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Possibilities of Changes in Energy Intensity of Production Depending on the Scale of Farm Investments in a Polish Region

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Abstract: The purpose of this paper was to analyze the possibility of changes in energy intensity of production in the context of farm investment scale. The empirical section relies on unpublished FADN microdata. The study answers the question of whether investments and fixed capital growth can contribute to improvements in environmental performance of agricultural production. As it turns out, the group of farms with the greatest amount of investments saw an increase in energy consumption costs, though at a much slower rate than growth in production value. As a result, there was a drop in energy intensity of production, defined as the ratio between energy costs and production value. These findings corroborate the hypothesis advanced in this study, namely that upon reaching a sufficiently large amount of investments, farms can become capable of reducing the energy intensity of their production activity. Hence, higher levels of capital productivity are attained when the farms invest in more energy-efficient fixed assets. Conclusions cannot be universal, as the analysis involved a portion of selected farms. However, the research indicates a trend in the study of energy intensity of production depending on the scale of investment and the validity of the investment comprehensiveness approach. These conclusions provide a basis for recommendations for an agricultural policy which should include support for investments that are large and comprehensive (in relation to the farm's assets) and go beyond the simple renewal of assets. Therefore, in its investment-oriented measures, the agricultural policy should take the innovativeness (including energy efficiency) criterion into account.

Keywords: investments; farms; energy consumption; energy intensity; FADN

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1. Introduction

Environmental degradation has an effect on how economies operate, although this varies for different industries and regionally. The progressing climate change has growing consequences for the environment, agriculture and social matters [1–3]. In turn, agriculture largely contributes to global environmental problems [4,5], such as greenhouse gas emissions and loss of biodiversity [6–8]. As it relies on environmental resources in the production process, it exploits them considerably and affects environmental conditions [9]. It emits greenhouse gasses (mostly methane) [10] while also being strongly dependent upon natural and climate conditions. This is what makes sustainable food production so important [11], as it may contribute to food security and strengthen the farmers' income flows [12] while minimizing agricultural impacts on climate change [13–15], including energy consumption. The sustainability concept considers environmental aspects to be just as important as the development of humanity [16,17]. On the one hand, the numerous transformations of European agriculture have contributed to solving the issue of food insecurity [18,19], but on the other, they exacerbated new, previously unknown problems, primarily including those involving environmental [20] and climate [21] aspects. Research at the local level is extremely important in this context due to the high complexity of environmental problems, including environmental problems in agriculture [22,23] related to the energy consumption.

If the climate is duly taken care of, it will guarantee the delivery of high-quality food [24,25]. The frequently changing climate conditions and the ever-growing population pose a serious threat to global food security [26]. Technological innovations are conducive to increasing agricultural productivity; in some parts of the world, they help people accommodate climate change [27]. The volume of agricultural production strongly depends on the quality and stability of environmental parameters [28,29]. Less developed countries lack enough capital [30] to invest in new agricultural technologies. Thus, by undertaking unsustainable activities, such as deforestation [31] or the unbalanced use of yield boosters, including fertilizers [32,33], they contribute to reducing the quality of the natural environment. Moreover, environmental challenges are also largely generated by agriculture becoming more and more capital-intensive [34]. This, in turn, makes farms strongly dependent on energy consumption [35,36]. However, the use of energy-efficient productive inputs in agriculture contributes to improvements in environmental performance [37]. It is important to introduce these changes at the microeconomic level, like at a farm level in this case. Analysis of the energy intensity of individual farms at the local level is important for achieving general social goals.

Farm energy can be defined as an aspect of productive inputs which makes work possible [38]. Therefore, it becomes an agricultural input which has been increasingly used over the recent years because of technological investments [39]. Greater capital inputs are necessary in order to substitute labor with capital [40]. However, in a period of intense industrialization, energy management in agriculture has often been unsustainable [41,42], whereas increasing production volumes and incomes was the key condition for extending machinery resources [43,44]. Industrial agriculture is known for being energy intensive [45] and toxic [46]. Furthermore, agricultural energy originates mostly from fossil fuels [47,48], and therefore poses a macro threat to improvements in energy efficiency and environmental performance [49,50]. Hence, there is need to seek the reasons behind great greenhouse gas emissions from agriculture [51,52], and to develop methods for cleaner management of agricultural production [53] in order to reduce emissions [54,55]. It should be noted, however, that industrial agriculture was a necessary level for achieving the next stage of economic development of individual economies [56]. It cannot be assessed only negatively, because it significantly increased production and thus prevented food insecurity [57].

