



Watt's the Cost? Relationship between expenditure of Renewable Energy and Farm Productivity in Sweden

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Vad kostar det? Samband mellan utgifter för förnybar energi och jordbruksproduktivitet i Sverige

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Abstract

The effect of renewable energy expenditure on farm productivity in Sweden was investigated by estimating its association with output-input efficiency at the farm level. An unbalanced panel of microdata from the Swedish Farm Accountancy Data Network (FADN), comprising 6.730 observations from 2008-2023, was used in a log-log Ordinary Least Squares (OLS) regression framework. The relationship was analysed across farm types and size quartiles to account for structural differences. The result showed no statistically significant association between renewable energy expenditure and productivity in the overall sample. However, higher renewable energy costs were significantly negatively associated with productivity among the largest field crop and grazing livestock farms, as well as among the smallest dairy farms. In contrast, smaller field crop and grazing livestock farms exhibited positive but statistically insignificant relationships. No significant association was found for large dairy farms. These findings suggest that both production type and farm size play a crucial role in determining the economic viability of renewable energy investments. The results can inform policy efforts aimed at supporting a fair and efficient transition to clean energy in agriculture.

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Abbreviations

Abbreviation	Description
FAO	Food and Agriculture Organization of the United Nations
OECD	Organisation for Economic Co-operation and Development

1. Introduction

Modern agriculture has evolved through the adoption of energy-intensive technologies such as mechanized equipment and synthetic inputs, much of which depend on fossil fuels FAO (2021). While these advancements have substantially improved agricultural productivity, they have also entrenched the sector's reliance on non-renewable energy sources; As the global energy system transitions in response to climate change and resource limitations, the environmental costs of fossil fuel-based agriculture ranging from greenhouse gas emissions to land degradation and biodiversity loss are increasingly scrutinized OECD (2022).

The energy sector remains the primary contributor to carbon dioxide emissions globally, reinforcing the urgency of a transition to more sustainable energy systems IEA (2023). Sweden has committed to achieving carbon neutrality by 2045, emphasizing renewable energy expansion across all sectors, including agriculture (Swedish Government, 2022). Although Sweden's electricity grid is predominantly renewable, high energy taxes and input costs continue to shape the operational strategies of farms. Energy has thus evolved from being a background input to a strategic determinant of cost structures, competitiveness and long-term viability.

Agriculture's growing dependence on energy makes understanding the economic implications of the renewable energy transition critical. For farms, energy costs can influence decisions about investment production, strategies, and technology adoption. Affordable energy is crucial for operating machinery, processing agricultural products, and maintaining storage systems. This is especially important in high-cost environments like Sweden where the operating margin can be narrow and input costs high.

This thesis addresses the central research question: *How does the expenditure of renewable energy affect the productivity of agricultural firms in Sweden?* To answer this, the study pursues three main objectives: (1) to quantify the relationship between renewable energy expenditure and farm productivity; (2) to examine how this relationship differs across farm types, and (3) to explore whether small and large farms experience different effects. To achieve these aims, the thesis offers empirical insights that can guide more equitable and effective policy frameworks to support energy transitions in the agricultural sector.

While the relationship between energy and agriculture has long been studied, most existing research has concentrated on the environmental benefits of renewables or the motivations for adoption. Ball et al. (2015) examine how energy prices affect productivity in U.S. agriculture, finding that rising energy costs are

associated with lower farm efficiency. Other studies focus on the economic incentives that influence farmers' decisions to adopt renewable energy, often emphasizing the role of subsidies, infrastructure, and policy support Al-Dalaeen (2023). Few studies have quantitatively assessed how the financial cost of renewable energy adoption impacts overall farm productivity, particularly in high-cost economies like Sweden.

Research in the Swedish context is limited. While some studies address energy usage or technical efficiency on Swedish farms, they rarely incorporate the financial costs of renewable energy into productivity analyses. Instead they focus on land use, environmental indicators or adoption dynamics. This thesis seeks to fill that void by leveraging farm-level data to examine how renewable energy costs relate to productivity, disaggregated by both farm type and scale.

The remainder of this paper is structured as follows: Section 2 reviews previous literature. Section 3 describes the data and methodology. Section 4 presents the empirical results. Section 5 discusses the findings and their policy implications. Section 6 concludes the study.

2. Previous research

Recent technological advances in renewable energy have opened new avenues for integration within agriculture. According to a study published by Liu et al (2018) the application of technologies such as solar photovoltaics, wind turbines, and anaerobic digestion systems in farming operations can reduce energy dependence and contribute to long-term sustainability. The study emphasizes that while these technologies hold great promise their adoption is heavily influenced by supportive policy frameworks, infrastructure availability, and economic incentives. Majeed et al. (2023) highlight the benefits of renewable technologies that can reduce dependence on fossil fuels, cost savings, increase energy security, and improve environmental sustainability.

Cross-country studies consistently report links between energy use and agricultural performance. Suproń et al. (2024) use panel data and vector autoregression methods across EU countries to show that higher renewable energy consumption is positively associated with agricultural output, particularly in countries with sustainable farming systems. Countries reliant on non-renewable energy sources experience stagnation or decline in productivity. These findings imply that renewables can complement traditional inputs and enhance output.

