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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 maximise profit. In the face of the changing political situation, the main social interest, besides food security, should be energy security. This article aims to indicate the direction of agricultural policy development so that it guarantees both the economic security of producers—farmers—and Europe's energy security. The work uses data obtained from the agri benchmark Cash Crop database. DEA method and stepwise multiple regression were used. The research showed that plants are already grown in Europe which will ensure high energy efficiency of production without compromising farm financial results (including oats, peas and winter rye) and that improving the involvement of certain inputs results in improved production efficiency (among others, by expenditure on agricultural advisory services). The significance of the presented research results from the fact that the recent COVID pandemic and escalation of the military conflict in Ukraine have led to a renewed interest in the concept of EU energy security, i.e. generation of generating the greatest possible amount of energy within the EU, to be used both for food and non-food purposes.

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1. Introduction

Energy demands from agricultural raw materials have existed since the beginning of humankind and will continue to do so [1]; however, their importance has evolved as human civilisation has developed. Initial energy acquisition from food sources aimed at meeting basic human needs. With the progress of civilisation and increased basic needs, the energy demands required to produce non-food goods have also grown The difference between energy demands lies in the fact that the energy demands to meet basic needs is limited by population size, whereas the energy demands to produce other goods are unlimited [2].

Non-food energy demands were first satisfied using nonrenewable sources, such as coal or oil. Given the accelerated global warming process and the gradual depletion of nonrenewable resources, there is now a growing demand for energy from renewable sources, including agricultural raw materials [3]. As a result, there is currently an unlimited demand for energy, which may be met using agricultural raw materials [4]. Agricultural sources may and should be energy sources for producing food products and – indirectly – non-food goods.

In the period of the dynamic development of European cooperation, attempts were made to maximally reduce the costs of energy production, which resulted in increasingly intensive importing of cheaper food and energy raw materials from outside the European Union (EU) [5]. The recent COVID pandemic and escalation of the military conflict in Ukraine have led to a renewed interest in the concept of EU energy security, i.e. generating the greatest possible amount of energy within the EU to be used both for food and non-food purposes [6]. Thus, conducting studies that broaden our understanding of agricultural production efficiency is necessary. In the EU, agricultural production

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should be evaluated considering economic efficiency and other aspects. In the current environment of geopolitical instability, it is equally important to analyse the efficiency of individual inputs (factors of production) based on the amount of generated energy [7,8].

However, it must be remembered that, as a consequence of the latest EU reforms, farmers operating within the EU make decisions on the specialised type of production primarily based on economic calculations. When operating based on market economy principles, farmers aim to maximise profits. Next to food security, the public interest should also include energy security [8]. However, this approach is regulated by the authorities of a given country or the EU, determining goals of the common agricultural policy.

Regardless of the external factors, we need to remember that the CAP (Common Agricultural Policy) aims to commercialise production [9,10]. The importance of subsidies to the total revenue of farmers is decreasing. Farmers are increasingly dependent on food markets. Instruments supporting specific production quotas are being replaced with those that support rural development and agriculture in general, forcing farmers to make decisions mainly based on an economic analysis of their operations [11].

In this paper, efficiency is understood depending on the analysed data in the following ways:

-economic efficiency, defined as an attempt to maximise profits per hectare (expressed in Euro/ha) at a given input level. Economic efficiency is investigated here, including and excluding subsidies.

-energy efficiency, 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 [12,13]. The proposed approach is novel, facilitating energy and economic efficiency incorporation within one analysis.

- economic energy efficiency, which 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 maximise the value of profit and energy per hectare at a given input level.

This article aims, therefore, to indicate in what direction agricultural policy should be developed to guarantee both the economic security of producers—farmers—and the energy security of Europe. Given the decision-making processes presented in the diagram, we hypothesise that it is feasible to manage agricultural production to maximise economic and energy efficiency.

Thus, a question arises as to which crops grown in the EU in recent years meet both the criteria of maximising economic and energy efficiency. The conditions to maximise energy efficiency differ from those to maximise economic efficiency: which of the incurred costs has the greatest effect on individual types of efficiency?

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.