Also, the shortage of fossil fuels will affect the performance of intensive agriculture [58,59]. Hence, it is important to look for conditions of and solutions to environmental and energy problems facing agriculture [60]. Sustainable agricultural practices combine traditional and modern methods [61] with a view to make efficient use of resources and, as a consequence, make agriculture insensitive to climate change [62]. The functioning of a modern farm is strictly related to the need for addressing the growing demand for energy [63], especially including electricity. The use of renewables [64], i.e., energy derived from rivers, winds, solar radiation, biomass or geothermal energy, is among the important components of sustainable development, and brings measurable environmental and energy effects [65]. The integration of renewables and smart technologies is especially needed in energy-intensive forms of agriculture [66], locally more and more common, but more so in highly developed countries. This, in turn, requires constant monitoring of changes in energy consumption. For instance, energy audits have become more and more widespread as a tool used in assessing the environmental performance of agriculture [67].

Any kind of assessment of sustainable farm development should be underpinned by real, representative data [68] in order to take sectoral particularities into account, especially if it includes reviewing investments and energy consumption. The above is corroborated by numerous studies on energy consumption in agriculture. Czyżewski and Guth [69] proved the existence of a long-term positive impact of capital intensity on all aspects of sustainable development. In their study, Hosseinzadeh-Bandbafha et al. [70] sought the optimum energy consumption in milk farms. In turn, Han and Zhou [71] demonstrated that as agricultural modernization goes on, agricultural energy consumption keeps growing, and improvements in energy efficiency do not result in energy consumption savings. This could be explained by Chinese agriculture being at an early stage of development. As regards Polish agriculture—which is at a higher level of technological development—investments entail improvements in energy efficiency, which is the primary subject of this study.

Capital absorption in agriculture, especially in the context of modernization of machinery resources, is an important driver of improvements in the production performance of farms [72,73]. At the micro level, the purpose of investments is to make labor safer [74] and more efficient [75] while also increasing production volumes, which ultimately is supposed to have a positive impact on farm incomes [76]. Hence, sustainable farming should rely on practices that take account of the need to protect the environment [77] and natural resources while seeking growth in target production volumes. Agricultural mechanization increases labor productivity in plant production [78], but is also of tremendous importance to environmental impacts, including regarding the generation of a carbon footprint [79]. According to a study by Guan et al. [80], agricultural mechanization is a major contributor to agricultural carbon emissions. Greater investments require making intense use of coal (due to fossil fuel consumption) and of energies derived from it [81]. Certainly, unfounded investments and bad decisions made by farm managers can also result in unsustainable energy consumption in farms; at the micro level, this can increase farming costs [82,83], whereas at the global level, it entails an increase in greenhouse gas emissions. However, the assumption is made that producers make optimum decisions, such that their farms continue to develop while implementing environmentally friendly investments (new technical and technological solutions which help in reducing the consumption of energy necessary to deliver a certain amount of agricultural production). Therefore, it is important to analyze the change in energy intensity of production in the context of investment scale at the microeconomic level.

If efficient farm investments contribute to improving productivity, it is assumed that they should also lead to improving the environmental efficiency of this production [84]. Due to the nature of its production, agriculture consumes more and more energy resources [85]. However, it should rationalize energy consumption while maximizing the economic effect [86]. Therefore, the analysis of changes in the energy intensity of production in the context of the scale of investment in farms, using the example of Poland, is essential for at least several reasons.

There are over 1.3 million farms in Poland. Agriculture in Poland is characterized by a large number of farms, agricultural land, number of farm animals and number of people working in agriculture [87]. Structural change is a challenge for Polish agriculture [88,89]. Compared to other EU countries, the percentage of people employed in agriculture is very high, and Poland is among the top EU countries in terms of the number of people working in agriculture [90]. The low labor productivity of Polish agriculture remains a weakness, as well as low productivity [91].

