VILNIUS TECH
Vilnius Gediminas Technical University

Journal of Business Economics and Management
ISSN 1611-1699 / eISSN 2029-4433
2023 Volume 24 Issue 1: 1–19
https://doi.org/10.3846/jbem.2023.17756

BIOENERGY PRODUCTION FROM SUNFLOWER HUSK IN UKRAINE: POTENTIAL AND NECESSARY INVESTMENTS

Jakub HORÁK[1], Yuriy BILAN[2,3], Andrii DANKEVYCH[4,5], Vitalii NITSENKO[6,7], Anatolii KUCHER[8,9], Dalia STREIMIKIENE[10*]

[1]*School of Expertness and Valuation, Institute of Technology and Business in Ceske Budejovice, Ceske Budejovice, Czech Republic*
[2]*Faculty of Social and Economic Relations, Alexander Dubcek University of Trencin, Trencin, Slovakia*
[3]*Sumy State University, Sumy, Ukraine*
[4]*Department of Economics and Law, National University of Food Technology, Kyiv, Ukraine*
[5]*Department of Economic Security, Public Administration and Management, Zhytomyr Polytechnic State University, Zhytomyr, Ukraine*
[6]*SCIRE Foundation, Warsaw, Poland*
[7]*Department of Entrepreneurship and Marketing, Ivano-Frankivsk National Technical Oil and Gas University, Ivano-Frankivsk, Ukraine*
[8]*Lviv Polytechnic National University, Lviv, Ukraine*
[9]*NSC "Institute for Soil Science and Agrochemistry Research Named after O. N. Sokolovsky", Kharkiv, Ukraine*
[10]*Kaunas Faculty, Vilnius University, Muitinės g. 8, LT-44280 Kaunas, Lithuania*

Received 23 May 2022; accepted 22 August 2022

Abstract. Sunflower is a strategic crop in the agriculture of Ukraine as it is important for food and energy production. Recently the processing of secondary products, solving the issues of waste disposal and improving the environment have been paid much attention. This is an example of a cyclic economy, as during the production of oil from sunflowers, their husk can be used for energy production. The ash obtained by burning husk is a valuable complex mineral fertilizer and can be further applied as ecological fertilizer. The aim of this article is to assess the energy and investment potential for sunflowers as an internal reserve for increasing production efficiency and reducing carbon dioxide emissions. In particular, the equivalents of energy substitution of sunflower husks for energy costs at fat-and-oil enterprises, the reduction of carbon dioxide emissions are estimated. A generalized scheme for the production of electricity from sunflower husks is considered. In particular, the use of ash from sunflower husks as a fertilizer is described. The research has shown that the sunflower husks available in Ukraine can be used more efficiently to produce electricity. Therefore policy recommendations were developed based on a study conducted.

Keywords: sunflower, biofuel, bioresource potential, sunflower husk, fertilizers, investment, Ukraine.

JEL Classification: M11, O13, O32, Q00, Q42.

*Corresponding author. E-mail: *dalia@mail.lei.lt*

Introduction

Various crops are currently widely used as bioenergy resources and strong competition among land use for energy and food production is emerging (Croitoru et al., 2021). Various agriculture holdings, agriculture cooperatives and farmers need to trade of between growing agriculture crops for bioenergy or food production. Green Deal and other environmental and climate change mitigation initiatives aiming at promotion of renewable energy source usage have also huge impact on strong competition between traditional use of crops and green energy production (Liang et al., 2021). Sunflower crops are especially important for food production however use of sunflower crops for bioenergy production provides more advantages for agriculture enterprises. Over the past 10 years, Ukraine, as a world leader in the sphere of sunflower cultivation, has made significant progress in modernizing production facilities in the oil and fat sector. At the same time, the outstripping growth rates of crops over the modernization of production capacities have a significant anthropogenic load on the environment, and the procession potential of generated waste is not used.

Sunflower and its processing waste have significant potential for renewable energy, which can be used to improve the trade balance, create jobs, modernize production, and improve energy security. Introduction of the newest technologies of biomass processing allows to solve a problem of harmful household and industrial waste utilization as well as to obtain lecithin and high-quality fertilizers as by-products.

The use of sunflower husk as a fuel is safer compared to natural gas from the environmental point of view. In particular, it reduces emissions of suspended solids, methane and non-methane volatile organic compounds. While burning sunflower husks, the amount of emitted carbon dioxide does not exceed that formed during the natural decomposition of wood.

For Ukraine, bioenergy is one of the strategic directions of the renewable energy sector development, given the country's high dependence on imported energy, primarily natural gas, and the great potential of biomass available for energy production. Nowadays Ukraine has probably the most developed biofuel industry in the Commonwealth of Independent States, however, the country is still far from full use of its resource potential compared to the EU (Croitoru et al., 2021).

One of the study's objectives is to implement a policy that promotes the rational disposal of waste and the balance of the nutrient cycle in the soil-plant-human chain. Even though sunflower being one of the most soil-depleting crops in terms of nutrient removal, including potassium and other macro- and micronutrients, returning them into the ecosystem is possible by attracting investment in the modernization of production and introduction of new technologies.

Innovations in waste recycling and production of the finished product hold significant reserves for improving the efficiency of both the industry and economic security of the country compared to the disposal of this waste or the production of only semi-products.

Nowadays the driver of modernization of the industry is presented by large agricultural holdings – vertically integrated structures with a closed cycle of production and processing. In the struggle for added value, they modernize production sites in order to maximize profits. In general, investments in renewable energy are constrained by high capital expenditures.

Though there are several studies dealing with assessment of benefits of sunflowers husk usage for energy production but the potential of energy production from sunflower husk and necessary investment were not evaluated for Ukraine, though country distinguishes with huge yields of sunflower crops. According to the research made by many scientists, sunflower husks can become an alternative source of energy economy (Dankevych et al., 2021; Bazaluk et al., 2021; Dehodiuk et al., 1988; Mishchenko & Vyhovska, 2006). Up to now, there are about 70 husk boilers in operation in Ukraine (Biliavskyi, 2020). However, only 10% of heat and power plants use husk-based (Lystopad & Kukhta, 2010; Geletukha et al., 2013). Studies proved that burning of husk is energy efficient, as usually the amount of non-combustible residues (ash content) does not exceed 3%.

The paper aims to overcome this research gap and provides comprehensive assessment of energy production potential and necessary investment for Ukrainian sunflower industry for increasing production efficiency and reducing carbon dioxide emissions.

The polynomial equations of autoregressive integrated moving average, model were applied for forecasting and evaluation of energy and investment potential in sunflower agri-complex.

The rest of the paper is structured in the following way: First section provides literature review, second section to introduces methods and data, third section analyses results, forth section provides discussion and fifth section concludes.

The future direction of research in the field of waste management is the priority protection of the environment from the negative impact of waste, ensuring the economical use of raw materials and energy resources and scientifically sound coordination of environmental, economic and social interests in waste generation and use for sustainable development.

