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Economic Efficiency versus Energy Efficiency of Selected Crops in EU Farms

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Abstract: The goal of farmers operating in a market economy is to maximize profit. In view of the changing political situation, the main social interest, in addition to food security, should be energy security. Here is a refined version of that sentence: This article examines the production efficiency of selected crops grown in the EU and how well their production can ensure both the economic security of the producers, i.e., the farmers, and Europe's energy security. In addition, it aims to determine which costs incurred in the production process have the greatest impact on productivity. The paper uses data obtained from the Cash Crop agricultural benchmarking database, covering 19 crops and 39 cost categories for each crop. The data (averaged for 2019–2021) came from 30 farms located in 11 EU member states. The DEA method and stepwise multiple regression were used. Research has shown that crops are already being grown in Europe that provide high energy efficiency in production without compromising farm performance (including oats, peas, and winter rye). Moreover, improving the involvement of certain inputs results in improved production efficiency (e.g., through spending on agricultural consulting services). In addition, crop economic efficiency, as assessed by profit with and without subsidies, was found to be strongly correlated with production efficiency. This could indicate that subsidies do not play a key role in farm efficiency within the EU. Crop productivity remains a key factor in achieving economic and energy efficiency. The significance of the findings presented in connection with the recent COVID-19 pandemic and the escalation of the armed conflict in Ukraine has led to renewed interest in EU energy security, i.e., generating as much EU energy as possible for food and non-food production.

Keywords: agricultural production efficiency; agricultural resources; economic security of farmers; Europe's energy security; EU agriculture; economics of land use; DEA method; stepwise multiple regression; profit with and without subsidies

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1. Introduction

The demand for energy from agricultural resources has existed since the beginning of mankind and will continue to exist [1]; however, its importance has evolved with the development of human civilization. Initially, obtaining energy from food sources was aimed at meeting basic human needs. However, as civilization progressed and basic needs increased, so did the need for energy to produce non-food goods.

The difference between energy demands is that the energy required to meet basic needs is limited by the size of the population, while the energy required to produce other goods is unlimited [2].

Non-food energy demand was initially met using non-renewable energy sources such as coal and oil. Given the accelerated global warming process and the gradual depletion of non-renewable resources, there is now a growing demand for energy from renewable sources, including agricultural raw materials [3]. As a result, there is now an unlimited demand for energy, which can be met with agricultural raw materials [4]. Agricultural sources can and should be sources of energy for the production of food products and, indirectly, non-food goods.

During the period of the dynamic development of European cooperation, efforts were made to reduce the cost of energy production as much as possible, resulting in increasingly intensive imports of cheaper food and energy raw materials from outside the European Union (EU) [5]. The recent COVID-19 pandemic and the escalation of the armed conflict in Ukraine have led to a renewed interest in the concept of EU energy security, i.e., generating as much energy as possible within the EU to be used for both food and non-food purposes [6]. Therefore, it is necessary to conduct research that will expand our knowledge of the efficiency of agricultural production. In the EU, agricultural production should be evaluated taking into account economic efficiency and other aspects. In the current environment of geopolitical instability, it is equally important to analyze the efficiency of individual inputs (factors of production) based on the amount of energy produced [7,8].

However, it should be remembered that, as a result of recent EU reforms, farmers operating in the EU make decisions on a specialized type of production primarily based on economic calculations. Operating under the principles of a market economy, farmers strive to maximize profits. In addition, they have to deal with numerous environmental challenges introduced by the 2013 reform (see, e.g., [9]). In addition to food security, the public interest should also include energy security [8]. However, this approach is governed by the authorities of the country or the EU, defining the goals of the Common Agricultural Policy (e.g., the Renewable Energy Directive [10]). Of course, EU regulations on agricultural policy, in addition to the economic factor, significantly affect farmers' decisions on the direction and scope of agricultural production.

Regardless of external factors, we must remember that the CAP (Common Agricultural Policy) aims to commercialize production [11,12]. The importance of subsidies to farmers' total income is declining. Farmers are increasingly dependent on food markets. Instruments that support specific production quotas are being replaced by those that support rural development and agriculture in general, forcing farmers to make decisions based mainly on economic analysis of their activities [13]. In this article, efficiency is understood as follows, depending on the data analyzed:

- Economic efficiency is defined as an attempt to maximize profits per hectare (expressed in EUR/ha) at a given input level. Economic efficiency is investigated here, including and excluding subsidies.
- Energy efficiency is defined as an attempt to obtain a maximum amount of energy per hectare (Mcal/ha) at a given input level. In other studies, energy efficiency is most frequently understood as the ratio of obtained energy to energy input [14,15]. The proposed approach is novel, facilitating energy and economic efficiency incorporation within one analysis.
- Economic energy efficiency is determined assuming that the explained variables include the value of generated profit per hectare and the value of energy obtained per hectare at the same time. It is understood as an attempt to maximize the value of profit and energy per hectare at a given input level.