The aims of the study were realised using nonparametric and parametric quantitative methods. First the Data Envelopment Analysis (DEA) method was applied for aggregated data. Next, based on the results obtained, stepwise multiple regression was used to assess which cost categories significantly affect the investigated types of efficiencies. The data collected from the agri benchmark Cash Crop database provided the analysis's starting point. Their advantage lies in the uniform methodology for individual EU countries and a detailed division of costs into individual types of agricultural production. To determine the energy value for the production of individual crops per 1 ha, the respective indexes published by FAOSTAT were applied [14] (pp. 66–79].

The adopted methodology and data description are given in the first two chapters. The following chapters present 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 and mixed (economic and energy) efficiency for individual crops, and the second presenting the structure of production costs to attain efficiency.

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2. Materials and Methods

2.1. The DEA Method

We applied the nonparametric DEA method to determine economic, energy and mixed efficiency. 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 [15,16].

The DEA analysis compares vectors of outcomes - products $\mathbf{q}_r$ (outputs; r = 1, 2, …, R) and inputs $\mathbf{x}_n$ (inputs; n = 1, 2, …, N) in all investigated entities (i = 1, 2, …, 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 **Q** and **X** combine vectors of products qr and inputs xn, respectively, for all entities in the study. Matrix **Q** (depending on whether the adopted study variant variables of profit included subsidies) was expressed in Euro (R = 2), respectively, 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 **X**. The values describing both the outputs and inputs (q_r and x_n) were established and given per 1 ha.

Before calculations, it was assumed that production technology adopted in the investigated farms would bring variable returns to scale (VRS) and that efficiency improvements would consist of output maximisation. With these assumptions, it was possible to solve the programme of linear equations [17,18] (p. 163). As a consequence, for each investigated entity, efficiencies θ_i (i = 1, 2, …, 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 labelled as θ(P), θ(PS), θ(E), θ(P&E) and θ(PS&E). However, despite its usefulness, the DEA method is not resistant to correlation of variables. Thus, it needs to be preceded by correlation analysis and the resulting adequate identification of the group of study data through clustering or selection. A detailed description of the DEA method may be found in Coelli et al. [18] and Thanassoulis, Portela and Despić [19].

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, the entities are ranked by efficiency, with the most efficient entities ranked first and the less efficient entities in lower positions. The calculations were made using the DEAP programme, available noncommercially from the Centre for Efficiency and Productivity Analysis see more: [20,21].

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 [22,23] (pp. 342–348). 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 in the model.

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 analysed efficiency. If a given variable proved to be significant 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 of efficiency, while a positive value indicates that an increase in efficiency occurred together with an increase in consumption of a given factor.

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The Statistica programme conducted all the calculations concerning 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 [24]. 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 organisation and framework conditions, under which these farms operate and their prospects for development [25] (p. 7). The advantage of this database is that detailed financial information and information concerning production technologies are collected directly from farms. Thus, using these data, the costs of crop cultivation, cultivation technologies, crop efficiency, and the obtained financial results may be compared for the production of a specific crop grown in different world regions.

In their comparative 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 labour organisation 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 characterise 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 is based on the following parameters: 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 characterised by having medium or high management standards [26] (pp. 2–14).

The presented study used data from the agri benchmark Cash Crop database concerning farms involved in crop production in the EU. The investigations included these crops grown on a given farm at least twice in the last three years. The analyses comprised multiannual means (min. 2-year means) from 2019 to 2021.

Overall, the study covered 30 farms growing 19 crops jointly. Each farm grew from three to seven crops. 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 FAO were applied [14] (pp. 66–79).

As mentioned above, the DEA method is not resistant to high correlations of variables describing individual objects. Consequently, it was not possible to introduce all cost categories to assess energy and economic efficiency. Thirty-nine costs were grouped 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 labour costs (TLC), contractor costs (CC), machinery costs (MC), fuel costs (FC), building costs (BC), land costs (LC) and miscellaneous costs (MiC).