1. Literature review

Among the main trends characteristic of the development of the oil and fat industry in recent years, we can highlight the increasing competitiveness of Ukrainian products through the active development of energy-saving technologies, namely – the implementation of projects for processing and further use of sunflower oil residual products such as husk, oil sludge, ash (Erickson & Lazarus, 2018; Nitsenko, 2020; Nitsenko et al., 2020). There is a steady trend towards the development of renewable energy sources and the gradual replacement of traditional energy generation (Osaulenko et al., 2020; Gavurova et al., 2021).

Analytical forecasts of the energy resource market do not stand in favor of fossil fuels. The authors (Erickson & Lazarus, 2018) note that global production and consumption of this type of fuel is estimated to be almost complete within 50 years. The powerful development of the latest energy technologies will promote the arrival of a "new energy era", and then the "new energy revolution" may take place earlier than expected (Zou et al., 2016; Bazaluk et al., 2021). Its prospect is a constant increase in the share of alternative energy resources in the economies of many countries. According to the International Renewable Energy Agency, Ukraine has the largest technical potential for the implementation of renewable energy sources in South-Eastern Europe. The total potential of the installed capacity in the country is estimated at 408.2 GW (excluding large hydropower plants), including biomass – 15 GW (4%) (Geletukha, 2017).

Ukraine has adopted a number of government decrees aimed at stimulating the replacement of natural gas with alternative fuels and new types of energy and at harmonizing the renewable energy sector of Ukraine with the European one, in particular:

- Granting the status of priority investment projects for the transfer of consumers from natural gas to other types of fuel and energy.
- Implementation of the term "biomass" in national legislation in accordance with Directive 2009/28/EU.
- Amendments to the Energy Strategy of Ukraine until 2030 in terms of reducing natural gas consumption, increasing the use of renewable energy sources and alternative fuels.
- Simplification of the land allotment procedure, reduction of terms of issuance and number of permits for the implementation of gas replacement projects. (Geletukha, 2017).

The biofuel market is developing dynamically, the number of entities is increasing, demand is growing. The raised problem is researched both in the world, and in the domestic scientific literature (Gavurova et al., 2018). Scientists unanimously state the presence of various negative processes associated with the accumulation of waste of various origins in the environment of Ukraine. Limiting the negative impact of waste on the environment at present is a global environmental problem that affects all areas of human life and activity (Andreichenko et al., 2021). This problem has become particularly severe in Ukraine due to large volumes of waste generation and accumulation and the lack of adequate response to the danger this creates for a long time.

The current production of the sunflower oil in Ukraine is based on the concept found on the technocratic-extensive and costly principle of its development (Rozin, 2021; Koval et al., 2020). In Ukraine, the production cost per unit of gross output, in particular, energy resources are 2–3 times higher than in Western Europe (Dankevych, 2017). The electricity consumption ranges from 96.6 to 198 kWh per ton of oil, and the heat consumption (steam) ranges from 348 to 1184 kWh per ton of oil (Biliavskyi, 2020). The decrease of electricity costs is of high priority to increase the competitiveness of the industry.

According to the research made by many scientists, sunflower husks can become an alternative source of energy economy (Dehodiuk et al., 1988; Biliavskyi, 2020). The key barriers to the development of renewable energy sources are:

- low confidence in the system of stimulating the development of renewable energy sources;
- uncertainty with the vector of long-term development of the energy sector, especially after 2030; abolition of tax benefits for renewable energy sources;
- reducing the rate of green tariffs; increase in the cost of connection to the electric grid; introduction of fines for imbalance in the electricity market (draft of a bill);
- limitation of the validity of technical conditions for connection to the power system (draft of a bill) (Zajemska et al., 2017; Geletukha, 2021).

Motivating factors for the development of renewable energy sources worldwide and, in particular, in Ukraine are further reductions in the cost of technology and renewable energy sources power plants. By 2025, a significant reduction in the cost of installing power plants

is forecast: the cost of installing production size solar power plants will decrease in 10 years by 57%, and the cost of installing wind power plants – by 13% (Geletukha, 2021).

The vast majority of investments in bioenergy in Ukraine are made by agro-holdings.

Their accumulation of financial, material, energy and labor resources provide favorable conditions for the implementation of investment bioenergy projects, improving the relationships between participants in the integration process and their interest in business results and profit maximization (Dubrovin, 2004). Improving the efficiency of co-operation of different types of renewable energy sources in electric grids is possible by optimizing the schemes of their connection, as well as automating part of the control functions, namely the optimal control of renewable energy sources modes taking into account the peculiarities of their primary energy conversion (Bazaluk et al., 2022).

The solution of the whole ecological and resource situation in Ukraine depends on waste management (Dankevych et al., 2021; Ivanov et al., 2021), because, on the one hand, waste is the main factor of environmental pollution, and, on the other hand, a certain part of resource and energy potential is "frozen" (not used) in it. Waste management affects the balanced development of Ukraine's economy in both environmental and resource terms. Hence the urgency of developing a set of legal, technical, scientific, managerial and other requirements and norms at both national and international levels follows (Stadzhy, 2019).

One of the directions of waste utilization is its application in natural form. There is a need to develop environmentally friendly technologies for disinfection and recycling of waste for use as a secondary raw material. Theoretical principles and practical mechanisms of ecologically safe, economically efficient utilization of sunflower husk biomass and subsequent utilization of the formed ash are reflected in the works of domestic researchers (Dankevych et al., 2021; Ostapchuk et al., 2021). The relevance of these issues, their theoretical importance and practical significance, especially in conditions of shortage of raw materials and energy resources, is beyond doubt.

Russia's invasion of Ukraine poses serious risks to global food security that will require a range of responses from governments and international organizations (Glauber & Laborde, 2022).

2. Data and methods

The data and methods applied for case study in Ukraine aiming to evaluate potential for sunflower crops use for bioenergy and necessary investments and economic and environmental benefits obtained from this are presented below.

The sources of data on the production of basic products were the data of the State Statistics Service of Ukraine /Ukrstat.org/ and the data of the website AgroChart Terms of Service. In Ukraine, no official body keeps statistics on the generation and disposal of waste in the oil and fat industry. Volumes of by-products were calculated based on the norms of output described and approved in the national standards of Ukraine (DSTU), interstate standards for oilseeds, products of their processing, feed (Rozin, 2021). In particular:

– DSTU 2423-94 "Vegetable oils. Production. Terms and definitions";
– DSTU 4492: 2017 Sunflower oil. Specifications.

To determine the resource potential of sunflower waste, comparative tables of calorific value (AgroChart, 2021) were used for some types of fuel (materials for designing boiler houses on solid fuel). These calculations are preliminary, as the heat of combustion for different fuels is approximate, it should be remembered that it depends on humidity, ash content, content of components (carbon, hydrogen, sulfur, etc.) and combustion conditions.

To predict the balance of sunflower production in Ukraine, a basic model of Box–Jenkins time series was used (Box et al., 2015). For the convenience of further research, forecasting, analysis and comparison of trends, linear vectors were presented in analytical form. The polynomial approximation method was used for such data representation.