This article therefore aims to examine the production efficiency of selected crops grown in the EU, considering the extent to which this production can ensure both the economic security of producers–farmers and the energy security of Europe. Taking into account the decision-making processes, we hypothesize that it is possible to manage agricultural production to maximize economic and energy efficiency. This raises the question of which crops grown in the EU in recent years meet both the criteria for maximizing economic and energy efficiency. The conditions for maximizing energy efficiency differ from those for maximizing economic efficiency: which of the costs incurred has the greatest impact on each type of efficiency? The recorded results will indicate the direction of future agricultural policy development to guarantee the economic security of producers, i.e., farmers, and the energy security of Europe. This topic is relevant to recent studies conducted at a broader level, using data on individual countries [16] or crops [17]. Such studies are increasingly being published in response to the energy crisis and the outbreak of war in Ukraine [5,6]. The objectives of the study were achieved using non-parametric and parametric quantitative methods. First, the Data Envelopment Analysis (DEA) method was applied to aggregate data. Then, based on the results, stepwise multiple regression was used to assess which cost categories significantly affect the types of efficiency studied. The data collected from the agri benchmark Cash Crop database provided the analysis's starting point. They have the advantage of a uniform methodology across EU countries and a detailed breakdown of costs by type of agricultural production. The relevant indicators published by FAOSTAT [18] were used to determine the energy value of the production of each crop per hectare (pp. 66–79).

The adopted methodology and data description are given in the first two chapters. The subsequent chapters present the results of the analyses conducted based on detailed data from the agri benchmark Cash Crop agricultural accounting in two subchapters: the first concerning economic efficiency, energy efficiency, as well as mixed (economic and energy) efficiency for individual crops, and the second presenting the structure of production costs to attain efficiency.

2. Materials and Methods

2.1. The DEA Method

We initially used the nonparametric DEA method to evaluate economic, energy, and mixed efficiency. This method is widely used in studies comparing the efficiency of agricultural production [13,16,19,20]. The conditions concerning the distribution of the explained variable required in parametric methods did not need to be met. The DEA method provides a solution comprising a series of linear equations, based on which the boundary of maximum technical efficiency is identified [21,22].

The DEA analysis compares the vectors of outcomes–products $\boldsymbol{q_r}$ (outputs; $r = 1, 2, \ldots, R$) and inputs $\boldsymbol{x_n}$ (inputs; $n = 1, 2, \ldots, N$) in all investigated entities ($i = 1, 2, \ldots, I$). Both the values of outputs and inputs must meet the condition that they are greater than zero. The units investigated in the analyses were individual crops in individual farms involved in field crop production in the EU. As a consequence, $I = 123$ such defined study units were collected. Matrices $\boldsymbol{Q}$ and $\boldsymbol{X}$ combine the vectors of products $\boldsymbol{q_r}$ and inputs $\boldsymbol{x_n}$, respectively, for all entities in the study. Matrix $\boldsymbol{Q}$ (depending on whether the adopted study variant variables of profit included subsidies) was expressed in Euro ($R = 2$), and the amount of energy obtained from agricultural production was expressed in Mcal. In turn, the values of individual production costs were grouped in $N = 9$ variables, which formed matrix $\boldsymbol{X}$. The values describing both the outputs and inputs ($\boldsymbol{Q_R}$ and $\boldsymbol{x_n}$) were established and given per ha.

Before the calculations, it was assumed that the production technology adopted on the farms under study would produce variable returns to scale (VRS) and that the efficiency improvements would be to maximize production. With these assumptions, it was possible to solve the program of linear equations [23,24] (p. 163). As a consequence, for each investigated entity, efficiencies θ_i ($i = 1, 2, \ldots, 123$) were determined, which, depending on the selection of variables to matrix Q, were denoted as economic efficiency (based on the value of profit or the value of profit including subsidies), energy efficiency, or mixed efficiency. As this paper later explains, they were labeled as θ(P), θ(PS), θ(E), θ(P&E), and θ(PS&E). However, despite its usefulness, the DEA method is not immune to the correlation of variables. Therefore, it must be preceded by correlation analysis and appropriate identification of the data group under study through clustering or selection. A detailed description of the DEA method can be found in Coelli et al. [24] and Thanassoulis, Portela, and Despić [25].

Regardless of the efficiency type, the value of the efficiency index for the i-th entity is 1 ($\theta_i = 1$), meaning that the i-th entity ran production efficiently compared to all the investigated entities. In turn, if $\theta_i < 1$, it indicates that competitors of the i-th entity would have reached the same volume of production using fewer inputs (on average smaller by $(1-\theta_i)$ %). Thus, such an entity is inefficient.

Based on the determined efficiency values, entities are ranked in order of efficiency, with the most efficient entities ranking first and the least efficient entities ranking lower. The calculations were made using the DEAP program, available non-commercially from the Center for Efficiency and Productivity Analysis, see more: [26,27]. It is worth noting that the study took into account the impact of the EU policy, measured by the amount of subsidies received by the farm, on the economic efficiency of the crops studied. Data on the subsidies per ha of crops for the farms analyzed were made available within the agri benchmark Cash Crop database. For this purpose, to assess the efficiency of individual crops using DEA analysis, the procedure was performed twice: first, considering the profit obtained from the crops without subsidies, and second, considering the profit increased by the value of subsidies per ha for each crop on a given farm.