Nevertheless, since Poland's accession to the European Union (EU), it has been developing at a rapid pace [92]. The agricultural sector, thanks to the resources of the Common Agricultural Policy, has become competitive [93] against the background of Europe and the world. The development of Polish agriculture has focused on subsidizing investments in farms. These investments have made it possible to achieve higher agricultural production, increase farmers' incomes, or improve the efficiency of production [94]. However, on the other hand, they have also increased costs, including the cost of energy consumption. Ten years after Poland's accession to the EU, it is necessary to consider how to effectively reduce the energy intensity of agricultural production without harming farms, for the benefit of society.

The study of the energy intensity of production on farms makes it possible to identify areas where improvements can be made and to what extent they depend on the degree of investment. This can consequently lead to a reduction in energy costs [95]. In the face of climate change and increasing demands for sustainability, analysis of the energy intensity of production allows some assessment of the impact of agriculture on greenhouse gas emissions. The relevance of analyzing the energy cost structure in agricultural production is in linking the context of energy intensity and investment in it. Investments in lower-energy-consumption technologies can bring long-term economic benefits [96].

Sometimes, efforts to reduce energy intensity can lead to the optimization of production processes [97], which contributes to increased production efficiency. In the region of Poland, the analysis of changes in the energy intensity of production in the context of the scale of investment in farms supports economic efficiency and sustainable development. In addition, it contributes to better adaptation of farms to changing market and regulatory conditions.

The results of this research are aimed at farm managers, in order to optimize investment paths in accordance with environmental and social goals, and for researchers to deepen research on changes in the energy intensity of agricultural production. In addition, the results are also addressed specifically to agricultural policy makers, in order to encourage more frequent subsidy investments in high technologies that use less energy than replacement ones. In environmental and social terms, this research addresses the three goals of equalized development related to food production in the context of energy-efficient economies (like: SDG 2 "zero hunger", SDG 7 "Affordable and clean energy" and SDG 13 "climate action"). The main objective of this paper is to analyze the possibility of changes in the energy intensity of production in the context of the scale of farm investment. The selected specific objectives are as follows:

- separation of three groups of farms based on the comprehensiveness of realized investments;
- indication of changes in production value and in energy costs recorded by farms as a function of investment comprehensiveness;
- calculation of changes in energy intensity of production recorded by farms as a function of investment comprehensiveness.

The results, while not universal, indicate the validity of examining energy intensity according to the complexity of on-farm investments. This approach indicates the demonstration of trends and dependence of energy intensity on the degree of complexity of investments.

2. Materials and Methods

Agriculture is one of the key sectors of the economy in the Wielkopolskie voivodship [98,99].

The reason for choosing the Wielkopolskie voivodeship was that its agriculture was at the highest relative development level (on a countrywide basis). Compared to the rest of the country, Wielkopolskie Voivodeship offers average, moderately favorable crop and livestock production conditions. Nevertheless, some regions may be identified which demonstrate outstanding production intensity and efficiency [100]. Professional farmers' skills provide faster and more dynamic development of the region, which already is ahead in terms of development compared to the rest of the country. A characteristic feature of the agricultural production of Wielkopolskie Voivodeship is the best-developed model of intensive family farming in Poland. The sown area in Wielkopolskie Voivodeship accounted for 13% of the total area in the country. Wielkopolskie is the largest producer of cereals, sugar beets, grain maize and potatoes in Poland, as well as a significant producer of rapeseed and fruit. A mixed agricultural production model with a large share of livestock production distinguishes agricultural production in the region. Farms in the region are the largest producers of pigs in Poland, as well as hen eggs, and the second province in terms of cattle production. These farms are also characterized by a relatively high level of investment. This is due to the intensity of their production. This may make the results not universal, but they indicate a trend, especially for more developed regions. This means that the pursuit of development justifies the study of the possibility of changes in energy intensity of production depending on the complexity of investments in regions with higher levels of agricultural development. A similar study of the relationship between production and energy costs in Polish agriculture was conducted by Maciulewski and Pawlak [101]; however, the research was based on data aggregated for all Polish FADN farms.

This study used unique farm-level microdata retrieved from the Farm Accountancy Data Network (FADN). The Farm Accountancy Data Network (FADN) is the EU system based on production, economic and financial data collection from representative samples of agricultural holdings. The field of observation of the European FADN system includes the commercial farms that produce about 90% of the value of Standard Production in a given region or country. It collects accountancy data from about 80,000 farms. It consists of an annual survey carried out by the Member States of the European Union. The FADN is the only source of microeconomic data based on harmonized bookkeeping principles in all Member States. Final information is aggregated into a Standard Results database [102].