This allowed to form polynomial equations of the first stage of application of ARMA (***p, q***) – algorithm, namely: to predict the area of sunflower crops, million hectares (Eq. (1)), gross production of sunflower seeds, million tons (Eq. (2)) and the yield of this agricultural crops, t / ha (Eq. (3)).

Accordingly:

$$y = -0.116x^3 + 0.8x^2 + 0.616x + 14.01; \quad (1)$$

$$y = 0.15x^3 - 1.25x^2 + 3.6x + 3.5; \quad (2)$$

$$y = -0.05x^3 + 0.4x^2 - 0.85x + 3.1, \quad (3)$$

where y is the value of the named forecast factor in the corresponding units mentioned above, x is the corresponding time period according to its index $i = 1,2,3\ldots.p$.

Eqs (2), (3), (4) obtained in the first stage of using the algorithm were modified to linear equations in the next stage, respectively:

1. For the area under sunflower, million hectares:

$$y = 2.19x + 13.15. \quad (4)$$

2. For gross production of sunflower seeds, million tons:

$$y = 0.47x + 5.7. \quad (5)$$

3. For sunflower yield, t / ha:

$$y = 0.11x + 2.45. \quad (6)$$

These modified equations were used in further analytical studies of the balance of sunflower production in Ukraine.

Analytical presentation of the data allowed to use them, in addition to the formation of the absolute value of the forecast factor in the relevant units, also to compare the dynamics of these factors. For this purpose, a comparative analysis of slope ratios (coefficients in arguments) of forecast value trends was used.

The analysis showed that the dynamics of increasing the area under sunflower crops. The standards of output were calculated, described and approved is more than an order of magnitude higher than the growth of sunflower yields, and the growth rate of gross production of sunflower seeds represents less than one-fifth of the growth rate of crop area.

The forecast balance of oil sludge and phosphatide concentrate production from sunflower waste and fertilizers from sunflower husk ash by 2021 was defined as derived from the gross production of sunflower specified in the forecast balance of sunflower production

by 2021 in the national standards of Ukraine (DSTU), products of their processing, as well as technical regulations of processing enterprises (Rozin, 2021). In particular:

– DSTU 4535: 2006 Oil sludge. Specifications.

– DSTU 7123: 2009 Sunflower husk. Technical conditions

Taking into account the CORINAIR "Guidelines for Inventory of Atmospheric Emissions" and a set of calculations published in directories and used by environmentalists of Ukraine to determine the amount of pollutants into the air, the Ukrainian Scientific Center for Technical Ecology has developed calculation methods for determining emission indicators for pollutants (Perea-Moreno et al., 2018), in particular, carbon dioxide:

$$k_{co2} = \frac{44}{12} \times \frac{C_r}{100} \times \frac{10^6}{Q_{ir}} \times \varepsilon_c, \quad (7)$$

where Q_{ir} – lower operating heat of fuel combustion, MJ/kg; C_r – mass content, respectively, of ash, sulfur, carbon in the fuel per working weight, %, the values taken according to the method; ε_c – the degree of oxidation of carbon fuel.

Calculations performed according to this method show that carbon dioxide emissions from the combustion of sunflower husks compared to natural gas in boilers, t / t of fuel is 1.7 times less and is 1556.78 against 2662.57 t / t of fuel, respectively.

The need for investment was formed based on the actual investment of investors in the industry for already launched facilities. Consultations with companies manufacturing technological equipment were also held.

3. Results of case study

3.1. Natural-climatic characteristics of Ukraine

Ukraine has the 8th largest farm land bank in the world (32.5 million ha). Arable land accounts for 54% of total Ukraine's territory among other countries with over 50% of territory under arable land which are Bangladesh, Moldova and Denmark. The study performed by the Food and Agriculture Organization revealed that almost 80% of total arable land in Ukraine is without major constraints. This provides for more efficient farming operations as it requires less capital & operational costs. The fact that 60% of agricultural land is flat is a highly favorable factor for agriculture.

3.2. Sunflower market overview in Ukraine

Ukraine is a world leader in the production and export of sunflower oil (31–37% of world exports), 90% of total oilseeds are sunflowers. Gross crop harvest amounted to 14.5 million tons in 2019 and 14 million tons in 2020. Sunflower production increased from 7.6 million tons in 2009/2010 to 14 million tons in 2019/2020, cultivation area: from 5,000 thousand hectares to 6,800,000 hectares. This is primarily due to favorable soil and climatic conditions for growing this crop as well as low cost of land cultivation.

Sunflower production could reach 17.5 million tons by 2021, both by increasing the cultivation area by 0.7 million hectares and increasing yields by 0.84 t/ha (Figure 1). This will also be facilitated by advances in selection and genetics.

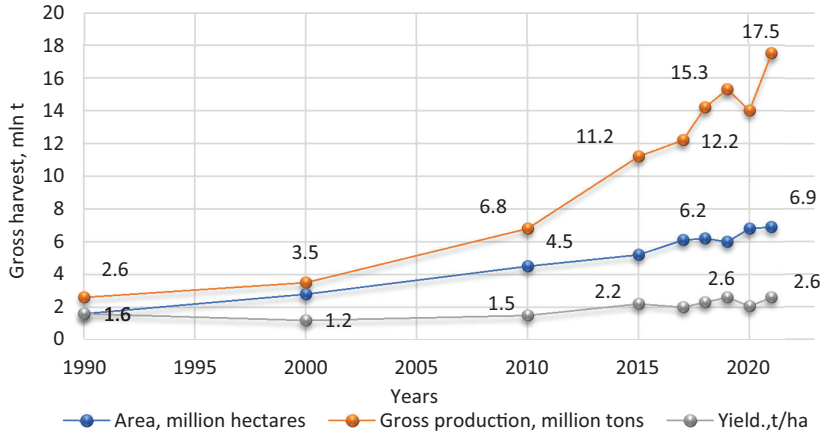

Figure 1. Status and forecast of the balance of sunflower production in Ukraine, 1990–2021 (source: compiled by the authors based on AgroChart, 2021)

The popularity of sunflower is due to its versatility for oil, seeds, animal feed, as well as with growing health concerns and climate change, sunflower plays an important role in improving diet and environmental protection, namely in providing a share of 130 million tons of plant oil that the world needs every year (Perea-Moreno et al., 2018). Sunflower is the most cost-efficient crop in terms of profitability, Earnings before Interest, Taxes, Depreciation and Amortization – exceeds $ 500 per ha (Lecithin market analysis, 2019).

The activities of agricultural holdings, which concentrated more than 7 million hectares of land, managed to implement the best world technologies, increase yields and production are important in this context (Lystopad & Kukhta, 2010). In particular, "Kernel", a world leader in the production of sunflower oil – cultivates more than 700 thousand hectares, of which 27.3% is sunflower (Allonsy, 2017; Bala-Litwiniak, 2021).