At the micro level, Wang et al. (2023) show that by analyzing data from 801 Chinese farms, the adopters of renewable energy systems have approximately 10% higher technical efficiency than non-adopters. This effect appears to be causal and is attributed to reduced energy costs and greater production stability. Khan et al. (2024) examine solar irrigation in Pakistan crop farms and report a positive correlation between adoption and farm income.

While international studies offer strong evidence for productivity gains, research on Swedish farms has largely focused on adoption factors rather than outcomes. Hahn et al. (2025) conducted interviews with Swedish farmers and found that many are motivated by environmental responsibility and long-term savings, but face barriers such as low profitability, policy uncertainty, and high initial investment costs. Jonsson et al. (2011) also find that environmental concerns are important motivators, but traditional practices, uncertainty, and land use concerns limit the wider adoption of energy crops.

As the articles above Adam et al. (2025) present a scenario in which Swedish dairy farms achieve fossil-free operations through the adoption of biogas-based energy systems. Their analysis indicates that such investments can yield both economic and environmental benefits without requiring additional agricultural land

or direct financial compensation for farmers. The study also emphasizes several sources of uncertainty such as fluctuations in diesel prices, interest rates, and capital loss which could impact the overall profitability of biogas systems. For risk-averse farmers, the potential for negative returns may serve as a barrier to adoption.

2.1 Research gaps

While previous studies provide valuable insights into renewable energy adoption among Swedish farmers, several critical gaps remain. Most existing research focuses on qualitative assessments of motivations and barriers, without systematically examining the economic impact of renewable energy expenditures on farm productivity. International studies often show positive associations between renewables and efficiency, but few isolate the cost component or apply this analysis in high-cost contexts like Sweden.

This thesis addresses that gap by combining farm-level microdata with an econometric model that directly links renewable energy costs not just adoption status to productivity outcomes. By disaggregating the analysis across farm types and sizes, it also provides a more nuanced understanding of how structural characteristics shape the economic viability of clean energy agriculture.

3. Data and Method

This study used data from the Swedish Farm Accountancy Data Network (FADN) from 2008 to 2023. The FADN is a source that collects micro-economic data in the European Union. It is vital for assessing agricultural policies in the Common Agricultural Policy (CAP). The Swedish Board of Agriculture collects the FADN data in Sweden.

Table 1 Description of Variables in Performed Regression

Variable name	Description
Productivity (ln)	Total Output / Total Input, representing the costs associated with the agricultural activity of the holding.
Cost of Renewable Energy (ln)	Cost of electricity / Cost of energy representing the share of energy that are renewable
Total subsidies (ln)	Subsidies for current production-related operations (excluding investments).
Environmental Subsidies (ln)	Subsidies on Environment that are a share of total subsidies
LFA Subsidies (ln)	Subsidies for Less Favored Areas or areas facing natural or other specific constraints. that is a share of total subsidies
Decoupled Payments (ln)	Single Farm Payment and Single Area Payment Scheme. that is a share of total subsidies
Economic Size (ln)	The value of the farm's standard output, expressed in thousands of SEK
Rented UAA (ln)	Farmland (in hectares) rented by the holder under a tenancy agreement lasting at least one year that is a share of total agricultural area
Total Utilized Agricultural Area	Total farmland area including owned, rented, share-cropped land, temporarily out of production land and kitchen gardens.
Organic	Dummy = 1 if the farm is organic
Training	Dummy = 1 if the Agricultural training of the manager
Organization	Dummy = 1 if the farm is driven by other parts not family
TF8	Type of farming 1 = Field crops 5 = Dairy 6 = Other grazing livestock

3.1 Key variable definitions

Productivity is the central outcome variable in this thesis and is just as important as the cost of renewable energy. It reflects how efficiently farms convert their inputs such as land, labor, capital, and energy into output. Making it a direct measure of performance. In agricultural economics, productivity is not only a key indicator of individual farm success but also a broader measure of sectoral competitiveness and sustainability. High productivity means that resources are being used effectively which is particularly important in countries like Sweden where input costs including energy are high.

In the context of the energy transition, productivity takes on even greater importance. As farms face rising costs due to investments in renewable energy systems, their ability to maintain or increase output with the same or fewer inputs will determine whether these investments are economically viable. If clean energy adoption leads to higher operating costs without corresponding efficiency gains, it may reduce profitability and discourage future investments, especially among small or capital-constrained farms. If productivity can be maintained or improved while transitioning to renewables, it suggests that clean energy use is compatible with farm-level economic resilience.

Tracking how productivity has evolved over time and across different farm types helps us understand where the structural capacity to absorb energy-related costs lies. If productivity is stagnant or declining in certain sectors for example grazing livestock those farms may struggle more with the financial demands of renewable energy. If it is rising in others for example dairy it may reflect better integration of technology or policy support. In this way, productivity serves not just as an outcome in the statistical model, but as a signal of how prepared each segment of the sector is to meet Sweden's broader climate and energy goals.

3.2 Econometric model and method

This study employs a log-log Ordinary Least Square (OLS) regression to estimate the relationship between renewable energy costs and farm productivity. OLS was selected due to its interpretability, ease of implementation, and suitability for cross-sectional analysis where the primary objective is to estimate average effects across observations.

