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Sunflower Residues-Based Biorefinery: Circular Economy Indicators

Valerii Havrysh [1,†], Antonina Kalinichenko [2,3,*], Pavlo Pysarenko [4] and Maryna Samojlik [4]

1 Department of Tractors and Agricultural Machines, Operating and Maintenance, Mykolaiv National Agrarian University, 54020 Mykolaiv, Ukraine
2 Institute of Environmental Engineering and Biotechnology, University of Opole, 45040 Opole, Poland
3 Department of Information System and Technology, Poltava State Agrarian University, 36003 Poltava, Ukraine
4 Department of Ecology, Sustainable Nature Management and Environmental Protection, Poltava State Agrarian University, 36003 Poltava, Ukraine
* Correspondence: akalinichenko@uni.opole.pl; Tel.: +48-787-321-587
† During the finalization of the article, the author lost his life as a result of the war in Ukraine.

Abstract: Fossil fuel price increases, their uneven distribution, environmental issues from their incineration, and lack of guarantees of their energy security are the main drivers for the development of green energy. Agricultural waste is an abundant resource for energy bioprocessing, which improves the functioning of the circular economy. In this study, the following were used as the main indicators: the share of renewable energy and the benefit from it, the coefficient of cyclical use of biomass, and the reduction in carbon dioxide emissions. The ways in which sunflower waste is applied for energy purposes are emphasized. The highest comprehensive ecological and economic effects are shown to be achieved in the production of biogas from sunflower residues with the incineration of this biogas in cogeneration plants. The residues from the biogas plant that are left after fermentation should be used as a biofertilizer. Such a cyclic system allows not only the full processing of all biomass waste that significantly reduces carbon dioxide emissions during the cultivation and processing of sunflower, but also an increase in the share of renewable energy used in technological processes up to 70%.

Keywords: biorefinery; circular economy; power generation; carbon dioxide emission; indicator

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1. Introduction

The development of fossil fuel-based energy is limited by the exhaustibility of resources, environmental issues, and rising prices. In addition, global crises, including the coronavirus, Russia's invasion of Ukraine, etc., have impacted the energy market. Thus, from 2021 to May 2022, energy prices almost doubled: crude oil rose from USD 41.52/MWh to USD 72.73/MWh, and natural gas rose from EUR 22.32/MWh to EUR 87.29/MWh [1,2]. For these reasons, renewable energy is the main trend for the near future [3]. Among renewable energy, wind and solar power generation are uncertain and volatile [4]. Unlike them, biomass may be the most promising feedstock for power generation and biorefinery [5]. The main reasons are as follows: abundant and widely distributed resources, low harmful emissions, and economic attractiveness due to rising fossil fuel prices [6].

Modern agriculture strives for a sustainability that achieves high yields and economic results with the lowest possible impact on the environment [7]. In addition, it should be profitable [8]. Innovative agricultural systems are increasingly based on renewable energy, which allows for the reduction of external energy inputs [9].

Greenhouse gas (GHG) emissions are also an issue for agriculture. In the European Union, agriculture is responsible for 11% of the total GHG emissions [10]. These emissions are divided into two groups (external and on-farm emissions) [11]. External emissions are the result of chemical (fertilizer, pesticides, etc.) production [12,13]. On-farm emissions are the result of fuel combustion [14].

The food sector is increasing vegetable oil consumption. In 2021/2022 MY, the global production of vegetable oils reached 200 million tons. The major oil crops are soybean, rapeseed, peanut, sunflower, etc. Rapeseed, soybean, and sunflower are the primary oil crops in European countries [15]. Sunflower oil is among the major vegetable oils. It is ranked fourth at approximately 20 million tons [16]. European countries produce approximately 75.8% of the total world sunflower oil production [17]. In Europe, sunflower seeds are cultivated in the southern regions of Ukraine, Romania, France, Spain, Bulgaria, Hungary, etc. [18]. In 2019, the top countries for sunflower oil production were as follows (million tons): Ukraine—5.413, the Russian Federation—4.834, Argentina—1.282, Turkey—0.994, Hungary—0.746, France—0.593, Spain—0.510, Bulgaria—0.504, and Romania—0.504 [19].

Ukraine was ranked first in global sunflower seed production. Its share was approximately 30% (Figure 1) [20,21]. Thus, Ukraine has abundant sunflower field-based and process-based residues that can be used for bioenergy.