A single farm from the Polish FADN sample represents, on average, 67 farms covered by the Polish FADN (FADN 2024 [103]). In this research, we covered all FADN farms located in the Wielkopolskie voivodeship that kept continuous FADN records between 2009 and 2021 (a total of 359 holdings). Based on FADN agricultural accountancy data, energy intensity of production was defined as the ratio between farm expenditure on energy (SE345: electricity, heating fuels, engine fuels and lubricants) and total production value (SE131). The same FADN data variable of energy cost was used in the regional analysis by Fusco et al. [104].

2.1. Investment Comprehensiveness

Having in mind the purpose of this study (determining the relationship between energy consumption and investment scale), three farm groups were identified based on the comprehensiveness of their investment projects. Comprehensiveness was measured as the ratio (IC) between gross total investment expenditure (SE516) and annual average value of the farms' fixed assets (SE441), excluding land (SE446). When land is excluded from the assets, the calculations are focused mainly on the farms' machinery, equipment and buildings. The farms covered by this study were split into three groups as per the following formula:

$$\text{Investment Complexity (IC)} = \begin{cases} \text{comprehensive} \\ \text{non-comprehensive, if} \ \dfrac{\sum_{t_{2009}}^{t_{2021}} \text{SE516}_t}{\bar{x}(\text{SE441} - \text{SE446})} \\ \text{nagative} \end{cases} \begin{matrix} \geq 50\% & N = 97 \\ \geq 0 < 50\% & N = 217 \\ < 0 & N = 45 \end{matrix} \quad (1)$$

Negative investments indicate a decline (decapitalization) in the value of assets, because the FADN defines gross investments as fixed assets purchased or manufactured by the farm, minus the value of fixed assets sold or donated by it within a financial year.

The above means that the farms were categorized as follows based on their investment levels:

(a) comprehensive investments: if total investments across the study period (2009–2021) were more than half the value of fixed assets (as recorded in 2009–2021);
(b) non-comprehensive, if total investments were between 0% and 50% of the value of assets;
(c) negative investments, if the farms recorded a decline (decapitalization) in the value of assets.

It was decided that only 3 groups of farms would be distinguished according to the complexity of investments, due to the proposed approach. From the perspective of the research presented in this article, it is important, firstly, whether the farm invests at all, and secondly, whether these investments are comprehensive. If such an approach shows that the degree of complexity of investments can contribute to changes in the energy intensity of production, then the research will be a reference for distinguishing other types in the future, e.g., in the context of the type of investments made.

The hypothesis advanced in this study is that upon reaching a sufficiently large amount of investments, farms become capable of reducing the energy intensity of their production activity. That process can be driven by higher productivity levels of extended capital assets (i.e., the ratio between production value and fixed assets minus land) and by the implementation of state-of-the-art technical and technological solutions which enable reducing the consumption of energy necessary to deliver agricultural production.

2.2. Statistical Significance of Differences

Analysis of variance was used to demonstrate statistically significant relationships between the energy intensities of production in the three designated farm groups. The distribution of variables failed to meet the assumptions for the use of parametric tests (normal distribution and homogeneity of variance). Therefore, this study used the non-parametric Kruskal–Wallis test (as a non-parametric equivalent of the one-way analysis of variance—ANOVA for independent samples) to reveal statistically significant differences in the energy intensity of production between the initial (average figures for 2009–2011) and final (average figures for 2019–2021) years of the analysis period. The results for one initial or final year (2009 and 2021) would not yield reliable conclusions because of potential incidental impacts (to which agriculture is particularly prone). This is why the calculations are conducted for average values recorded in 2009–2011 (the initial period, T_0) and in 2019–2021 (the final period, T_1). In this test, the null hypothesis is that all group means μ (1, 2, . . . , i) are equal (H_0: $\mu_1 = \mu_2 = \mu_3 = \ldots = \mu_i$), whereas the alternative hypothesis is that for H_1, a difference exists between two or more group means. Therefore, the alternative hypothesis is that at least two populations differ in the mean level [105].