2.2. Stepwise Regression

The Forward Stepwise Method was applied to determine which detailed costs from the database significantly affected the level of attained economic efficiency, energy efficiency, and mixed efficiency [28,29] (pp. 342–348), [30]. It included all cost categories from the database (38 categories). In addition to the costs, crop yield and sale price variables for produced agricultural produce were incorporated into the model. The choice of this method was dictated by the number of cost categories. It allowed for a multidimensional analysis of all cost categories in a single procedure. This approach takes into account not only the one-dimensional impact of each cost on profit but also the interactions between costs.

The results presented below must be understood as follows: If a given variable was not included in the model or the estimated parameter proved to be nonsignificant, this indicates that the current level of costs had no significant influence on the level of analyzed efficiency. If a given variable proved to be important in the model, this variable's consumption level significantly affected the level of attained efficiency. A negative value of a parameter means that its increase causes a reduction in efficiency, while a positive value indicates that an increase in efficiency occurred together with an increase in consumption of a given factor.

The Statistica program performed all calculations for stepwise regression and basic descriptive statistics.

3. Data

The data used in this study come from the agri benchmark Cash Crop database. This database is available for project participants; otherwise, it is provided commercially [31]. The agri benchmark network is a global platform for agricultural economists, advisers, and producers. Its primary aim is to exchange expertise based on reliable information related to production technologies, farm organizations, and framework conditions, under which these farms operate, and their prospects for development [32] (p. 7). The advantage of this database is that detailed financial information and information concerning production technologies are collected directly from farms.

Such precise financial data are not included in other databases on agriculture, such as FADN or EUROSTAT, which are often used in the literature (see, e.g., [9]). The authors also used these databases on several occasions (see, e.g., [13,33]). Despite their numerous advantages, FADN or EUROSTAT data do not allow for a detailed analysis of the production costs of growing a specific plant.

The FADN Public Database provides detailed financial data on field crops but per 1 farm (EUR/1 farm). Within the FADN, it is possible to define the specialization of this farm, e.g., Specialist COP (specialist cereals, oilseed, and protein crops), however it is not possible to obtain separate data for the cultivation of a specific plant, e.g., it is not possible to obtain data on the sowing costs for 1 ha of winter wheat (EUR/1 ha). Such precise data are available within the agri benchmark Cash Crop database.

For this reason, the authors have used comparative agricultural data in this article. By using these data, it is possible to compare the cost of cultivation, cultivation technologies, crop yields, and the financial results obtained for the production of a specific crop grown in different regions of the world.

In its benchmarking analyses, the agri benchmark platform uses data from typical farms, which is an actual farm or a set of characteristics describing a farm located in a specific region, having a significant share in the production of investigated products, applying a production system characteristic to a given product and being a combination of land, capital resources, and an appropriate labor organization system.

To ensure the best possible representativeness of farms, typical farms were selected in cooperation with researchers and advisers from a given region or country, i.e., individuals who know the parameters required to characterize such a farm. As was mentioned above, a typical farm is selected from a region of importance for the production of a given raw material, e.g., wheat or rape. This region is identified based on available statistical data, with the typical farm selected based on certain parameters which include the following: the level of revenue, the production system, farm size, and management method. Typical farms may be those in which over 50% of revenue comes from the farm or can support only one family member. The production system adopted is characteristic of a given farming region. A typical farm is also of average size for a given region or is a large one. Such a farm is characterized by having medium or high management standards [34] (pp. 2–14).

Agri benchmark data are commercially available by contacting them via the following website: http://www.agribenchmark.org/home.html (accessed on 20 May 2024).

The study presented here used data from the agri benchmark Cash Crop database on farms engaged in crop production in the EU. The study included those crops that were grown on the farm at least twice in the last three years. The analyses comprised multi-annual means (min. 2-year average) from 2019 to 2021.

The agri benchmark database contains 39 cost categories for the crops grown on a given farm. The categories of these variables are presented graphically in Figure 1. A detailed list of cost variables is included in Appendix A. All of them were used in the article. The isolation of those that turned out to be crucial for the efficiency of a given crop was made using stepwise regression.

Overall, the study covered 30 farms growing 19 crops jointly. Each farm grew from three to seven crops. These farms are located in Bulgaria (1), the Czech Republic (3), Germany (7), Denmark (2), Spain (3), France (3), Hungary (4), Italy (1), Poland (3), Sweden (2), and Lithuania (1). The DEA analysis comprised 123 objects, i.e., crops grown in the investigated farms. Each of the objects was described using 39 cost categories. Each crop's energy produced per hectare was also determined for each plant. For this purpose, indexes published by the FAO were used [18] (pp. 66–79). As mentioned above, the DEA method is not immune to high correlations of variables describing individual facilities. Therefore, it was not possible to incorporate all cost categories into the evaluation of energy and economic efficiency. Thirty-nine costs were grouped by applying the division adopted in the agri benchmark nomenclature (compare Figure 1). A total of nine groups of costs were considered: establishment costs (EC), other direct costs (ODC), total labor costs (TLC), contractor costs (CC), machinery costs (MC), fuel costs (FC), building costs (BC), land costs (LC), and miscellaneous costs (MiC).

Table 1 presents the values of correlations between individual groups of costs. Their value did not exceed 0.7. Thus, such cost groupings meet the formal requirements for applying the DEA method. In the second stage of the study, consisting of stepwise regression, the data concerning all 39 available cost categories were included. In addition, due to the requirements of the DEA method (the values of the variables must be >0), the profit outcome variables were rescaled by adding to each the value of the largest loss recorded in the group of entities studied.