The log-log functional form allows coefficient estimates to be interpreted as elasticities, making it useful for assessing how proportional changes in energy costs relate to proportional changes in productivity.

While panel data techniques such as fixed effects or random effects models could control for unobserved heterogeneity over time, the available dataset (FADN) is not a balanced panel and contains many gaps across farm types. These limitations reduce the reliability of fixed effects estimates when within farm variation is limited. Moreover, the primary aim of this study is not to isolate time-invariant farm characteristics but to explore general patterns across farms of different sizes and types.

Instrumental variables (IV) were also considered. However, valid instruments for renewable energy costs that strongly correlated with the cost variable yet uncorrelated with the error term were not available in the dataset. In the absence of strong instruments, OLS provides a more transparent and stable estimation approach.

While acknowledging that OLS may be susceptible to omitted variable bias, this concern is mitigated by including a comprehensive set of control variables such as farm size, subsidies, and farm specialization.

$$\begin{aligned} \ln Y_i = & \beta_0 + \beta_1 \ln(\text{Expenditure of Renewable Energy})_i \\ & + \beta_2 \ln(\text{Economic size})_i + \beta_3 \ln(\text{Total Subsidies})_i \\ & + \beta_4 \ln(\text{Environmental Subsidies})_i + \beta_5 \ln(\text{LFA Subsidies})_i \\ & + \beta_6 \ln(\text{Decoupled Payments})_i + \beta_7 \ln(\text{Rented UAA})_i \\ & + \beta_8 (\text{Organic})_i + \beta_9 (\text{Organization})_i + \beta_{10} (\text{Training})_i + \varepsilon_i \end{aligned}$$

The econometric model is specified as a log-log OLS regression with the natural logarithm of productivity as the dependent variable. The main explanatory variable is the log of clean energy adoption and control variables include the log of farm size, various subsidy components, and additional farm characteristics. Binary variables such as organic, training, and organization are included as dummies.

In addition to analyzing differences across farm types, this study also disaggregates results by farm size, dividing the sample into quartiles based on the total utilized agricultural area. This is motivated by the fact that farm size plays a critical role in determining access to capital, investment capacity, and risk tolerance all of which influence whether and how renewable energy technologies are adopted. Larger farms often benefit from economies of scale, more favorable financing

conditions, and a greater ability to absorb the upfront costs of energy investments. In contrast, smaller farms may face tighter budget constraints, making renewable adoption more difficult or less economically viable in the short term. Empirical research, such as Key (2019) has shown that productivity growth in the US corn belt has been closely tied to structural change and farm consolidation, highlighting the importance of scale in shaping economic outcomes. Therefore, in addition to comparing different farm types, this study also examines results by farm size, focusing specifically on the smallest quartiles and the biggest quartiles of farms within each type.

3.3 Data and Summary statistics

This study focused on three different TF8 classifications field crops, dairy, and other grazing livestock. Field crops are primarily growing cereals, oilseeds, protein crops, mixed cropping, or engage in mixed/general cropping. Dairy is specialized in milk production and Other grazing livestock are specialized in cattle rearing, fattening, sheep or goat. Data cleaning was performed and an Ordinary Least Squares (OLS) with 6,730 observations from 2008 to 2023 was utilized in the analysis. All the continuous variables are log-transformed. This transformation improves the linearity of the model and the variables can be interpreted as an elasticity. Data cleaning, transformation, and analysis were conducted in Stata. Exchange rate adjustments were made using a SEK-to-Euro index to ensure consistency in monetary values across years. The summary statistics of the variables used in this study are presented in three different tables where Table 2. Present summary statistics for the variables used in the study.

3.4 Descriptive Statistics overview

Table 2 Descriptive Statistics

VARIABLES	Field crop farms		Dairy Farms		Livestock grazing farms	
	(1) mean	(2) sd	(3) mean	(4) sd	(5) mean	(6) sd
Productivity	0.87	0.38	0.93	0.19	0.77	0.25
Cost Share of clean energy	0.20	0.14	0.39	0.15	0.28	0.17
Economic Size	970.18	1,233.73	3,826.38	4,378.60	1,371.92	1,773.65
Total Subsidies	358,004.97	492,152.14	863,930.58	944,440.20	623,610.70	672,899.51
Environmental Subsidies	0.07	0.12	0.17	0.13	0.23	0.16
LFA Subsidies	0.19	0.10	0.21	0.10	0.20	0.13
Decoupled Payments	0.67	0.16	0.42	0.15	0.46	0.13
Rented UAA	0.50	0.33	0.60	0.29	0.52	0.31
Organic	0.13	0.33	0.24	0.43	0.37	0.48
Organization	0.12	0.33	0.23	0.42	0.18	0.38
Training	0.81	0.40	0.62	0.48	0.70	0.46
Observation number	606		4552		2831	

Table 2 shows the descriptive statistics for the farm types where the mean and standard deviation are presented.

Columns 1 and 2 show statistics for field crop farms shown. The average productivity is 0.87, meaning these farms generate 0.87 units of output per unit of input on average. Productivity varies substantially ranging from 0.01 to 2.78 indicating wide performance differences across farms.