In total, six companies account for almost 80% of the market. According to the latest data, the annual capacity for sunflower processing in Ukraine is about 19 million tons, thus it covers the volume of the crop by 135% (Li et al., 2018). About half of all oil and fat capacities in Ukraine is controlled by the largest market players: Kernel of Andriy Verevsky, MHP of Yuri Kosyuk, Optimus Agro of Anatoliy Martynov, Vioil of Viktor Ponomarchuk and the international corporation Bunge (Table 1).

Table 1. Production capacity for sunflower processing in Ukraine, 2020 (source: compiled by the authors based on Lysohor, 2021)

Plant	Capacity per year, thousand tons	Beneficiary
Starokostiantynivsky MEZ	1000	Kernel, Andriy Verevsky, Vitaliy Khomutynnyk
CJSC "Prydniprovsky SEZ"	920	
Ukrainian Black Sea Industry LLC	630	
Bandursky Elevator LLC	520	
CJSC "Poltava MEZ"	440	
OJSC "Kirovogradolia"	440	

End of Table 1

Plant	Capacity per year, thousand tons	Beneficiary
OJSC "Prykolotnyansky SEZ"	435	
Hellas LLC	340	
PJSC "Vovchansky SEZ"	375	
PJSC "Vinnytsia Oil and Fat Plant"	970	Vioil, Victor Ponomarchuk
PJSC "Chernivtsi MZhK"	160	
PJSC "Zaporizhzhya MZhK"	900	Optimus Agro, A. Martinov
LLC Nikolaev oil extraction plant	800	Bunge, United States
Allies Black Sea LLC	700	Allseeds, Vyacheslav Petryshche
PJSC "Pologi SEZ"	626	Svetlana Novikova
LLC "ATK" (Under construction)	550	ATK, V. Shkolnyk, Stanislav Andrievsky, D. Motuzko
Vinnytsia Poultry Factory LLC MHP	510	MHP, Yuri Kosyuk
OJSC "Myronivsky ZPKK"	420	
Katerynopil Elevator LLC	200	
Delta Wilmar CIS LLC	500	Delmar PTE Ltd
LLC "Dniproolia"	495	Ruslan, Olga and Tatiana Evstafieva, Ahmet Peniche
Kakhovka branch of CJSC JSC "Kargil"	470	Cargill Holdings, USA
PJSC "Dnipropetrovsk SEZ"	465	Bunge, United States
Satellite LLC	460	Cofco Agri, Hotel China
PE "Oliyar"	410	Irina Zalizna
PE "Victor and K"	360	Victor the King
PE "Bessarabia-B"	252	Dmitry Shidereev, V. Tkach
UkroliyaProduct LLC	230	UkrOlia, Bohdan Yesipov, V. Shvachka, Y.Shevchenko
Gradolit LLC	220	Gradoil Holdings, Cyprus
PJSC "Nizhyn Fat Factory"	180	Georgy Voloshchuk
Sanpro Trading LLC	100	Sergey Yakimenko

Note: * n/d – Data not available.

3.3. Management of sunflower energy potential

Processing of sunflowers gives a significant number of by-products such as meal, oilcake and husk as well as phosphatide concentrate. About one-fifth of the weight of sunflower seed is the husk. Until 2015, a significant part of it was exported to Poland, Italy, Belgium, Lithuania and Latvia. However, reduced subsidies for the use of solid biofuels at large power stations in European countries, including Poland, have led to lower demand and a reorientation of supplies to the domestic market.

In Table 2, the calorific value of 2.52 million tons of sunflower husk emits was evaluated as much heat as 2.99 million tons of wood fuel, 1.02 billion m^3 of natural gas, 0.98 million liters of diesel fuel, 1.04 million liters of fuel oil, 1.96 million tons of coal.

Table 2. Energy potential of sunflower husk and energy equivalents obtained from them and energy cost substitution equivalent in the oil and fat sector by sunflower husk (source: authors' own calculations based on Geletukha, 2021)

Indicator	The cost of husks for processing products, t	Volumes of energy resources are equivalent to sunflower husk		
		Steam, t	Gas, m^3	Thermal energy, Gcal
For processing 1 ton of sunflower	0.052	0.240	21.0	0.158
For the production of 1 ton of oil n / r	0.120	0.554	49.0	0.370
For the production of 1 ton of refined deodorized oil	0.043	0.200	17.3	0.130
Only for 1 ton of processing	0.215	0.994	87.3	0.658
1 Ton of husk is equated	1.000	4.600	406.0	3.100
Units of measurement	Million tons of husk	Million tons of steam	mln m^3 of gas	Million Gcal
Potential 2.52 Million tons of husk of the 2020 harvest	2,52	11,6	1023,1	7,8
Average price, dollars per unit	111,1	x	370,4	x
Cash equivalent, million dollars	280	x	378,926	x

Taking into account the costs of maintenance of cogeneration units on already implemented Kernel projects, 2.52 million tons of husk will produce 3.734 billion kWh in 2020. In terms of this, it is 2.5% of the total electricity production in Ukraine in 2020. For comparison, this amount covers 40% of the annual need in electricity of the Ukrainian capital Kyiv with the population of 4.3 million people including workers from the outside of the city. Investments in this project are estimated at 1.86 billion US dollars and there is a need for ash disposal. By 2025, with the introduction of necessary innovations, sunflower husks will fully provide the population of the Ukrainian capital with electricity.

The installation and re-equipment of boilers for burning sunflower husks, which minimized dependence on external heat and energy on an industrial scale were the first step in this process. It also reduces energy consumption and cost of the main product (Table 2), which saves up to 200 million m3 of gas annually, and allows obtaining an increase of about 20% in the profitability of basic production.

The studies given in Table 2 show that while processing 1 ton of sunflowers and oil the energy consumption is equivalent to 0.215 tons of sunflower husk. That is, when investing in our own raw materials, 100% energy independence of the industry is ensured. The analysis shows that the potential of the husk allows to fully cover the processing needs in energy consumption, and an extra 30% of energy can be sold at the market. Despite the obvious advantages, nowadays only half of the annual volume of the husk is burned in boilers in order to produce heat energy (Ciesielczuk et al., 2011).

Figure 2 presents a generalized scheme of electricity production from sunflower husk:

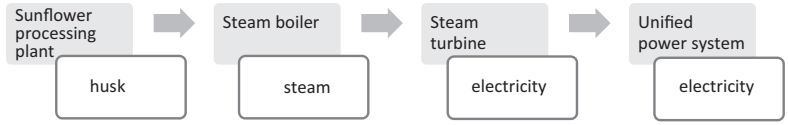

Figure 2. Scheme of electricity production from sunflower husk (source: based on Hrytsyuk, 2008)

Due to various circumstances, after satisfying their own energy needs, companies face the problem of selling surplus electricity or heat to external consumers. In particular: there are difficulties with connection to electric grids; limited information on technical possibilities of connection, forecasting of terms and non-transparency of the process of obtaining technical conditions and signing of the contract on connection to electric grids; limitation of the validity of technical conditions for connection to electric grids; poor technical condition of electrical grids increases the cost of connection and complicates their design.