The input data are *n*-element samples of observations divided into *k* disjoint groups (*k* is the number of groups) with counts $n_1, n_2, \ldots, n_k$ (*n* is the number of observations in group *i*). The entire sample is ranked (r_{ij} is the rank of *j* observation from *i* group).

Then, the Kruskal–Wallis test statistic is applied:

$$T = \frac{12}{n(n+1)} \sum_{i-1}^{k} n_i \left(r_i - \frac{n+1}{2} \right)^2$$

where:

$$r_i = \frac{1}{n_i} \sum_{j=1}^{n_i} r_{ji}$$

This statistic is a measure of the deviation of sample means of ranks from the mean value of all ranks. Finally, the decision to reject or not reject the null hypothesis is made by comparing *T* to a critical value. The null hypothesis is rejected if *T* is bigger than the critical value.

The analysis focused on differences in the energy intensity ratio, and the farms were classified into three groups based on the comprehensiveness of their investments, as described above. Economic values were expressed at constant prices in the last year of the analysis, as adjusted with consumer price indexes.

3. Results and Discussion

Energy contributes significantly to agriculture's production inputs [106]. In the process of continuously striving to reduce costs and improve efficiency, and finally increase farm productivity and profitability, one of the actions undertaken in farms is investment. Increasing the capital factor leads to replacing human work with machinery or replacing techniques with even more advanced ones [107]. It results in energy consumption increasing due to the adoption of technology in the agricultural sector, increasing the energy demand [104] with increasing energy consumption [108]. With rising energy prices and dwindling resources, the issues of energy costs in agricultural production and its efficient use are becoming increasingly important [109].

Energy intensity, defined as the relationship between energy expenditure and production value, will obviously be affected by changes in the numerator and in the denominator of the ratio between the two variables. As for the decline in energy intensity in 2017

(Table 1, Figure 1), it should be clarified that it was due to an increase in the prices of most agricultural products, reaching a level much higher than a year before, while energy prices remained at a relatively unchanged level.

Table 1. Changes in production value and in energy costs recorded by farms as a function of investment comprehensiveness.

Investment Scale	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Total production value (PLN 1000)													
Comprehensive	351.5	399.0	479.0	529.3	547.5	560.4	524.1	589.4	664.8	634.3	693.0	698.6	796.9
Non-comprehensive	215.1	228.6	253.0	274.5	264.1	246.0	226.7	240.0	268.8	244.7	239.0	240.2	276.6
Negative	162.8	177.0	193.5	195.7	184.5	163.8	142.8	144.0	163.0	139.9	141.0	134.4	145.7
Energy costs (PLN 1000)													
Comprehensive	25.6	28.2	33.1	36.8	39.2	40.9	36.4	37.1	38.3	42.2	44.4	38.5	45.1
Non-comprehensive	15.6	16.9	19.4	20.9	19.7	18.8	16.5	16.5	16.9	18.4	17.7	15.7	17.0
Negative	10.3	11.8	13.3	14.0	14.9	13.3	11.7	11.6	11.8	12.7	12.5	12.5	14.1

Source: own study based on unpublished FADN data.