The renewable energy expenditure has a mean of 0.20, indicating that 20% of total energy expenditure on average comes from renewable sources. Some farms report negative or zero values, which may reflect estimation noise or net sales to the grid.

The average economic size of farms is 970 thousand SEK, but the high standard deviation (1.23 million) and maximum value (17.2 million) indicate substantial variation in the economic size of the farms. Total subsidies average 358 thousand SEK but range up to 6.7 million SEK.

Regarding subsidy composition, environmental subsidies make up 7% of total subsidies, LFA subsidies 19% and decoupled payments 67%. This breakdown reflects the policy structure within Sweden's CAP payments. On average, 50% of land used is rented.

In terms of the binary variables, 13% of farms are organic, 12% are operated by non-family organizations. 81% of farm managers have formal agricultural training.

In 3 and 4 presents data for dairy farms, which report the highest average productivity and the sample at 0.93, with relatively low variation 0.22 to 1.99. These farms are also more energy-intensive with an average renewable energy costs share of 39% suggesting broader adaptation of technologies for instance biogas or solar panels.

Dairy farms are larger in economic terms with a mean output value of 3.8 million SEK and some exceeding 72 million SEK. Total subsidies average 864 thousand SEK though the standard deviation is large and one farm reports subsidies over 11 million, and 60% of the total land are rented.

For the subsidy composition: 17% are environmental subsidies, 21% are LFA subsidies and 42% are decoupled payments. For the dummy variables are 24% organic, 23% non-family-operated, 62% of managers have agricultural training.

In 5 and 6 displays the descriptive statistics for grazing livestock farms. These farms report the lowest average productivity at 0.77 and a wide productivity range 0.002 to 2.62.

The renewable energy expenditure averages 28% which is lower than dairy but higher than field crops. Notably, the minimum value is negative -0.64, potentially reflecting data inconsistencies or net energy production exceeding consumption.

Economic size averages 1.37 million SEK and total subsidies average 624 thousand SEK, again with high variability. Grazing farms receive the highest average share of environmental subsidies (23%). The other subsidies are 20% LFA and 46% decoupled payments. 52% of farmland is rented.

For the binary variables are 37% of the farms organic, 18% are non-family managed 70% of farm managers have formal training.

Figure 1 Change in Mean Productivity by Farm Type (2008-2023)

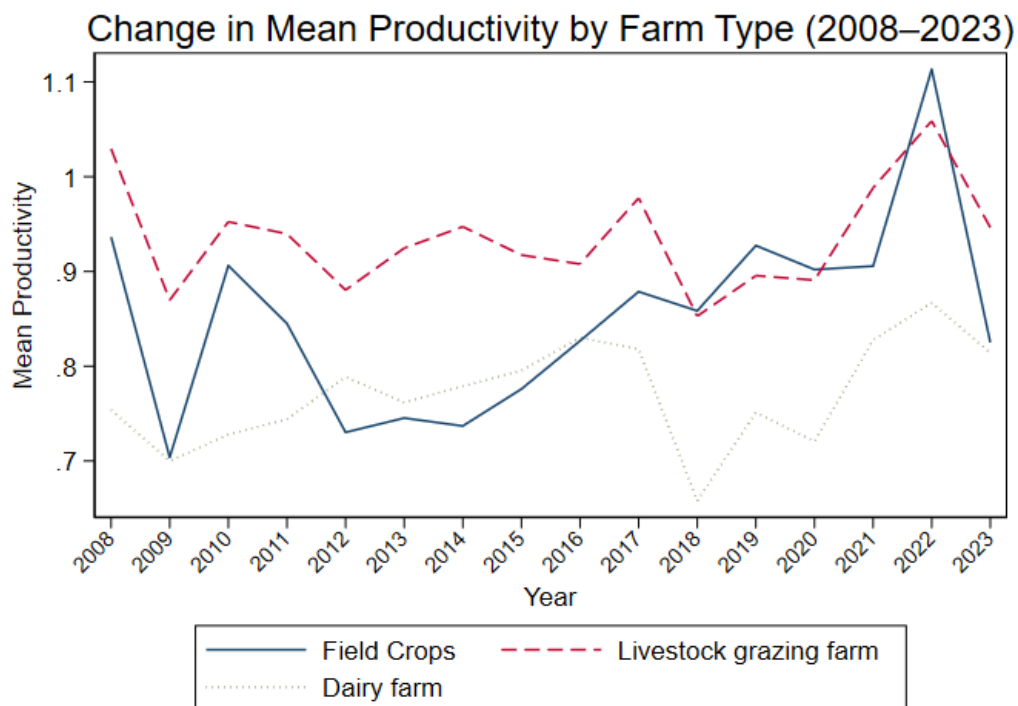


Figure 1 illustrates the evolution of average farm productivity in Sweden between 2008 and 2023, disaggregated by farm type. Livestock grazing farms consistently exhibit the highest average productivity throughout most of the period, maintaining levels near or above 0.9. This pattern indicate that these farms may

