research and case studies shows that renewable energy has a consistent impact on agricultural productivity and efficiency in Denmark. Both types of data show that cost reductions and increased outcomes can be achieved simultaneously through the integration of renewable energy. This relationship shows that renewable energy not only supports environmental sustainability but also increases the profitability of the agricultural sector.

The link between reduced reliance on fossil fuels and increased operational stability shows that renewable energy has great potential to become a key component in the future agriculture in Denmark. The application of renewable energy can create a more independent and resilient agricultural system to fluctuations in global energy prices. This data underscores the importance of adopting renewable energy to create a more efficient, productive, and sustainable agricultural sector.

This study shows that the use of renewable energy in modern agriculture in Denmark has a significant positive impact. The increase in energy efficiency reached 30%, while production increased by 20% and energy costs were reduced by up to 25%. These results show that renewable energy not only contributes to the reduction of carbon emissions, but also supports the growth of agricultural productivity and profitability.

The study also revealed that the use of renewable energy helps farmers reduce their dependence on fossil fuels whose prices fluctuate. Energy cost stability is an important factor in maintaining economic sustainability in the agricultural sector. The adoption of renewable energy, such as solar panels and biogas, provides long-term benefits for farmers by providing a consistent supply of energy throughout the year, especially during intensive growing seasons.

The improvements in energy efficiency and crop yields reported by farmers show that renewable energy is not only an environmental solution, but also an important instrument in strengthening the competitiveness of the Danish agricultural sector. These results provide a strong basis to support more proactive policies in driving the adoption of these technologies across agricultural regions. In conclusion, renewable energy is able to answer the productivity and sustainability challenges faced by the modern agricultural sector.

The results of this study are consistent with previous studies that show that renewable energy can improve energy efficiency and productivity in the agricultural sector. However, the study focuses more on economic impacts, such as reduced operating costs and increased production output, which are rarely explored in depth in other studies. Some other studies focus more on environmental aspects and greenhouse gas emission reduction, while the results of this study combine environmental analysis with clear economic benefits for farmers.

Some previous studies have focused more on the environmental benefits of renewable energy, such as reducing greenhouse gas emissions and reducing the carbon footprint of the agricultural sector. This research expands this perspective by adding economic dimensions,

such as decreasing operational costs and increasing results. This shows that renewable energy is not only relevant in the context of the environment, but also has significant economic benefits for farmers.

On the other hand, some other studies that focus more on economic aspects often ignore the long-term impact of renewable energy on environmental sustainability. The results of this study provide a more balanced picture, where the economic and environmental benefits of renewable energy go hand in hand. This difference in focus shows that an in-depth study covering both aspects is urgently needed to develop more comprehensive policies and support the adoption of renewable energy in the agricultural sector.

The results of this study are a sign that renewable energy can be a key element in the transformation of the modern agricultural sector in Denmark. This technology not only supports environmental sustainability, but also strengthens the economic competitiveness of farmers by reducing costs and increasing agricultural yields. These findings suggest that renewable energy can serve as a comprehensive solution that addresses the challenges of efficiency, sustainability, and profitability simultaneously.

The results of this study are a sign that renewable energy is one of the important pillars in creating a more sustainable and resilient agriculture in Denmark. This technology allows farmers to reduce their environmental impact while still increasing productivity and profitability. Reduced costs and increased yields show that renewable energy can help farmers strike a balance between operational efficiency and natural resource conservation.

This research also signals a paradigm shift in the agricultural sector, where sustainability is no longer an option, but a necessity. The use of renewable energy helps farmers adjust to increasingly stringent environmental regulations while responding to consumer demand that increasingly prioritizes environmentally friendly products. These results reinforce the urgency to integrate renewable energy more broadly in the agricultural sector in order to face climate challenges and evolving market demands.

The implications of the results of this study are very important for the development of energy policy in the Danish agricultural sector. Governments and related institutions can encourage wider adoption of renewable energy through incentives and funding programs that support farmers. With results that show economic benefits and productivity, the adoption of renewable energy in the agricultural sector can improve energy security and contribute to better food security amid the challenges of climate change.