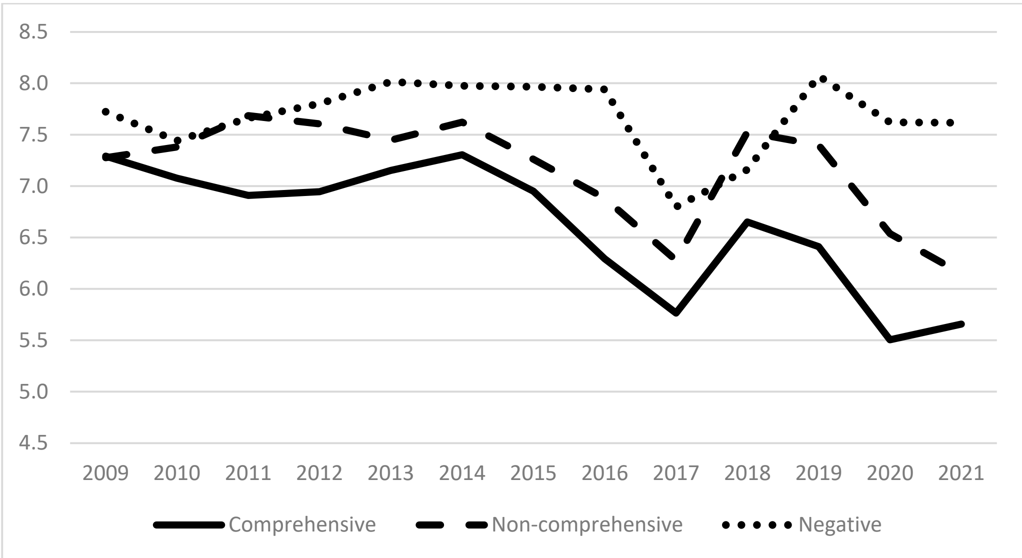

Figure 1. Changes in energy intensity of production recorded by farms as a function of investment comprehensiveness. Source: own study based on unpublished FADN data.

The production value alone tells much about the differentiating effect of the scale of farm investments (Table 1). In the first period of the analysis, the production value of farms which implemented comprehensive investments was 80% higher than that of farms with non-comprehensive investments, and more than twice that of farms with negative investments. Large-scale investments resulted in more than doubling the production value. Production went up by 30% in the case of non-comprehensive investments, and declined in the last group. As a consequence, in the final period, the first group reinforced its advantage, with the production value being 3 and 5 times greater than what the other two groups recorded, respectively. As the farms grew, so did the costs of energy consumption. Compared to changes in production value, the increase in energy costs was smaller (150% and 10%, and a decline by 10%, respectively). The differences in growth rates were a decisive driver of differences in energy intensity of production (Figure 1).

Farms which implemented comprehensive investments recorded a clearly higher increase in energy consumption costs throughout the period from 2009 to 2021. However, it did not cause an increase in energy intensity. Moreover, that group of farms witnessed the fastest decline in the energy-to-production ratio. A similar yet slower trend was discovered in farms with non-comprehensive investments. Conversely, the lack of development investments does not at all entail a drop in energy intensity. That adverse pattern is particularly widespread in Poland, which is home to a large number of small, economically weak farms whose condition makes them unable to invest significant amounts of money. What also needs to be emphasized is that the FADN does not cover the complete structure of farms, because it only includes holdings above a certain minimum economic size. Despite the above, even the FADN group in that region included 13% of farms at negative investment levels. Findings from this study prove that agricultural restructuring is necessary for a number of reasons, and energy intensity of production operations is one of them. This is corroborated by Zhang et al. [110] who, based on analysis of maize production, concluded that "increasing farm size could benefit sustainable production when matched with technical innovation and machinery coordination". Maciulewski and Pawlak indicate [101] that the lowest production and energy cost values characterize the smallest farms, while the highest values are found on the farms with the largest acreage. Samson et al. [111] showed that farms specialized in cereals and cash crops showed high energy use. On the other hand, in a study by Gołasa [109], energy costs are most significant on horticultural farms.

The differences between the groups considered were assessed based on the median test (Table 2). As regards the median of mean values for the three-year initial period (2009–2011), the examination did not reveal any statistically significant difference in energy intensity of production between the three farm groups identified based on the ratio between their investment scale and the value of fixed assets minus land. Thus, the groups shared a very similar starting point, and the differences between them were statistically insignificant.

Table 2. Results of variance analysis with the Kruskal–Wallis test for energy intensity of production in two measurement periods: T_0 and T_1 (N = 359).

Kruskal–Wallis Test T_0 (2009–2011)			**Kruskal–Wallis Test T_1 (2019–2021)**		
Farm groups	Comprehensive (N = 97; Me = 7.6)	Negative (N = 45; Me = 8.4)	Farm groups	Comprehensive (N = 97; Me = 6.4)	Negative (N = 45; Me = 9.0)
Non-comprehensive (N = 217; Me = 7.9)	0.4429	1.0000	Non-comprehensive (N = 217; Me = 7.6)	0.0083	0.474887
Comprehensive (N = 97; Me = 7.6)	x	1.0000	Comprehensive (N = 97; Me = 6.4)	x	0.0028

Source: own study based on unpublished FADN data.