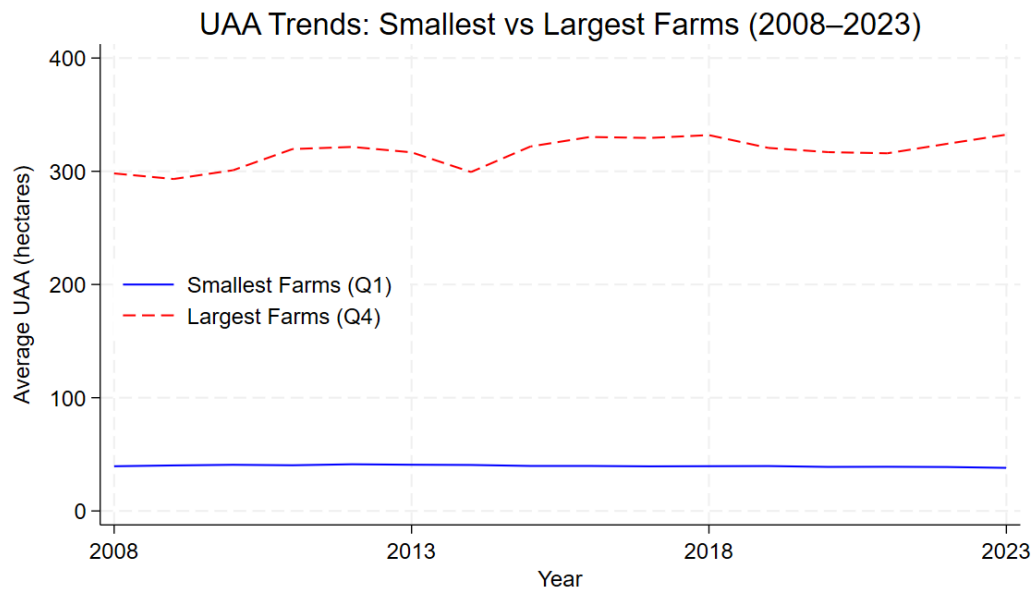
benefit from more diversified production systems, greater input flexibility or structural advantages in managing costs. Notably, productivity in this group increased steadily after 2018, peaking 2022, before declining.

Field crop farms show more volatility over time. After a sharp drop 2009, productivity recovered and remained relatively stable until 2014, followed by a gradual upward trend through 2021 and a dramatic spike in 2022. This surge may reflect favourable market or weather conditions in that year, but the sharp decline in 2023 underscores the sensitivity of crop-based systems to external shocks such as price fluctuations or input cost changes.

Dairy farms display the lowest and most stable productivity levels, generally fluctuating between 0.6 and 0.8. This stability may reflect the capital-intensive and biologically constrained nature of dairy production, where short-term gains in technical efficiency are more difficult to achieve.

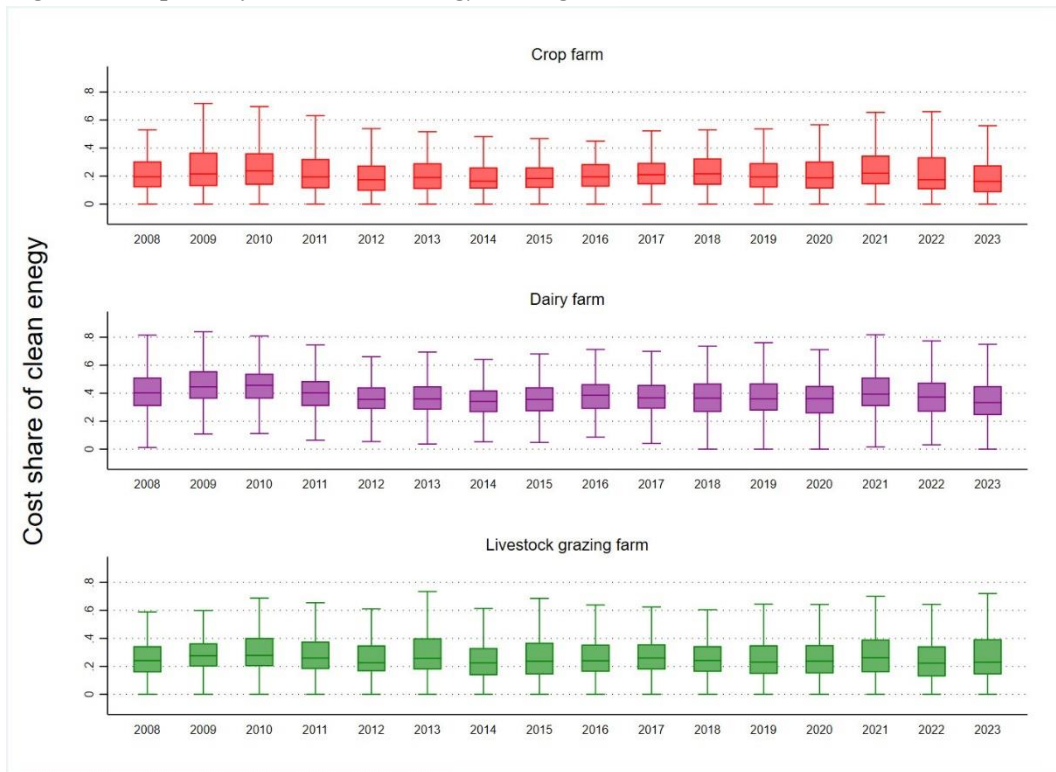
The renewable energy transition makes these productivity patterns particularly relevant. Since productivity reflects a farm's financial resilience, it reveals which operations can realistically absorb the costs of clean energy investments. High-performing farms can likely integrate renewable technologies without jeopardizing their economic stability. In contrast, farms with weak productivity may need additional assistance to participate in sustainable energy initiatives without facing disproportionate financial hardship.