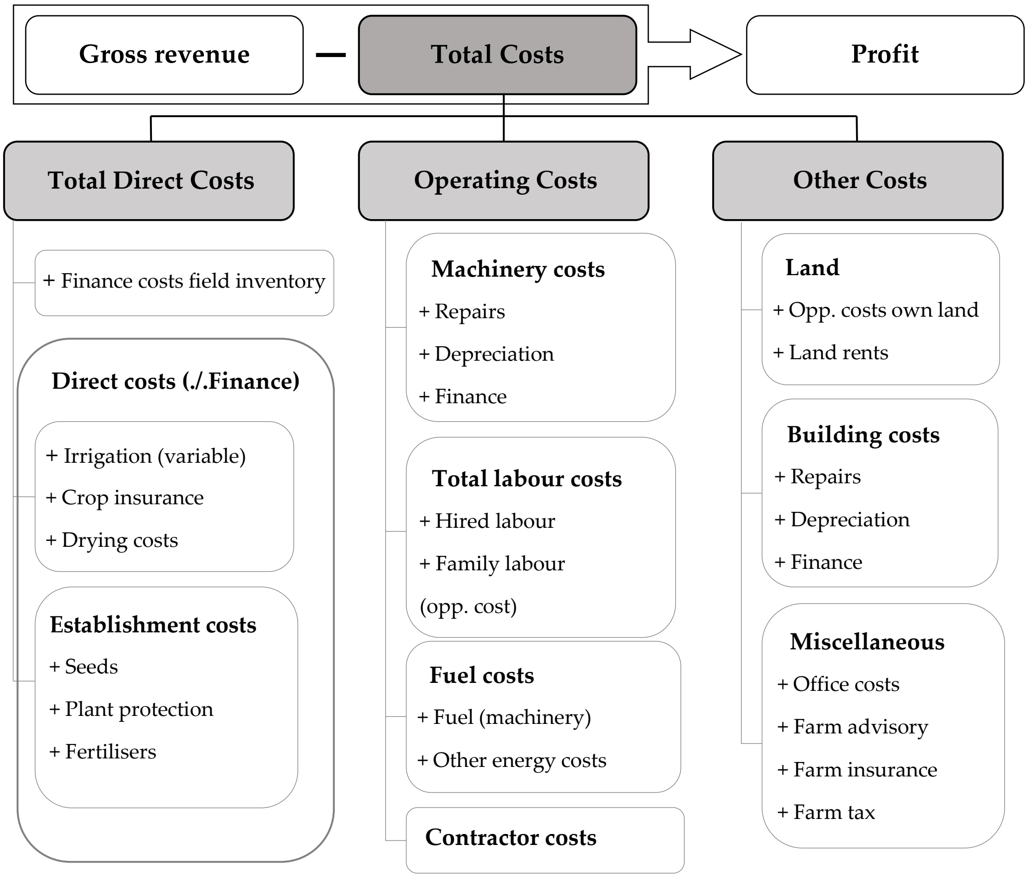

Figure 1. Cost classification for crops adopted in the agri benchmark database. http://www.agribenchmark.org/cash-crop/publications-and-rojects0/methodology.html (accessed on 23 May 2024).

Table 1. Correlations between aggregated inputs.

Var.	Mean	Stand. Dev.	Correlation Coefficients								
			EC	ODC	TLC	CC	MC	FC	BC	LC	MiC
EC	453.11	263.08	1.00	0.58 *	0.57 *	0.50 *	0.55 *	0.53 *	0.52 *	0.21 *	0.47 *
ODC	66.91	179.46	0.58 *	1.00	0.36 *	0.47 *	0.33 *	0.09	0.21 *	0.17	0.31 *
TLC	210.05	126.86	0.57 *	0.36 *	1.00	0.14	0.68 *	0.32 *	0.53 *	0.34 *	0.49 *
CC	74.05	114.23	0.50 *	0.47 *	0.14	1.00	0.10	−0.05	0.28 *	0.23 *	0.32 *
MC	258.71	158.10	0.55 *	0.33 *	0.68 *	0.10	1.00	0.40 *	0.36 *	0.14	0.51 *
FC	93.01	46.60	0.53 *	0.09	0.32 *	−0.05	0.40 *	1.00	0.47 *	0.00	0.17
BC	48.11	46.03	0.52 *	0.21 *	0.53 *	0.28 *	0.36 *	0.47 *	1.00	0.38 *	0.48 *
LC	322.07	188.50	0.21 *	0.17	0.34 *	0.23 *	0.14	0.00	0.38 *	1.00	0.26 *
MiC	66.78	50.32	0.47 *	0.31 *	0.49 *	0.32 *	0.51 *	0.17	0.48 *	0.26 *	1.00

* Establishment costs (EC), other direct costs (ODC), total labor costs (TLC), contractor costs (CC), machinery costs (MC), fuel costs (FC), building costs (BC), land costs (LC), and miscellaneous costs (MiC). Source: the author's elaboration is based on agri benchmark data [31]. Results marked by one asterisk correspond to determined correlation coefficients that are significant with $p < 0.05$, $N = 123$.