Consumption of heating pellets is projected to increase over the next decade. The main motivating factor for development was the issue of reducing natural gas consumption. The capacity of the pellet market in the near future will grow in the range of 4–6% due to the increase in solid fuel consumption in Ukraine. The development of bioenergy using pellets is not only a factor in improving the energy security of the state, but also has a positive effect on the environment.

The volume of production of pellets and briquettes in Ukraine is about 1 million tons per year (Figure 3). This production is focused on both export deliveries to Europe and domestic consumers.

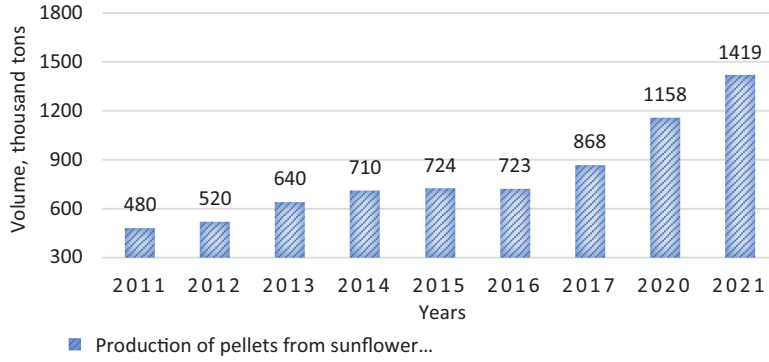

Figure 3. Dynamics of production volumes of pellets and briquettes from sunflower husk in 2011–2021, thousand tons/year (source: Geletukha, 2021)

There are about 162 pellet producers at the market, of which 30% are husk producers (Figure 4). Research shows that the availability of its own raw materials guarantees success of this type of business. Therefore, the production is concentrated in oil extracting plants and affiliated companies.

The development of renewable energy is an important contribution to achieving the set policy goals – reducing dependence on natural gas imports and diversification of energy sources. Such energy supply will also better ensure the energy security of both the enterprise and the state as a whole.

Figure 4. Grouping of regions by average annual capacity of one enterprise for the production of pellets, thousand tons/year (source: based on Lysohor, 2021)

The solution of this problem was largely facilitated by the state policy in the sphere of alternative energy development. From 2009 to 2030, renewable energy facilities in Ukraine received the right to use the green tariff. Green tariff (Feed-in tariff) – an economic mechanism for rewarding the generation of electricity from renewable energy sources. Ukraine has joined the European Energy Community and has committed itself to producing 11% of electricity from renewable energy sources by 2020 and 25% by 2035 (Stadzhy, 2019). The key mechanism for stimulating the production of "green" energy in Ukraine is the "green" tariff. For electricity producers using renewable energy sources, the green tariff is set at the level of the retail tariff for consumers of the second voltage class as of January 2009, and then multiplied by the green tariff coefficient. After 2014, 2019 and 2024, these figures will decrease from the basic value by 10%, 20% and 30%, respectively (Apk-inform, 2020).

3.4. Other potential uses of sunflower waste

Ukraine exports more than 12000 tons of phosphatide concentrate a year, while the potential raw material base allows it to produce about 42 thousand tons. That is, the waste potential in this segment, for various reasons, is used only for 28%. The line for the production of 8 t/day of phosphatide concentrate (for the finished product) will cost $2 million. The projected investment in modernizing the industry is estimated at $ 30 million.

Status and forecast balance of production of hydro processed oil sludge and phosphatide concentrate from sunflower waste in Ukraine, during 1990–2021 is provided in Figure 5.

A valuable product (hydro processed oil sludge) – liquid lecithin (phosphatide concentrate) was obtained from this material, and in its turn dry powdered lecithin was obtained from

liquid lecithin, and thus the profitability of oil refining was significantly increased. Up to 620 kg of liquid lecithin can be obtained from 1 ton of hydro processed oil sludge. If earlier hydro processed oil sludge was utilized, now the cost of one ton reaches almost $220. And the phosphatide concentrate which is made from it, is exported at the price of about $800–1100 per ton.

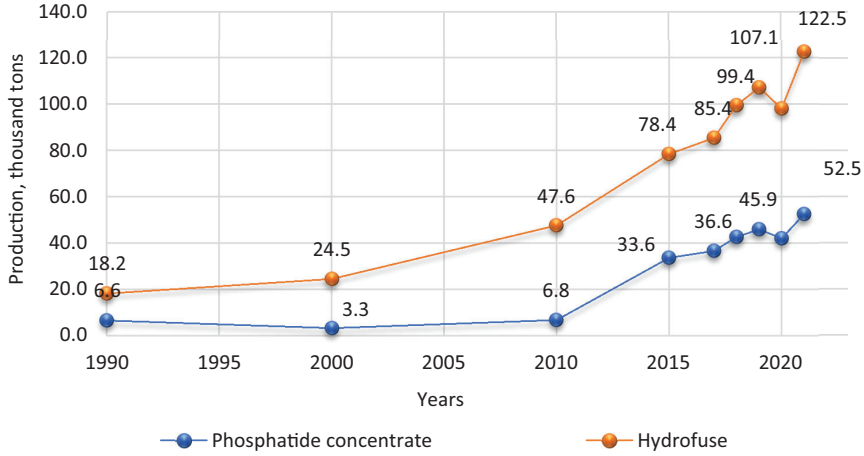

Figure 5. Status and forecast balance of production of hydro processed oil sludge and phosphatide concentrate from sunflower waste in Ukraine, 1990–2021 (source: based on Lysohor, 2021; AgroChart, 2021; Agroportal, 2022)

In the period from 2008 to 2018, exports of sunflower phosphatide concentrate from Ukraine increased almost sixfold.

Sunflower lecithin is a set of phospholipids of plant origin. Lecithin is actively involved in metabolic processes and is responsible for energy balance in the body. According to the projected indices of industrial production in this direction, lecithin consumption will grow by about 3% per year (Mikhno et al., 2021).

Phosphatide concentrate processing has not been established on an industrial scale in Ukraine. Ukraine is the raw material base for manufacturing this product. Inside the country there is no culture of lecithin consumption. Manufacture of end products, especially in the sphere of medicine and pharmaceuticals and technology, is concentrated in European countries. The use of plant biomass from agricultural production as a biofuel is one of the urgent problems for our country. However, there is a problem of utilization of ash, which is formed during the combustion of this biomass (Spirchez et al., 2019). Some researchers believe it is possible to solve this problem by using ash as fertilizer (Le Clef & Kemper, 2015; Lecithin market analysis, 2019).

Granular ash is an environmentally friendly fertilizer because it contains significantly fewer toxic elements such as lead, cadmium, arsenic, and fluoride compared to the content of these toxins in traditional fertilizers.