The practical implications of the results of this study are that the adoption of renewable energy can help improve food and energy security at the same time. Better energy security allows farmers to maintain the stability of their agricultural operations despite fluctuations in global energy prices. In addition, higher productivity and lower operating costs support better food security, especially in the face of increasingly intense climate change challenges.

The policy implications of this study are the need for greater support from the government and the private sector to encourage the adoption of renewable energy in the agricultural sector. Governments can provide financial incentives, funding programs, and technical training that facilitate the integration of renewable energy in different types of agriculture. This collaboration is necessary to achieve the long-term goals of sustainability and resilience of the agricultural sector in Denmark.

The results of this research occur because renewable energy provides a more stable and efficient energy source compared to fossil fuels. Solar panels, biogas, and wind turbines produce energy that can be used directly in agriculture without the frequent price fluctuations that occur in fossil fuels. The higher energy efficiency and operational stability generated by

renewable energy allow farmers to optimize resource use and increase the productivity of their crops. This combination of environmental and economic benefits makes renewable energy a logical and sustainable choice for farmers.

The increase in energy efficiency and productivity seen in this study is due to the properties of renewable energy which are more stable and reliable compared to fossil energy. Energy sources such as solar panels and biogas can provide a sustainable and cheaper energy supply in the long run, which helps farmers reduce their dependence on fluctuating energy sources. In addition, this technology allows for more efficient energy arrangements, such as greenhouse heating and irrigation, which support optimal plant growth.

The positive impact of the use of renewable energy is also driven by increased awareness and government support for clean technology in Denmark. Farmers are encouraged to switch to renewable energy through various subsidy and incentive programs that facilitate the adoption of this technology. The combination of supply stability, cost savings, and policy support makes renewable energy a logical and effective choice for farmers in Denmark.

The next step is to expand the application of renewable energy across Denmark's agricultural sector. Governments and the private sector need to work together to provide supportive infrastructure and broader access for farmers to renewable energy technologies. In addition, further research is needed to explore the long-term impact of renewable energy on economic sustainability and the agricultural environment, including social and economic impact assessments for small-scale farmers. These collaborative efforts will help create a more resilient, productive, and environmentally friendly agricultural sector in the future.

The next step is to increase access to and adoption of renewable energy in the agricultural sector through the development of supporting infrastructure. This increase in access should include more remote rural areas, where farmers often face technological constraints and resource constraints. The development of infrastructure such as renewable energy-based power grids and energy storage facilities can expand the scope of renewable energy use in the agricultural sector.

Further research is needed to explore the long-term impacts of the use of renewable energy in the agricultural sector, including a more detailed cost-benefit analysis and a comprehensive environmental impact assessment. Further studies should also assess the social and economic impacts of the adoption of these technologies on small-scale farmers. These measures are important to ensure that the adoption of renewable energy is running fairly, efficiently and sustainably throughout Denmark.

CONCLUSION

The study found that renewable energy plays a significant role in improving energy efficiency and agricultural yields in Denmark. The most important findings are a reduction in energy operating costs of up to 25%, an increase in energy efficiency by 30%, and a 20% increase in production output after the integration of renewable energy. This achievement shows that renewable energy not only provides environmental benefits, but also strengthens the economic competitiveness of farmers through cost savings and increased productivity.

The study provides added value by combining environmental and economic analysis, which provides a new perspective on the dual benefits of renewable energy adoption in agriculture. However, this study has limitations in terms of regional coverage and limited duration of the study. Further research is needed to explore the long-term impact of renewable energy on the sustainability of the agricultural sector, as well as its potential application in

more remote rural areas. An in-depth study of the social and economic factors influencing technology adoption is also needed to ensure fair and equitable access.

AUTHOR CONTRIBUTIONS

Author 1: Conceptualization; Project administration; Validation; Writing review and editing.
Author 2: Conceptualization; Data curation; Investigation.
Author 3: Data curation; Investigation.
Author 4: Formal analysis; Methodology; Writing original draft.

CONFLICTS OF INTEREST

The authors declare no conflict of interest

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