4. Results

4.1. Economic Efficiency, Energy Efficiency, and Mixed Efficiency

First, economic, energy, and mixed (economic–energy) efficiencies were determined for each location analyzed. To verify which cost categories have the greatest impact on the obtained yields of each crop, the correlation coefficients between the values of each group of inputs and the obtained yields were determined.

Economic efficiency, determined by the level of revenue without subsidies, was strongly correlated with economic efficiency based on revenue with subsidies included. Therefore, it can be concluded that the subsidy system used does not have a significant impact on economic efficiency. Labor costs (TLC) and land costs (LC) had the greatest impact on the level of economic efficiency achieved. A relatively strong impact was also observed for machinery costs (MC) and miscellaneous costs (MiC).

An efficiency analysis based on the amount of produced energy per hectare at a specific level of inputs indicates that it is not significantly associated with the financial result obtained from growing crops. This supports the assumption that energy security is affected differently by crop inputs than when analyzing farmers' economic security.

For this reason, economic and energy security is a derivative of these two models. This is confirmed by the correlation analysis presented in Table 2, which shows the highest correlation between economic efficiency calculated without subsidies (θ(P)) and with subsidies (θ(PS)). Mixed economic and energy efficiency (θ(P&E) and θ(PS&E)) was positively correlated both with economic efficiency (r = 0.610) and energy efficiency (r = 0.870), which may indicate that the model of double efficiency relatively uniformly reflects the economic interest of farmers and the energy security of a given region.

Table 2. Correlation coefficients between values of individual input groups and attained economic and energy efficiency.

Categories	**θ(P)**	**θ(PS)**	**θ(E)**	**θ(P&E)**	**θ(PS&E)**
Profit (P)	0.585	0.589	0.072	0.367	0.373
Profit + subsidies (PS)	0.535	0.560	0.031	0.345	0.357
Energy (E)	−0.342	−0.302	0.320	0.253	0.248
EC	−0.221	−0.203	−0.216	−0.101	−0.101
ODC	−0.123	−0.122	−0.130	−0.102	−0.096
TLC	−0.566	−0.549	−0.266	−0.325	−0.330
CC	−0.191	−0.154	−0.117	−0.115	−0.093
MC	−0.411	−0.399	−0.247	−0.225	−0.222
FC	−0.081	−0.092	−0.165	−0.054	−0.063
BC	−0.391	−0.356	−0.207	−0.210	−0.208
LC	−0.557	−0.525	−0.136	−0.225	−0.214
MiC	−0.421	−0.375	−0.287	−0.227	−0.204
θ(P)	1.000	0.989	0.404	0.605	0.610
θ(PS)	0.989	1.000	0.403	0.610	0.621
θ(E)	0.404	0.403	1.000	0.870	0.854
θ(P&E)	0.605	0.610	0.870	1.000	0.996
θ(PS&E)	0.610	0.621	0.854	0.996	1.000

Next, for each analysis of efficiency, the ranking of the 123 objects included in the DEA analysis was established. Then, the mean efficiencies and the mean ranking positions were determined for the 19 crops. The results of this comparison are given in Table 3. Due to the method adopted, efficiency may be compared only vertically, not horizontally. Thus, comparisons of efficiency for individual crops are more reliable when based on the mean ranking position of a given crop.

The ranking results presented in Table 3 confirmed the conclusion that the strongest correlation between economic efficiency was calculated excluding subsidies (θ(P)) and with subsidies (θ(PS)). The differences in rankings in these two categories are found only in the case of legumes (fresh peas, fava beans, soya beans) and root crops (potato, sugar beet), as well as spelled, which are granted special production subsidies [35]. At the s, same time, their average ranking position improved. Hence, we will refer only to the results concerning profit with subsidies (θ(PS)) related to production.

Table 3. Mean levels of analyzed efficiencies and ranking positions depending on the species of field-grown crops.

Grown Crops	**Number of Farms** [1]	**Mean DEA Efficiencies**				**Mean Ranking Positions**			
		θ(P)	**θ(PS)**	**θ(E)**	**θ(PS&E)**	**θ(P)**	**θ(PS)**	**θ(E)**	**θ(PS&E)**
oats	1	1	1	1	1	1	1	1	1
peas	4	1	1	1	1	1	1	1	1
winter rye	1	1	1	1	1	1	1	1	1
sunflower	7	0.96	0.96	0.92	0.97	10	11	18	15
soybeans	7	0.85	0.88	0.69	0.89	33	31	79	46
spelt	1	0.85	0.91	0.82	0.93	59	55	87	92
corn	13	0.82	0.81	0.99	0.99	44	46	13	14
fava beans	3	0.81	0.83	0.96	0.96	35	32	28	32
chickpeas	2	0.78	0.79	0.62	0.79	44	43	62	59
winter barley	11	0.77	0.78	0.97	0.97	37	37	10	11
winter wheat	27	0.75	0.75	0.95	0.95	54	54	28	31
potato	4	0.67	0.68	0.64	0.84	55	54	104	56
winter rapeseed	18	0.65	0.65	0.67	0.76	67	68	88	82
durum	3	0.64	0.62	0.68	0.74	62	64	99	75
winter triticale	3	0.59	0.57	0.82	0.82	68	71	62	69
summer wheat	1	0.58	0.46	0.99	0.99	85	99	73	79
sugar beet	11	0.48	0.54	0.99	0.99	93	90	8	9
fresh peas	1	0.47	0.57	0.13	0.57	97	86	123	122
summer barley	5	0.46	0.46	0.90	0.90	96	97	52	58
Number of pairs (θi = 1)		48	48	72	78	48	48	72	78
min		0.001	0.001	0.132	0.422	1.000	1.000	1.000	1.000
mean		0.729	0.735	0.871	0.913	52.821	52.805	41.203	37.577
max		1	1	1	1	123	123	123	123

[1] Number of farms growing a given crop. The authors' calculations are based on DEA results and raw data from the agri benchmark database [31].