Figure 2 UAA over time



The graph displays the average utilized agricultural area for the smallest 25% and the largest 25% of farms between 2008 and 2023. The difference between these two groups is compelling. In 2008 the largest farms began at approximately 300 hectares, while the smallest started at around 40 hectares. Over time the average area of the largest farms increased to about 320 hectares by 2023, whereas the smallest farms remained at 40 hectares. This highlights why it is relevant to compare the smallest and largest farms. Larger farms tend to have higher output and are more likely to have the capacity to absorb the investment costs required to adopt renewable energy technologies.

Figure 3 Adoption of Renewable Energy Among Swedish Farms



The graph below illustrates the adoption of renewable energy among Swedish farms from 2008 to 2023. Despite Sweden's international reputation for clean energy leadership highlighted by the World Economic Forum (2018), which claimed Sweden would reach its climate targets ahead of schedule the data reveals that on farm adoption of renewable energy has remained largely unchanged over the past decade. This demonstrates that progress in Sweden's broader renewable energy transition has not yet been mirrored within the agricultural sector.

4. Result

4.1 Regression Results by Farm Type

This study conducted ten regression models to examine the relationship between farm characteristics. The analysis includes a general model incorporating all farm types, followed by models for specific farm categories and additional regressions focusing on the top and bottom quartiles of farms by utilized agricultural area.

Table 3 Results from Regression

VARIABLES	(1) All Farms	(2) Field Crops	(3) Dairy	(4) Other Grazing Livestock
Ln Clean Energy Share	-0.0037 (0.0059)	-0.082** (0.033)	-0.0084 (0.0071)	-0.034*** (0.011)
Ln Total Subsidies	-0.14*** (0.0084)	0.028 (0.058)	-0.11*** (0.010)	-0.010 (0.022)
Ln Economic Size	0.17*** (0.0066)	0.078 (0.056)	0.10*** (0.0089)	0.067*** (0.021)
Ln Environmental Subsidies	-0.00016 (0.0040)	0.011 (0.031)	0.014*** (0.0038)	-0.0059 (0.010)
Ln LFA Subsidies	0.0099** (0.00476)	0.027 (0.038)	-0.013*** (0.0047)	0.025** (0.0098)
Ln Decoupled Payments	0.037*** (0.0115)	0.18** (0.087)	0.032*** (0.012)	0.19*** (0.029)
Ln Rented UAA	-0.011** (0.0046)	0.0084 (0.033)	-0.010** (0.0047)	-0.022** (0.0089)
Organic	-0.029*** (0.0089)	-0.14 (0.089)	-0.017** (0.0087)	-0.050*** (0.017)
Organization	-0.044*** (0.011)	-0.10 (0.10)	-0.058*** (0.0098)	-0.020 (0.023)
Training	-0.057*** (0.010)	-0.015 (0.093)	-0.018* (0.0099)	-0.0085 (0.021)
Constant	0.062*** (0.0093)	0.027 (0.12)	0.070*** (0.0084)	-0.064** (0.025)
Observations	6,730	275	4,187	2,268
R-squared	0.157	0.109	0.140	0.071

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Note: The dependent variable is the natural logarithm of productivity

In the baseline model that includes all farm types, renewable energy expenditure is not statistically significant. This suggests that when analysing farms as a single group there is no clear relationship between renewable energy costs and productivity.

For field crop farms, the renewable energy expenditure is statistically significant and negatively associated with productivity at the 5% level. This means that higher spending on renewable energy is linked to lower output efficiency. This contrasts with findings from developing contexts such as Wang et al. (2023), where renewable adoption was linked to improved efficiency.

In dairy farms, the coefficient on the renewable energy expenditure is negative but statistically insignificant. This means that renewable energy expenditures are not significantly related to productivity in this group. This finding differs from several previous studies, such as Adam et al. (2025) and Wang et al. (2023), which report positive effects of renewable energy adoption on farm performance.

For grazing livestock, the cost variable is negatively associated with productivity and statistically significant at the 1% level. This result is consistent with Jonsson et al. (2011), who identified structural and economic constraints limiting the efficient use of renewable systems in extensive livestock operations.

Across all models, several control variables are being used. Economic size is positive and highly significant across all farms except field crops. This indicates that larger farms tend to be more productive or can have better access to technology that help them to adopt the renewable energy much more effortlessly.

The subsidy-related variables are expressed as shares of total subsidies, rather than absolute amounts. Their coefficients therefore reflect how the composition of subsidy support, rather than its total value relates to productivity. Environmental subsidies show a positive and significant association only in dairy farms which can mean that the dairy farms can integrate the environmentally targeted measures more effectively into the production. LFA subsidies are positively associated in all farms except in the dairy farms and the field crops farms are not significant at all. Decoupled payments have a positive and significant relationship across all farm types. As these subsidies are not tied to production decisions, they may provide flexible capital that farms can reinvest in productivity-enhancing areas including infrastructure or renewable technologies.