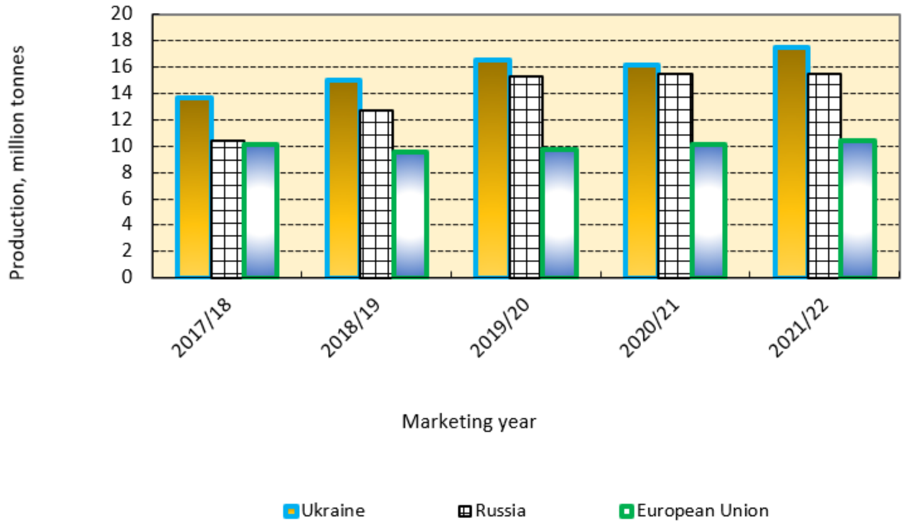

Figure 1. The major producers of sunflower seeds.

Sunflower seed production requires the use of energy-intensive technologies. The total energy inputs range from 1671 to 26,973 MJ/ha. These energy inputs result in the specific energy of seeds being in the range of 3.52 to 9.37 MJ/kg [22–28]. Carbon dioxide emissions vary from 438 to 2043 kgCO_2/ha [18,27,29]; their average value is 376 kgCO_2 per ton of seeds [25–28].

The technological process of sunflower oil production requires electricity and heat. Conventional oil mills receive electricity from the grid. Heat is generated by steam boilers. The specific electric consumption varies from 96.6 to 198 kWh per ton of oil, the specific heat consumption ranges from 348 to 1184 kWh per ton, and their average values are 132.5 and 779.1 kWh per ton, respectively [30,31]. The energy and material flows of sunflower oil production are presented in Figure 2.

In major producers of sunflower oil, the share of hydrocarbon fossil fuels in electricity generation varies from 9% (France) to 60–62% (the Russian Federation and Argentina) [32–35]. Turkey, Bulgaria, and Ukraine have the highest share of coal in power generation (Figure 3). In addition to carbon dioxide, the combustion of fossil fuels emits many harmful compounds, such as nitrogen oxides, sulfur dioxide, particles, etc. [36]. Coal-based power plants are significant contributors to these emissions [37]. Sunflower husks are a waste product of sunflower oil production. According to conventional technology, this waste product is stored in landfills, and its storage results in GHG emissions of approximately 433 kgCO_2eq./t [38].