Oats, peas, and winter rye proved to be most efficient regardless of the efficiency type (mean ranking position *p* = 1). In terms of economic efficiency with subsidies (θ(PS)), the lowest-ranked positions were held by summer wheat (*p* = 99), summer barley (*p* = 97), and sugar beet (*p* = 90). The most expensive crops in terms of obtained energy at a specific level of inputs included fresh peas (*p* = 123), potato (*p* = 104), and durum (*p* = 99).

In terms of mixed efficiency (*θ*(PS&E)), fresh peas (*p* = 122), spelled (*p* = 92), and winter rapeseed (*p* = 82) were in the lowest-ranked positions.

4.2. The Structure of Production Costs and Attained Efficiencies

The last point of the analysis is to show how the structure of costs for the most efficient crops differs from that of the least efficient in terms of economic, energy, and mixed efficiency.

The forward stepwise regression was applied to determine which specific costs from the database significantly affect the level of each efficiency as mentioned above. All cost categories from the database (39 categories) were considered. In addition to these costs, variables such as the yields and selling prices of agricultural products were included in the model.

Apart from the inputs incurred, economic efficiency is influenced by production costs and the value of production, which in turn is a product of crop yield and price. Energy efficiency is affected by costs and crop yield only (the energy value of the crop yield).

This dependence was confirmed by the results of the stepwise regression presented in Table 4. The effect of price levels in the case of agricultural products proved to be significant only in the case of economic efficiency, while crop yield was substantial in all three analyzed efficiencies.

Table 4. Values of linear coefficients obtained from forward stepwise regression [1].

Explained Variable	**θ(PS)**	**θ(E)**	**θ(PS&E)**
R^2	0.7772	0.7049	0.6589
Explanatory variables	b_n	b_n	b_n
Absolute term	1.052546 *	1.108250 *	1.050565 *
BC_Building depreciation		−0.000454	
BC_Building finance debt	−0.009917		−0.008200
BC_Building finance equity	0.009178		−0.007763 *
Crop price	0.000658 *	−0.000090	0.000141
Crop yield	0.039470 *	0.054857 *	0.046495 *
DC_Crop Insurance net cost		−0.003423 *	−0.001787
DC_Dry energy cost	−0.001460 *		
DC_Finance cost debt field inventory		−0.014362 *	−0.008890 *
DC_Fungicides		−0.000526	−0.000306
DC_Herbicides		0.000819 *	0.000659 *
DC_Irrigation cost (var.)	0.000903 *		0.000450
DC_Lime	−0.001365		
DC_Nitrogen	−0.000777	−0.000557	−0.000781 *
DC_Other direct costs	−0.003473 *	−0.000362 *	−0.000382 *
DC_Other fertilizer costs	−0.003281 *	−0.001168	−0.001079
DC_Phosphorus	0.001210		
DC_Potash	−0.001719 *	0.001893 *	0.000775
DC_Seeds	−0.000535	−0.001271 *	−0.000929 *
LC_Land cost	−0.000381 *	−0.000225 *	−0.000175 *
LC_Land improvement	−0.007769 *		
MC_Farm accounting cost	−0.007461 *	0.008664 *	0.004722 *
MC_Farm advisory cost	0.014145 *	−0.014721 *	
MC_Farm insurance (related to activities)	−0.005514	−0.006588 *	−0.005666 *
MC_Farm insurance (related to inventory)		−0.002744 *	−0.002103 *
MC_Farm office cost		−0.000774	
MC_Farm tax (related to inventory)	−0.001768 *	−0.000525	
MC_Other farm costs	−0.001492		
OC_Machinery finance equity	−0.006388 *	−0.003686 *	−0.001738
OC_Machinery repairs		−0.000147	
OC_Contractor	−0.000155	−0.000593 *	−0.000467 *
OC_Family labor	−0.001928 *	−0.000537 *	−0.000882 *
OC_Hired labor	−0.001092 *	−0.000554 *	−0.000693 *
OC_Machinery depreciation cost	0.000678		
OC_Other energy costs		−0.001561	−0.000383

[1] The authors' calculations are based on forward stepwise regression results and raw data from the agri benchmark database [31]. * Results marked by one asterisk correspond to their significance based on the level used α = 0.05.

Based on the results of stepwise regression, it may be stated that labor costs (both of own and hired labor) and land costs negatively affected the level of each of the analyzed efficiencies. The costs of grain drying and land improvement only harm economic efficiency.

We need to focus on direct costs, whose parameter values are positive, e.g., irrigation costs (positively correlated with economic efficiency). This means that water limits the full utilization of incurred inputs. In contrast, herbicides and potassium fertilizers correlate positively with energy efficiency, while herbicides were correlated only with mixed economic and energy efficiency. Higher levels of potassium fertilization and higher herbicide treatments improve this efficiency.