As mentioned before (Figure 1), over the successive years, the fastest drop in energy intensity of production was witnessed in the group which implemented comprehensive investments. In this case, the medians for the initial and final periods were 7.6 and 6.4, respectively (Table 2). A slight decline, from 7.9 to 7.6, was recorded in farms with non-comprehensive investments. In turn, the negative investments group even saw growth in energy intensity of production (from 8.4 to 9.0), ultimately reaching the highest level of all the three groups identified. As a result of these evolutions, the difference in the energy intensities of production between the three farm groups became statistically significant (at the significance level of 0.001) in the final period (2019–2021). The multiple comparison test for all the three groups suggests that energy intensity of production in farms with comprehensive investments significantly differed from what was revealed in other groups (with non-comprehensive or negative investments). Although FADN data does not enable an in-depth interpretation (e.g., of changes in the energy or investment mix), there are grounds for concluding that the purpose of these investments was to support the implementation of state-of-the-art energy-efficient farm technologies. The economic benefits are not the only core, but also the climate–environmental dimension arguments to reduce emissions and waste are now more and more important [111,112]. When it comes to buildings, investments allow the use of techniques that boost their energy performance. The benefits are revealed by improved heat insulation, more efficient ventilation, lighting, heating and cooling systems. As regards machinery (which has a dominant share in the structure of Polish investment expenditure), modern engines consume less fuel and energy, and offer better performance to work energy-efficiently [113]. Also, they enable the implementation of the components of the energy-saving solutions referred to by Pellizzi et al. [114], i.e., changes in cropping systems and intensity of farming efforts, choosing energy-efficient production methods, and launching advanced monitoring of the production process. As the scale of investments grows, so does production, though at a much higher rate, as mentioned by Pimentel [115], indicating that improved technologies result in more effective use of resources, increase food production or lower energy inputs in agriculture can be obtained [116], e.g., by the use of energy efficient technologies in crop and livestock production. This corroborates the conclusions from a study by Nasalski and Juchniewicz [117], namely that through investment farms should ensure that they have the resources to operate in a sustainable manner, without negative environmental and sanitary impacts and with an economical use of energy developed in a pro-efficiency manner at the same time. Also, as indicated by Latruffe [118], productivity improvements can result from a more efficient use of existing technology, technological change or by exploiting economies of scale. Other studies also prove the desirability of public intervention to reduce the cost of energy access for farmers [119]. In the context of this research, this could be investment subsidies in energy-efficient inputs. On-farm innovation is the main reason for improving energy intensity on farms [120].

4. Conclusions

Possible changes in the energy intensity of production in the context of the investment scale at the microeconomic level are an important aspect in making farms more efficient. Indeed, the changing environmental and climate conditions translate into how food is produced. The key to solving the conflict between the need for producing food and the imperative to protect the environment primarily consists of modernizing the agriculture sector and providing it with adequate technical equipment and production techniques. Rationalization of energy management on the farm promotes respect for the environment, and it involves increasing the efficiency of energy inputs by improving the technology of production processes [116]. This study proved that there are relationships between the complexity of investments and changes in the energy intensity of production on farms. It is the basis for further distinguishing subsequent investment complexity groups and proving which of them may have a greater or lesser impact on changes in the energy intensity of production. The main conclusions are as follows:

- As the farms grew, so did the costs of energy consumption.
- This study has proven that, upon reaching a sufficiently large amount of investments, farms may become able to reduce the energy intensity of their production activities (but this will also be influenced by other factors, e.g., the type of agricultural production conducted).
- A decline in energy intensity was recorded in farms which implemented comprehensive investments.
- Conversely, the worst performance was recorded in farms with negative investments, i.e., those which witnessed decapitalization.

Not only they did not improve their energy efficiency levels, but they reported a decline in that respect. A reduction in energy intensity can be driven by higher productivity levels from extended capital assets and by the implementation of state-of-the-art technical and technological solutions which enable the reduction of the consumption of energy necessary to deliver agricultural production. Large-scale investments are the only way to change the production patterns in line with social expectations for environmental care, which in this case means using energy-efficient production methods.

In view of the social expectation for climate-neutral agricultural production processes (including making production less energy-intensive), agricultural policy should support the investment initiatives of farm managers. Findings from this study suggest that support should be granted for investments that are large enough (in relation to the farm's assets) and go beyond the simple renewal of assets. Therefore, in its investment-oriented measures, the agricultural policy should take innovation (including energy efficiency) criterion into account.

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