Rented UAA, calculated as the share of rented land within the total utilized agricultural area, is negatively associated with productivity in most models. This suggests that higher reliance on rented land may reduce long-term investment incentives or management efficiency, particularly in dairy and grazing farms.

Organic is negatively associated with productivity in all of the models, especially among field crops and grazing livestock farms. This implies that the organic practices can lead to yield lower output, although they may deliver other benefits eg price premiums, or environmental gains not captured by this productivity measure. The organization variable is also negatively associated with productivity in all models. The training variable also shows negative results. This could indicate that while formal training is important, it may not be sufficient without complementary access to modern tools, capital, or support services.

4.2 Regression Results by Farm Size

Table 4 Results from Regression - Smallest Farms

VARIABLES	(1) Field Crop Low 25%	(2) Dairy Low 25%	(3) Other Grazing Livestock Low 25%
Ln Clean Energy Share	0.034 (0.21)	-0.059*** (0.020)	0.034 (0.033)
Ln Total Subsidies	0.90*** (0.31)	-0.071** (0.029)	0.026 (0.073)
Ln Economic Size	0.26 (0.37)	0.13*** (0.024)	0.19*** (0.063)
Ln Environmental Subsidies	0.27** (0.12)	-0.018* (0.010)	-0.00046 (0.027)
Ln LFA Subsidies	0.097 (0.21)	-0.074*** (0.015)	0.048 (0.044)
Ln Decoupled Payments	0.22 (0.28)	0.11*** (0.035)	0.092 (0.093)
Ln Rented UAA	-0.42 (0.31)	-0.0053 (0.011)	-0.0090 (0.026)
Organic	-0.067 (0.40)	0.072*** (0.023)	-0.13*** (0.050)
Organization	-0.37 (0.38)	-0.098*** (0.020)	-0.11* (0.065)
Training	0.095 (0.36)	-0.13*** (0.025)	-0.10* (0.054)
Constant	2.18*** (0.76)	0.21*** (0.031)	0.36*** (0.11)
Observations	45	929	442
R-squared	0.297	0.189	0.081

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Note: The dependent variable is the natural logarithm of productivity

Among the smallest farms, renewable energy costs show a significant and negative association with productivity in dairy farms. This highlights how smaller producers may lack the economies of scale or financial buffer needed to absorb energy-related investments. These findings support Hahn et al. (2025), who report that smaller Swedish farms face substantial barriers to renewable adoption due to limited profitability, capital, and risk tolerance. This also aligns with Adam et al. (2025), who cautions that uncertainty in prices and returns may discourage smaller, risk-averse farms from embracing biogas or solar systems.

Table 5 Results from Regression - Biggest Farms

VARIABLES	(1) Fieldcrops High 25%	(2) Milk High 25%	(3) Other grazing livestock High 25%
Ln Clean Energy Share	-0.086** (0.033)	0.0056 (0.010)	-0.050*** (0.014)
Ln Total Subsidies	-0.27** (0.11)	-0.093*** (0.017)	-0.042 (0.035)
Ln Economic Size	0.22*** (0.079)	0.10*** (0.013)	0.077*** (0.029)
Ln Environmental Subsidies	-0.058 (0.045)	0.023*** (0.0058)	-0.067*** (0.013)
Ln LFA Subsidies	-0.011 (0.044)	0.0025 (0.0058)	0.010 (0.010)
Ln Decoupled Payments	-0.41 (0.26)	0.042** (0.017)	0.18*** (0.040)
Ln Rented UAA	0.070 (0.047)	-0.020** (0.0094)	-0.052*** (0.011)
Organic	-0.081 (0.099)	-0.048*** (0.013)	0.0096 (0.024)
Organization	-0.15 (0.13)	-0.036* (0.019)	-0.010 (0.034)
Training	-0.063 (0.12)	0.050*** (0.017)	0.039 (0.031)
Constant	0.22 (0.17)	0.0042 (0.017)	-0.16*** (0.037)
Observations	101	1,119	660
R-squared	0.367	0.232	0.233

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Note: The dependent variable is the natural logarithm of productivity

Among the largest farms, results are more nuanced. Renewable energy costs remain significantly and negatively associated with productivity in field crops and grazing livestock farms, suggesting that scale alone does not guarantee productivity gains from clean energy investments. However, in large dairy farms is the relationship small and statistically insignificant, possibly due to better integration of biogas systems and capital access. This is consistent with Liu et al. (2018), who note that technical integration alone may not guarantee productivity gains without economic and structural support.

Economic size is positively associated with productivity across most models in both size categories. Total subsidies display both positive and negative associations depending on the model. Environmental, LFA, and decoupled payments vary in statistical significance.

The share of rented UAA is included as a control and shows differing levels of significance across models. Organic, organization, and training display variability in both magnitude and statistical significance across farm types and size categories.

5. Discussion

The findings of this study indicate that the impact of renewable energy expenditure on agricultural productivity, with the effects varying notably by farm type and size. While the aggregate regression model reveals no statistically significant association between renewable energy expenditure and productivity across the full sample, disaggregated analyses expose more nuanced patterns. Specifically, the negative and statistically significant relationship observed among field crop farms particularly within the smallest quartile indicates that the financial burden of renewable energy adoption may disproportionately affect capital-constrained farms with limited technological flexibility.