Ukraine's potential for sunflower husk ash is estimated at 50,000 tons by the end of 2020. About 12 thousand tons of fertilizer from ash is produced which is 30% of the raw material base. The line for the production of 5,000 tons of fertilizers will cost approximately $1 million. The approximate investment in the modernization of the industry, taking into account the development of infrastructure is estimated at 10 million dollars. An obstacle to

the implementation of these plans is the unsatisfactory quality of raw materials. The main reasons for this are: the lack of modern boilers, of proper infrastructure for their storage in the places of formation and logistical difficulties associated with delivery of the raw materials to processing sites.

The use of potassium-calcium fertilizer reduces the accumulation of radionuclides in plants, because in the absence of potassium and calcium in the soil, plants begin to intensively absorb their "substitutes" – cesium and strontium. In addition, calcium deficiency increases soil acidity, which enhances the transfer of radioactive substances into plants. This fertilizer is especially relevant in the northern regions of Ukraine, which are characterized by acidic, potassium-poor soils, great part of which is contaminated with radionuclides as a result of the disaster at the Chernobyl nuclear power plant in 1986. The contaminated area is over 42 thousand square km (Ukrainian Scientific Center of Technical Ecology, 2004).

4. Discussion of results

Agricultural production of Ukraine is based on ecologically unlimited use of production resources, as a result of significant anthropogenic load associated with the accumulation of waste of various origins, including ash (Stadzhy, 2019). It shifts the well-being perception due to the negative links with its ecological dimension (Mishchuk & Grishnova, 2015; Svazas et al., 2019; Streimikiene, 2021; Tvaronavičienė et al., 2022). To diminish the negative consequences, many states support sustainable agriculture and energy development protecting both environment and producers' interests (Vo, 2020; Cui et al., 2019; Hurst, 1951), however, it does not completely eliminate the problem of waste.

Some scientists are positive about the use of husk as fuel. Given the need to provide environmentally friendly rigid parameters of the obtained electricity to successfully solve these problems, researchers recommend using an automated control system for all technological cycles of this production, which will differ from the existing ones by better control indicators. Barriers to market entry are: limited information on the possibility of connecting to the electric grid; a complex system of approval, a large number of permits (Zeleniuc et al., 2019).

Some scientists, recommends to consider the following innovations for the rational use of energy in sunflower processing: the use of granular sunflower husk as a fuel for technological processes in the processing of oils and fats; the scheme of reuse of high pressure condensate in the processes of deodorization and hydrogenation; heat recovery system during production; use of contact, jet heat exchangers; reconstruction of the scheme during cooling of oils in deodorization processes; the use of electricity to maintain the temperatures of oils and fats. The development and implementation of these measures will reduce the consumption of conventional fuel by 7–10% (Jiang et al., 2019).

A number of researchers note favorable climatic conditions in Ukraine and predict further growth of sunflower cultivation, both due to increased yields of about 30%, and the expansion of crop areas (Geletukha, 2021).

Significant start-up investments are seen as a restraining factor in attracting investment in bioenergy of RES. Agricultural holdings have become a wonderful remedy in this matter.

The principles underlying the integrated formations based on the symbiosis of specialization, automation, concentration, diversification and closed production cycle generate potential and encourage the holdings to move away from the raw materials economy and start producing finished products. They are not subject to change depending on social order, or transformation of property relations, or change in forms of management (Streimikiene, 2020).

When comparing prices for fossil fuels (primarily natural gas) and biomass for heat energy production, the authors state that bioenergy is economically feasible and can be recommended for heat producing facilities in the industrial and budget sectors.

Studies show the progressive movement of Ukraine's economy to the transition to alternative types of electricity. To solve the problem of energy supply, it is proposed to use sunflower husk – waste obtained in the process of processing sunflower at the plant – for electricity production. This makes it possible not only to address the issue of waste disposal, but also to obtain cheap electricity, reduce the use of natural gas in energy.

The group of authors sees the main improvements in the situation: simplification of permitting procedures for connection to the electric grid and their coordination with the national system of stimulating the development of renewable energy sources together with the support for electrical power network modernization programs (especially with a voltage of 154 kV and below) (Zeleniuc et al., 2019).

The main principles of state policy in the sphere of waste management are the priority protection of the environment and human health from the negative impact of waste, ensuring the economical use of raw materials and energy resources, scientifically sound coordination of environmental, economic and social interests in waste generation and use in order to ensure its sustainable development.

Conclusions

Traditionally, Ukraine specializes in oil exports, having large capacities, sufficient harvest, and a high share of processing (98–99% of the harvest). The blockade of ports had forced logistics to adapt, reorient, negotiate at the interstate level, open new corridors, and apply all measures that had yielded results in April this year, when exports went up. Despite the military action, sunflower exports from Ukraine in the 2021–2022 marketing year could reach 1 million tons. Given the good harvest – 2022, potentially, Ukraine will be able to put on the world market next year – sunflower oil in the amount of at least the last few seasons. At the same time, experts do not rule out the possibility of further reviewing the consumption of vegetable oils in the EU in the direction of declining against the background of a shortage of oilseeds.

With significant agricultural potential, as a world leader in the production of sunflower and sunflower oil, Ukraine continues to be a raw material appendage of the world. Nowadays only 10% of sunflower husk is used to produce electricity, the rest is either burned over an open fire or in furnaces with relatively low efficiency without complying with environmental regulations.

Climate change has contributed to the large-scale growth of sunflower crops in Ukraine, 6.3 million hectares of arable land have become suitable for growing sunflowers and have allowed

the accumulation of a large number of by-products, the potential of which is enormous.

New policies and measures to promote use of sunflower crops for bioenergy production are necessary in Ukraine due to the expected wide benefits. As existing sunflower husks can provide an annual electricity demand of 4.3 million people, while reducing energy dependence on gas imports by 1 billion m^3. This creates new added value, at least plus 20% to the profitability of production, improves the environment and economy. The available ash makes it possible to obtain 47 thousand tons of complex organic fertilizers suitable for use in organic production, which means the use of 240 thousand hectares of agricultural lands, improvement of their fertility, production of ecologically clean foodstuff and solving of the problem of waste utilization. With 1 ton of granular ash, 85.1 kg of calcium, 49.7 kg of magnesium, 37.5 kg of sulfur, 51 kg of total phosphorus, and 209.8 kg of total potassium can be applied to the soil.

Modernization of the industry requires significant production, human and financial resources. According to our estimates, mere investments in obtaining alternative electricity from sunflower husks will cost $1.86 billion. In addition, during burning of sunflower husks, 1.7 times less carbon dioxide is emitted compared to natural gas, which helps reduce harmful substances emissions and improve the environmental situation in Ukraine.

This study shows the benefits of using sunflower husks as an alternative fuel. At the same time, the practice of implementing the proposed measures in the real sector of production needs further research. The uncertainty of development conditions during martial law can worsen the investment expectations of producers and reduce the resource potential of agriculture and the oil and fat industry.