A positive effect on the level of economic efficiency is also found for the costs of advisory services. The higher the inputs on the farm advisory services, the greater the economic efficiency. In addition, cost categories such as building depreciation and repair costs, fuel costs, and machinery depreciation and repair costs were not among the costs that significantly affect productivity. Input costs, i.e., factors of production, also play an important role.

Other direct costs (e.g., potato sorting and grading, transport and cleaning of sugar beets) proved to significantly influence all efficiency categories, which, again, shows that the level of these inputs should not be neglected.

5. Discussion

Farms equipped with basic factors of production (fixed costs) may realize various production goals. In the decision-making processes, economic factors are usually decisive [36,37]. However, after economic security for farmers, energy security is next of importance to society (including farmers themselves) [8]. The European Union, through the introduction of directives (see, e.g., [10]), supports the demand for specific agricultural raw materials (e.g., the share of bio components in liquid fuels), thereby influencing the market price increase of these raw materials. This, in turn, improves the profitability of specific crops from the perspective of individual farmers' decisions. This is one of the explanations why, in the analysis, profits from plant cultivation without subsidies were strongly correlated with overall profits without subsidies.

This dependence is presented in the following diagram (Figure 2).

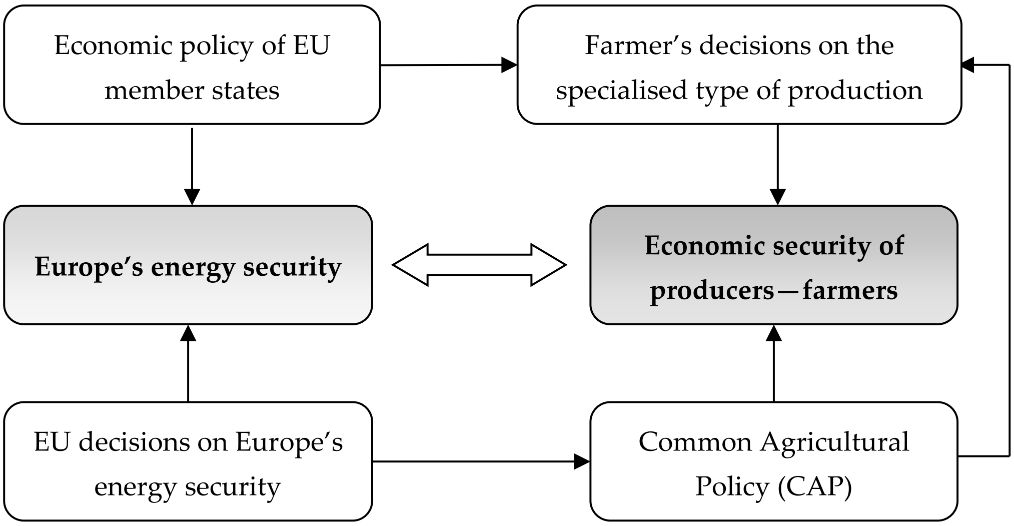

Figure 2. Economic efficiency and energy efficiency in present-day Europe.

The research indicates that crop yields are a significant factor influencing both economic and energy efficiency. This finding aligns with the recommendations in the publication [17], which focuses only on wheat cultivation. It suggests that, given the current political and energy crises, decision-makers should prioritize improving crop quality to enhance domestic production.

The analysis finds that certain crops guarantee both the above-mentioned security criteria. The most efficient crops in terms of economic and energy efficiency are those considered niche crops, given their cropped area, i.e., oats, peas, and winter rye. These results confirm the theses of other researchers formulated at a more general level [38]. Other conclusions can be found in publications on Czech agriculture. A comparison of the economic and energy efficiency of three crops—winter wheat, spring barley, and mustard—taking into account soil tillage systems is presented in publications [39] and [40]. The results show that winter wheat cultivated using a minimum tillage system exhibited the highest economic and energy efficiency.

The high efficiency of niche crops can be explained by the fact that their production technology is extensive, with a limited number of cultivation and tillage operations, resulting in relatively low labor intensity and machine use [32]. Furthermore, farms growing these crops could maintain an adequate combination of inputs to reach desirable effects, which proved to be the most efficient. Moreover, these crops are grown on relatively large farms, meaning they may rationally utilize labor resources and machinery. In smaller farms, particularly family farms, where resources per ha are much greater, this is more difficult to attain [33,41].

The analyses also identified the crops providing high energy efficiency, exceeding economic efficiency, including sugar beets, maize, and winter barley. This indicates that under the current economic conditions, they are not adequately valued by the market. However, when needing to meet energy demands for the production of non-food goods, these crops may constitute an efficient energy source for the local populations [15,42]. Market failure may occur because it does not broadly consider the public interest. For this reason, it is important to create a rational policy supporting the cultivation of such crops, whose production effectively combines the goals and interests of both producers and the general population.