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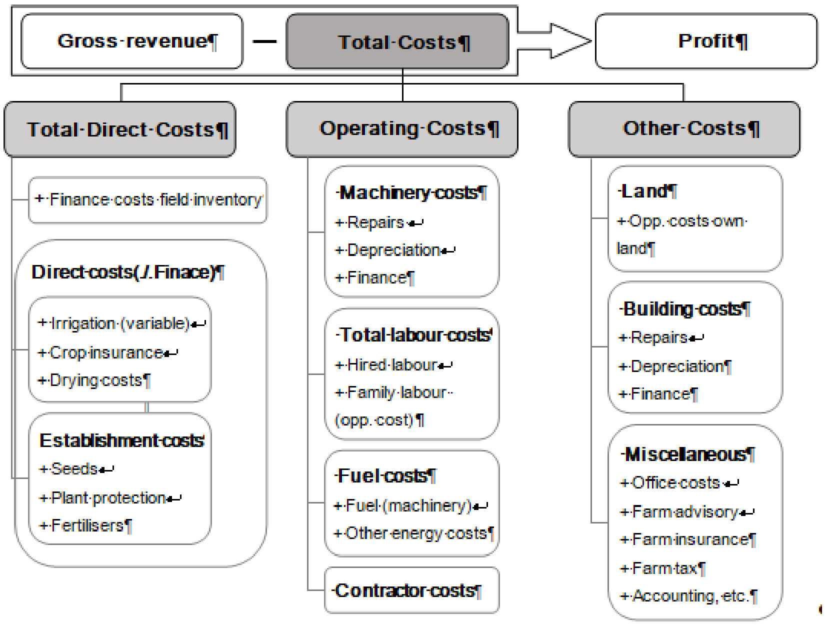

Figure 1. Cost classification for crops adopted in the agri benchmark database. http://www.agribenchmark.org/cash-crop/publications-and-rojects0/methodology.html.

Table 1 presents the values of correlations between individual groups of costs. Their value did not exceed 0.7. Thus, such cost groupings meet 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. Moreover, due to the requirements of the DEA method (values of variables have to be >0), outcome variables concerning profits were scaled, adding the value of the greatest loss recorded in the group of investigated entities to each of them.

Table 1.

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

* Source: the authors' elaboration based on agri benchmark data [24]. Results marked by one asterisk correspond to determined correlation coefficients 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 and energy) efficiencies were determined for each analysed object. To verify which cost categories have the greatest effect on obtained efficiencies of individual crops, correlation coefficients were determined between the values of individual groups of inputs and attained efficiencies.

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Economic efficiency, determined based on the level of revenue without subsidies, was strongly correlated with economic efficiency based on revenue including subsidies. Thus, it may be concluded that the system of subsidies applied has no significant effect on economic efficiency. The greatest effect on the level of attained economic efficiency was recorded for labour costs (TLC) and land costs (LC). A relatively strong effect was also observed in the case of 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 confirms the assumption that energy security is influenced differently by outlays incurred in crop farming than in farmers' economic security analysis.

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 position 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.

Table 3. Mean levels of analysed 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

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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 [24].

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 [27]. At the same time, their average ranking position improved. Thus, we will refer only to the results concerning profit with subsidies (θ(PS)) related to production.

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

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affect the level of each efficiency as mentioned above. All cost categories from the database (39 categories) were considered. The model incorporated variables such as crop yield and sale prices of agricultural products, in addition to these costs.

Apart from the outlays 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 analysed efficiencies.

Based on the results of stepwise regression, it may be stated that labour costs (both of own and hired labour) and land cost negatively affected the level of each of the analysed efficiencies. Costs of grain drying and land improvement have a negative effect only on economic efficiency.

We need to focus on direct costs, whose parameter values are positive; they include, e.g. irrigation costs (positively correlated with economic efficiency). This means that water limits the full utilisation of incurred outlays. In turn, herbicides and potassium fertiliser positively correlate with energy efficiency, while herbicides were only correlated with the mixed economic and energy efficiency. A higher potassium fertilisation level and higher outlays on herbicide treatments improve these efficiencies.

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

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

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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 [24]. Results marked by one asterisk correspond to their significance based on the level used α=0.05.

A positive effect on the level of economic efficiency is also found for costs of advisory services. The higher the outlays on the farm advisory services, the greater the economic efficiency. Furthermore, among costs significantly affecting efficiency, there were no cost categories such as depreciation of buildings and building repair costs, fuel costs and machine depreciation and repair costs. Financing input costs, i.e. production factors, also play a certain 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 outlays should not be neglected.

5. Discussion

Farms equipped with basic factors of production (fixed costs) may realise various production goals. In the decision-making processes, economic factors are usually decisive [29,30]. However, after farmer' economic security, energy security is important for society (including farmers) [8]. This dependence is presented in the following diagram (Figure 2).