These results align with the findings of Hahn et al. (2025), who emphasize that while Swedish farmers generally recognize the long-term value of renewable energy, financial uncertainty and high upfront investment expenditures are significant barriers to adoption. Similarly, Adam et al. (2025) demonstrate that risk-averse farmers are more likely to emphasize the potential downsides of renewable energy investments, potentially deterring adoption even when long-term gains are achievable.

In contrast to international studies conducted in lower-expenditures or energy-insecure contexts such as those by (Wang et al. 2023; Khan et al. 2024). Which finds positive correlations between renewable energy use and farm efficiency or income. Those studies are set in developing countries where renewable systems often replace unreliable or expensive fossil-based infrastructure. In Sweden where the electricity grid is already renewable and stable the marginal benefit of installing on-farm renewables may be smaller while the cost burden remains high.

Grazing livestock farms present a more complex picture. While renewable energy costs are negatively associated with productivity in some models. The effects are smaller and less consistent. This may reflect the more complex production systems on these farms, where energy is used in diverse ways making it more difficult to realise efficiency gains from any single investment. It may also signal that renewable technologies are not being optimally allocated across the different activities within these farms.

Farm size remains a decisive factor in shaping the effect of renewable energy investments. Among small farms cost burdens are consistently linked to reduced productivity. While larger farms show mixed or neutral outcomes. These findings show a broader structural challenge: renewable energy adoption is easier to justify for farms with economic scale. Diversified income sources or better access to

capital and credit. Without targeted support, smaller farms may struggle to engage in the energy transition creating an uneven playing field and potentially widening existing efficiency gaps.

While renewable energy technologies exist and have been shown to reduce the energy dependence and enhance long term sustainability on farms the adoption is often constrained by the need of robust policy frameworks, reliable infrastructure and economic incentives (Majeed et al. 2023; Liu et al. 2018). These benefits can be good for some farms but for the smaller ones lack the capital or policy support needed to implement such systems.

Although Sweden has made strong commitments to climate neutrality by 2045. The pathway to agricultural decarbonization must be economically feasible for all the different types of farms and can face the constraints that follow, to ensure that all farms can participate in the transition without sacrificing productivity. The results of this study suggest that a more tailored approach to energy policy in agriculture is needed including investment support, guaranteed pricing schemes, or training programs focused on energy integration.

In conclusion the study offers new empirical evidence that renewable energy investments while environmentally necessary can have short term productivity trade-offs. Particularly for smaller and less capitalized farms. Policy must therefore not only incentivize renewable adoption but also address the structural conditions that determine whether these investments translate into sustainable productivity gains.

5.1 Limitations

While this study provides new insights into the relationship between renewable energy costs and farm productivity in Sweden, several limitations should be acknowledged.

Data limitations were a key constraint. The FADN dataset used in this study while rich in detail was unbalanced across years and farm types.

There is a potential risk of measurement error, as the cost share of clean energy variable does not differentiate between renewable energy generated on farm and the purchased from external sources. It may conflate distinct energy sources and obscure their respective impacts on farm productivity.

Selection bias may influence the findings. Farms that invest in renewable energy may differ in unobservable ways such as risk preferences, innovation mindset or access to credit which are not fully accounted for in the model. These factors could affect both their productivity and their energy investment decisions.

Methodological limitations also apply to the interpretation of results. The use of Ordinary Least Squares (OLS) regression allows the identification of statistical associations between renewable energy expenditure and productivity, but it does not establish causality. Without a clear counterfactual or a valid instrument variable, it is not possible to determine whether renewable energy costs directly cause changes in productivity. Unobserved factors such as farm management quality, regional infrastructure, or energy policy exposure may simultaneously influence both variables leading to potential endogeneity. Therefore, the results should be interpreted as correlational rather than causal.

6. Conclusion

This thesis examined the relationship between renewable energy costs and agricultural productivity in Sweden using micro-level data from the Farm Accountancy Data Network (FADN) between 2008 and 2023. While Sweden is internationally recognized for its renewable energy leadership, the findings of this study highlight that the economic effects of renewable energy adoption in agriculture are uneven and shaped by structural farm characteristics.

The baseline regression model, which included all farm types, found no significant relationship between renewable energy costs and productivity. When the analysis was disaggregated by production type and farm size clear patterns emerged. Field crop farms particularly those in the smallest size category showed a significant and negative relationship.

These findings show that renewable energy investments, while critical for meeting environmental goals, may introduce productivity trade-offs, particularly in capital-constrained or less diversified farm operations.

The study contributes to the existing literature by providing empirical evidence on how the cost of renewable energy, not just its adoption affects farm level performances. It complements previous research that focused primarily on environmental outcomes or adoption motivations and brings attention to the importance of structural support and targeted policy interventions.

Future research could use another method like unbalanced panel data or quasiexperimental designs to better establish causal relationships between renewable energy expenditure and farm productivity. Comparative studies across countries with varying energy policies, cost structure and subsidy regimes could also provide valuable insights into the conditions under which renewable investments are most economically viable. Additionally, future work could differentiate between specific types of renewable technologies such as biogas, solar panels or wind turbines to assess their distinct economic impacts.

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