Acknowledgements

The article was supported by project IVSUZO001 – Benchmark of the world economy in the context of the principles of the circular economy and determining the value of the company. Some material was prepared within the framework of the scientific project “Strategy and innovative technologies for the processing of organic animal waste in the context of ensuring land degradation neutrality: from linear to circular economy” (state registration number 0122U001484).

Informed consent statement

Informed consent was obtained from all subjects involved in the study.

Data availability statement

Data sharing not applicable.

Conflicts of interest

The authors declare no conflict of interest.

References

AgroChart. (2021). *Oilseeds. Black Sea. Oilseed, sunflowerseed. Area harvested*. https://www.agrochart.com/en/usda/section/38/oilseeds/region/5/black-sea/commodity/22/oilseed-sunflowerseed/attribute/1/area-harvested/

Agroportal. (2022). *TOP-10 most powerful oil extraction plants in Ukraine*. http://agroportal.ua/news/ukraina/kto-vladeet-masloekstratsionnymi-zavodami-ukrainy/

Allonsy, A. (2017). *Uses for sunflower seed shells*. Sciencing. https://sciencing.com/uses-for-sunflower-seed-shells-12588918.html

Andreichenko, A., Andreichenko, S., & Smentyna, N. (2021). Ensuring biosphere balance in the context of agricultural waste management. *Philosophy and Cosmology*, *26*, 46–61. https://doi.org/10.29202/phil-cosm/26/4

Apk-inform. (2020). *On the question of phosphatide concentrate*. https://www.apk-inform.com/ru/oil-processing/9778

Bala-Litwiniak, A. (2021). Environmental and economic aspects of combustion of biomass pellets containing a waste glycerol. *Combustion Science and Technology*, *193*(11), 1998–2008. https://doi.org/10.1080/00102202.2020.1746774

Bazaluk, O., Havrysh, V., Fedorchuk, M., & Nitsenko, V. (2021). Energy assessment of sorghum cultivation in Southern Ukraine. *Agriculture*, *11*, 695. https://doi.org/10.3390/agriculture11080695

Bazaluk, O., Havrysh, V., Nitsenko, V., Mazur, Y., & Lavrenko, S. (2022). Low-cost smart farm irrigation systems in Kherson province: Feasibility study. *Agronomy*, *12*(5), 1013. https://doi.org/10.3390/agronomy12051013

Biliavskyi, M. (2020). *Guidelines for the development of alternative energy in Ukraine until 2030*. https://razumkov.org.ua/statti/oriientyry-rozvytku-alternatyvnoi-energetyky-ukrainy-do-2030r

Box, G. E. P., Jenkins, G. M., Reinsel, G. C., & Ljung, G. M. (2015). *Time series analysis: Forecasting and control* (5 ed.). John Wiley and Sons Inc.

Ciesielczuk, T., Kusza, G., & Nems, A. (2011). Fertilization with biomass ashes as a source of trace elements for soils. *Environmental. Protection and. Natural. Resources*, *49*, 219–227.

Croitoru, G., Oprisan, O., Robescu, V. O., Dumitrache, A.-M., Hubel, S.-R., Paraschiv, G. I., & Tudoran, V.-I. (2021). Streamlining the risk management process in the framework of sustainable development and projects to increase the competitiveness of agricultural holdings at the level of private organizations. *Transformations in Business and Economics*, *20*(2A/53A), 673–684.

Cui, X., Yang, J., Shi, X., Lei, W., Huang, T., & Bai, C. (2019). Pelletization of sunflower seed husks: Evaluating and optimizing energy consumption and physical properties by response surface methodology (RSM). *Processes*, *7*, 591. https://doi.org/10.3390/pr7090591

Dankevych, A. I. (2017). Analysis of the investment potential of enterprises in the agricultural sector of the economy. *Problems of Theory and Methodology of Accounting, Control and Analysis*, *3*, 37–42. https://doi.org/10.26642/pbo-2017-3(38)-37-42

Dankevych, A., Sosnovska, O., Dobrianska, N., Nikolenko, L., & Mazur, Yu. (2021). Ecological and economic management of innovation activity of enterprises. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, *5*, 112–118. https://doi.org/10.33271/nvngu/2021-5/118

Dehodiuk, E. H., Mamontov, V. T., & Hamalei, E. H. (1988). *Ecological bases of fertilizer use*. Urozhay.

Dubrovin, V. O. (2004). *Biofuels (technologies, machines and equipment)*. TsTI "Enerhiia ta elektryfikatsiia".

Erickson, P., & Lazarus, M. (2018). Would constraining US fossil fuel production affect global CO_2 emissions? A case study of US leasing policy. *Climatic Change*, *150*(1–2), 29–42. https://doi.org/10.1007/s10584-018-2152-z

Gavurova, B., Kocisova, K., Behun, M., & Tarhanicova, M. (2018). Environmental performance in OECD countries: A non-radial DEA approach. *Acta Montanistica Slovaca*, *23*(2), 206–215.

Gavurova, B., Megyesiova, S., & Hudak, M. (2021). Green growth in the OECD countries: A multivariate analytical approach. *Energies*, *14*(20), 6719. https://doi.org/10.3390/en14206719

Geletukha, G. (2017). *Current state and prospects of bioenergy development in Ukraine*. Bioenergy Association of Ukraine. https://www.biobased-ukraine.nl/assets/uploads/sites/12/2018/11/09-45-Geletukha-22-November-2018_EN.pdf

Geletukha, G. G. (2021, April 30). What will be the bioenergy of Ukraine in 2050. *Ukrainian Pravda*. https://www.epravda.com.ua/columns/2021/04/30/673528/

Geletukha, G. G., Zheliezna, T. A., & Drozdova, O. I. (2013). Comprehensive analysis of technologies for energy production from solid biomass in Ukraine. Part 1. *Industrial Heat Engineering*, *3*, 56–63.

Glauber, J., & Laborde, D. (2022). *How will Russia's invasion of Ukraine affect global food security?* https://www.ifpri.org/blog/how-will-russias-invasion-ukraine-affect-global-food-security

Hrytsyuk, P. M. (2008). Evidence for low dimensional chaos in grain production system of Ukraine. *Material of the International Symposium RA08,* (pp. 34–37). Riga–Jurmala.