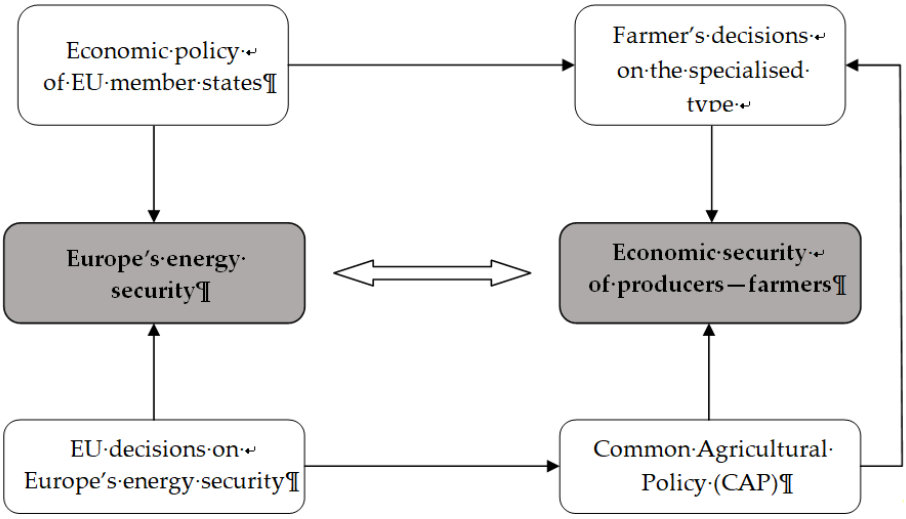

Figure 2. Economic efficiency and energy efficiency in present-day Europe.

The analysis finds that certain crops guarantee both the abovementioned 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 [31].

The high efficiency of niche crops can be explained by the fact that their production technology is extensive in character, with a limited number of cultivation and tillage operations, resulting in relatively low labour intensity and machine use [24]. 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 in relatively large farms, meaning they may rationally utilise labour resources and machinery. In smaller farms, particularly family farms where resources per 1 ha are much greater, this is more difficult to attain [32,33].

The analyses also identified the crops providing high energy efficiency, exceeding economic efficiency, including sugar beets, maize and winter barley. This indicates that under current economic conditions, they are not adequately valued by the market. However, when needed to meet energy demands for the production of non-food goods, these crops may constitute an efficient energy source for the local populations [13,34]. 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 cultivation of these 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 considerable share in the cropping structure, were relatively inefficient, both economically and in terms of energy. An example is winter rape [35]; although it fails to attain a satisfactory level of both investigated efficiencies (its cultivation technology is simply relatively expensive) and its substitutes are available in some countries (e.g. sunflower), rape continues to have a considerable share in the cropping structure of farms [36]. Such a situation may be an example of centrally controlled targeted demand for selected agricultural raw materials. Despite the lack of considerable economic or energy efficiency, considerable amounts of rape are used as a biocomponent for the production of biofuels [37]. Given the above, further studies are required to investigate potential improvement of crop efficiency, which demand is controlled and regulated by political decisions.

This study also included an analysis of the production cost structure for investigated crops to indicate key factors influencing attained efficiencies. This analysis focused on these cost categories, which increase caused an improvement in efficiency. Economic efficiency is improved by increasing outlays on irrigation, while energy efficiency is enhanced by increasing outlays on herbicides and potassium fertilisation. Attempts to increase yields thanks to increased outlays on potassium fertilisation improves energy efficiency, although it may also decrease economic efficiency.

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 [38].

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 [38–40].

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 abovementioned goals. Maximising economic and energy efficiencies is met by the production technology of such crops as oats, peas and winter rye. This conclusion indicates that at present, certain technological solutions ensure high energy efficiency without harming the financial performance of farms.

Economic efficiency evaluated on the basis of earned profit excluding subsidies proved to be strongly correlated with efficiency based on profit earned 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 outlays, resulting in increased production, also leading to improved efficiency. For example, increased outlays on irrigation or farm advisory services improve economic efficiency, whereas increased outlays on potassium fertilisation improve both economic and energy efficiency.

The positive effect of outlays 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 enhancing production efficiency, providing an optimal combination of factors of production for specific farming conditions.

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