The study also showed that some crops, whose cultivation area accounts for a significant share of the crop structure, were relatively inefficient, both economically and in terms of energy. An example is winter rapeseed [43]. Winter rapeseed fails to attain a satisfactory level of both, the productivity studied (its cultivation technology is simply relatively expensive) although its substitutes can be found in some countries (e.g., sunflower). Rapeseed continues to have a considerable share in the crop structure of farms [44]. Such a situation may be an example of a centrally controlled targeted demand for selected agricultural raw materials. Despite the lack of significant economic or energy efficiency, considerable amounts of rapeseed are used as a bio component for the production of biofuels [45]. Given the above, further studies are required to investigate the potential improvement of crop efficiency, for which demand is controlled and regulated by political decisions.

The study also included an analysis of the productive cost structure of the crops studied to identify the key factors affecting the productivity achieved. This analysis focused on those cost categories whose increases resulted in improved productivity. Economic efficiency improves by increasing irrigation inputs, while energy efficiency improves by increasing herbicide and potassium fertilizer inputs. Attempts to increase yields by increasing potassium fertilizer rates boost energy efficiency, however, they can also reduce economic efficiency.

The literature contains descriptions of other studies on the impact of individual production costs on production efficiency. Although, these studies were conducted for wheat grown in specific countries: the USA [46], Australia [47], and Canada [48]. In the United States, the efficiency of wheat cultivation was significantly influenced by the cultivation method, farm size, and the use of insecticides. Moreover, research on wheat cultivation in the United States and Canada revealed that the best farms and their cost structures should serve as a benchmark for less efficient farms. The authors have highlighted the necessity of knowledge transfer—similar to our research, effective farm advisory services are crucial [46,48]. Despite the narrow scope of the study, the findings of the positive impact of the knowledge of top management staff [48] and the costs associated with agricultural consulting services have significantly improved the efficiency of agricultural production.

Finally, it is important to acknowledge the role of other direct costs in the cost structure. As shown by the analysis, these costs significantly affect the level of attained production efficiency [49]. Additionally, costs having no significant effect on efficiency included such categories as building depreciation and repair costs, fuel costs, and machinery depreciation and repair costs. However, this does not mean that these costs were low; rather, it indicates that they need to be treated as fixed costs, incurred regardless of the volume or type of production. As shown in other studies, they result from the specific character of agricultural production in Europe [49–51]. For comparison, in Australia, the important factor in improving the efficiency of wheat cultivation is high machinery investment per ha [47], and not the cost of maintaining this equipment.

Based on the research conducted, possible limitations of the DEA method as well as the Forward Stepwise Method can also be identified. Future studies using the same data can use one extension of the DEA method (see [52] for more details). Instead of the detailed stepwise method, other multidimensional techniques such as decision trees or principal component analysis may be used. This suggests new areas of research that should be explored in the future.

6. Conclusions

The analyses showed that up until now, there has been no strong relationship between economic efficiency and energy efficiency. Thus, the recommendations suggesting how to attain economic and energy security were based on a model to uniformly combine the interests of farmers (economic efficiency) and the general population (energy efficiency).

These analyses showed that, despite the low correlation between energy and economic efficiencies attained by the investigated farms, these crops are now being grown, combining the above-mentioned goals. Maximizing economic and energy efficiencies is met by the production technology of such crops as oats, peas, and winter rye. The conclusion indicates that currently, some technological solutions provide high energy efficiency without harming the financial performance of farms.

Economic efficiency assessed based on earned profit excluding subsidies was found to be strongly correlated with efficiency based on earned profit including subsidies. This means that subsidies do not play a key role in EU farm efficiency. It was also shown that crop yield is a key factor in attaining economic efficiency and energy efficiency; in the case of economic efficiency, a significant role is also played by the market price for the products.

This study also showed that improved involvement of certain inputs, resulting in increased production, also leads to improved efficiency; increased inputs on irrigation or farm advisory services improve economic efficiency, whereas increased inputs on potassium fertilization improve both economic and energy efficiency.

The positive effect of inputs on farm advisory services on economic efficiency indicates that, despite progress on automation and technical change in agriculture, specialist knowledge continues to be a factor in enhancing production efficiency, providing an optimal combination of factors of production for specific farming conditions.

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Appendix A. List of Cost Variables from Agri Benchmark Cash Crop Database

Categories of Variables	Cost Variables (EUR/1 ha)
Direct costs	DC_Seeds; DC_Nitrogen; DC_Phosphorus; DC_Potash; DC_Lime; DC_Other fertilizer cost; DC_Herbicides; DC_Fungicides; DC_Insecticides; DC_Other pesticides; DC_Dry energy cost; DC_Irrigation cost (var.); DC_Crop Insurance net cost; DC_Other di-rect cost; DC_Finance cost equity field inventory; DC_Finance cost debt field inventory
Operating costs	OC_Hired labor; OC_Family labor; OC_Contractor; OC_machinery depreciation cost; OC_machinery finance equity; OC_machinery finance debt; OC_machinery repairs; OC_Diesel; OC_Other energy cost
Building costs	BC_buildings depreciation; BC_Buildings finance equity; BC_Buildings finance debt; BC_buildings repairs
Land	LC_land cost; LC_land improvement
Miscellaneous	MC_Overhead water cost; MC_Farm tax (related to inventory); MC_Farm insurance (related to inventory); MC_Farm insurance (re-lated to activities); MC_Farm advisory cost; MC_Farm accounting cost; MC_Farm office cost; MC_Other farm cost

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