Hurst, H. E. (1951). Long-term storage of reservoirs. *Transactions of the American Society of Civil Engineers*, *116*, 776–808. https://doi.org/10.1061/TACEAT.0006517

Ivanov, V., Shevchenko, O., Marynin, A., Stabnikov, V., Gubenia, O., Stabnikova, O., Shevchenko, A., Gavva, O., & Saliuk, A. (2021). Trends and expected benefits of the breaking edge food technologies in 2021–2030. *Ukrainian Food Journal*, *10*(1), 7–36. https://doi.org/10.24263/2304-974X-2021-10-1-3

Jiang, Y., Havrysh, V., Klymchuk, O., Nitsenko, V., Balezentis, T., & Streimikiene, D. (2019). Utilization of crop residue for power generation: The case of Ukraine. *Sustainability*, *11*(24), 7004. https://doi.org/10.3390/su11247004

Koval, V., Mikhno, I., Trokhymets, O., Kustrich, L., & Vdovenko, N. (2020). Modeling the interaction between environment and the economy considering the impact on ecosystem. *E3S Web Conferences*, *166*, 13002. https://doi.org/10.1051/e3sconf/202016613002

Le Clef, E., & Kemper, T. (2015). Sunflower seed preparation and oil extraction. In E. Martínez-Force, N. T. Dunford, & J. J. Salas (Eds.), *Sunflower chemistry, production, processing, and utilization*. Academic Press and AOCS Press. https://doi.org/10.1016/C2015-0-00069-7

Lecithin market analysis. (2019). https://www.megaresearch.ru/news_in/analiz-rynka-lecitina-1331

Li, X., Rubæk, G. H., & Sørensen, P. (2018). Availability of potassium in biomass combustion ashes and gasification biochars after application to soils with variable pH and clay content. *Archives of Agronomy and Soil Science*, *64*(8), 1119–1130. https://doi.org/10.1080/03650340.2017.1414198

Liang, C., Xingqing, Y., & Ma, J. (2021). Can e-commerce improve the profitability of agricultural cooperatives? *Transformations in Business and Economics*, *20*(2A), 684–704.

Lysohor, M. (2021). In Poltava, KERNEL built a 10 MW biopower plant running on sunflower husk. *Poltavshchyna*. https://poltava.to/news/59568/

Lystopad, V. L., & Kukhta, V. H. (2010). Sunflower husk market in Ukraine, and implementation of projects for the production of solid fuel in the fat and oil industry. *Oil Fat Complex*, *2*(29), 13–17.

Mikhno, I., Koval, V., Shvets, G., Garmatiuk, O., & Tamošiūnienė, R. (2021). Green economy in sustainable development and improvement of resource efficiency. *Central European Business Review*, *10*(1), 99–113. https://doi.org/10.18267/j.cebr.252

Mishchenko, V., & Vyhovska, H. (2006). Waste management: Standards as a management tool. *Standardization, Certification, Quality*, *4*, 37–40.

Mishchuk, H., & Grishnova, O. (2015). Empirical study of the comfort of living and working environment – Ukraine and Europe: Comparative assessment. *Journal of International Studies*, *8*(1), 67–80. https://doi.org/10.14254/2071-8330.2015/8-1/6

Nitsenko, V. S. (2020). Innovative development of the oil and fat industry in the context of the functioning of agricultural holdings: The case of Ukraine. *Visnyk KhNAU im. V.V. Dokuchaieva, Seriia "Ekonomichni nauky"*, *2*, 360–364. https://doi.org/10.31359/2312-3427-2020-2-371

Nitsenko, V. S., Hanzhurenko, I. V., & Ingram, K. L. (2020). The potential for development of oil and fat industry enterprises. *Visnyk KhNAU im. V.V. Dokuchaieva, Seriia "Ekonomichni nauky"*, *3*, 226–238. https://doi.org/10.31359/2312-3427-2020-3-226

Osaulenko, O., Yatsenko, O., Reznikova, N., Rusak, D., & Nitsenko, V. (2020). The productive capacity of countries through the prism of sustainable development goals: Challenges to international economic security and to competitiveness. *Financial and Credit Activity: Problems of Theory and Practice*, *2*(33), 492–499. https://doi.org/10.18371/fcaptp.v2i33.207214

Ostapchuk, T., Orlova, K., Biriuchenko, S., Dankevych, A., & Marchuk, G. (2021). Defuzzification in the process of managerial estimating the value of agricultural lands. *Agricultural and Resource Economics: International Scientific E-Journal*, *7*(4), 62–81. https://doi.org/10.51599/are.2021.07.04.04

Perea-Moreno, M.-A., Manzano-Agugliaro, F., & Perea-Moreno, A.-J. (2018). Sustainable energy based on sunflower seed husk boiler for residential buildings. *Sustainability*, *10*, 3407. https://doi.org/10.3390/su10103407

Rozin, V. (2021). From engineering and technological process to post-cultural technology. *Future Human Image*, *15*, 99–109. https://doi.org/10.29202/fhi/15/9

Spirchez, C., Lunguleasa, A., & Croitoru, C. (2019). Ecological briquettes from sunflower seed husk. *E3S Web of Conferences*, *80*, 01001. https://doi.org/10.1051/e3sconf/20198001001

Stadzhy, D. (2019). *Sesame and hemp. What oils to make money on for Ukraine.* https://www.dsnews.ua/economics/kunzhut-i-konoplya-na-kakih-maslah-zarabatyvat-ukraine-23042019110000

Streimikiene, D. (2020). Ranking of Baltic States on progress towards the main energy security goals of European energy union strategy. *Journal of International Studies*, *13*(4), 24–37. https://doi.org/10.14254/2071-8330.2020/13-4/2

Streimikiene, D. (2021). Externalities of power generation in Visegrad countries and their integration through support of renewables. *Economics and Sociology*, *14*(1), 89–102. https://doi.org/10.14254/2071-789X.2021/14-1/6

Svazas, M., Navickas, V., Krajnakova, E., & Nakonieczny, J. (2019). Sustainable supply chain of the biomass cluster as a factor for preservation and enhancement of forests. *Journal of International Studies*, *12*(2), 309–321. https://doi.org/10.14254/2071-8330.2019/12-2/20

Tvaronavičienė, M., Mazur, N., Mishchuk, H., & Bilan, Y. (2022). Quality of life of the youth: assessment methodology development and empirical study in human capital management. *Economic Research-Ekonomska Istraživanja*, *35*(1), 1088–1105. https://doi.org/10.1080/1331677X.2021.1956361

Ukrainian Scientific Center of Technical Ecology. (2004). *Collection of emission factors (specific emissions) of pollutants into the atmosphere by different production.* (1 ed.). Ukrainian Scientific Center of Technical Ecology.

Vo, H. D. (2020). Sustainable agriculture & energy in the U.S.: A link between ethanol production and the acreage for corn. *Economics and Sociology*, *13*(3), 259–268. https://doi.org/10.14254/2071-789X.2020/13-3/16

Zajemska, M., Urbańczyk, P., Poskart, A., Urbaniak, D., Radomiak, H., Musiał, D., Golański, G., & Wyleciał, T. (2017). The impact of co-firing sunflower husk pellets with coal in a boiler on the chemical composition of flue gas. *E3S Web of Conferences*, *14*, 02021. https://doi.org/10.1051/e3sconf/20171402021

Zeleniuc, O., Brenci, L.-M., Cosereanu, C., & Fotin, A. (2019). Influence of adhesive type and content on the properties of particleboard made from sunflower husks. *BioRes*, *14*(3), 7316–7331.

Zou, C., Zhao, Q., Zhang, G., & Xiong, B. (2016). Energy revolution: From a fossil energy era to a new energy era. *Natural Gas Industry B*, *3*(1), 1–11. https://doi.org/10.1016/j.ngib.2016.02.001