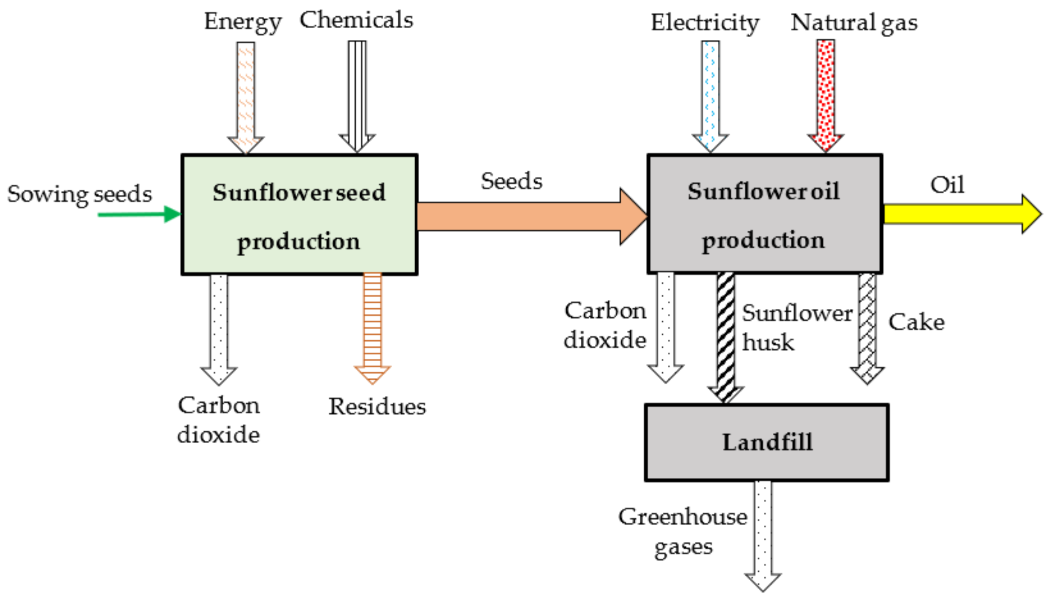

Figure 2. The energy and material flows of sunflower oil production (conventional technology).

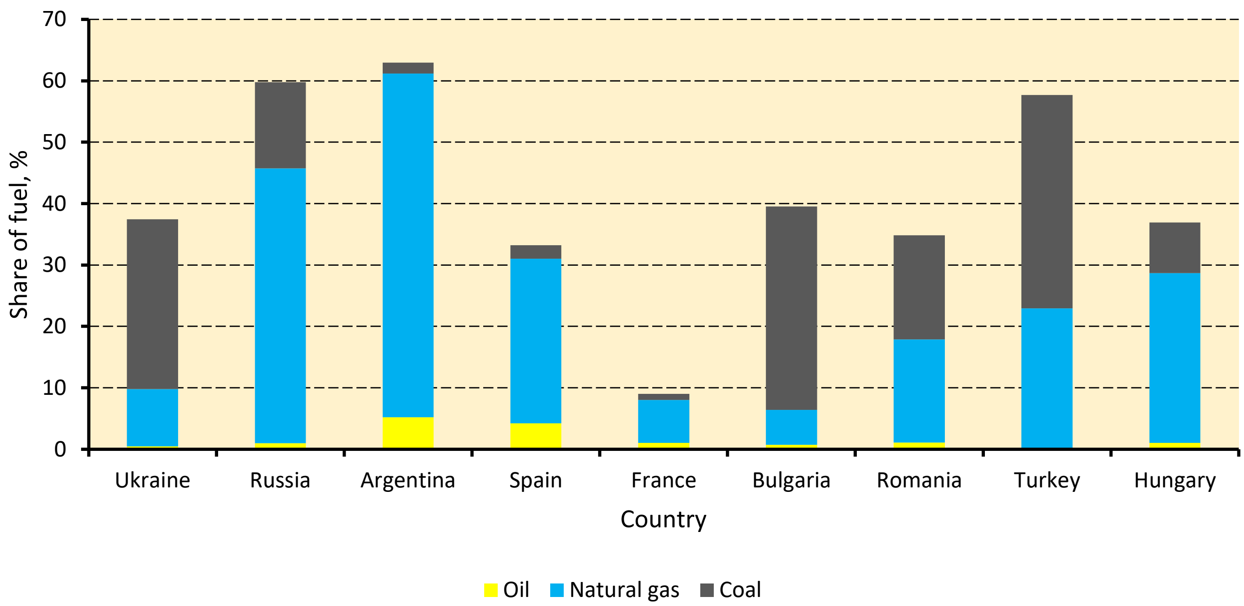

Figure 3. Electricity generation by fossil fuels.

Agriculture consumes energy to operate machinery, produce chemicals, etc. [39,40]. Crop residues can cover part of the energy consumed. They contain nutrients that can be recycled to maintain soil productivity [41]. Numerous researchers studied the impact of sunflower residues incorporated into the soil on crop germination [42,43]. However, the energy and environmental aspects of this practice have been insufficiently studied. Nizami et al. [44] examined the potential of waste biomass biorefineries for energy. Geletukha et al. [45] estimated sunflower residues as the feedstock for bioenergy production. The research regarding the reliability of power equipment was also carried out [46,47]. The transition of agricultural practices to a circular economy model enables farmers to reduce exhaustible energy consumption [48].

The energy supply systems of oil plants based on biomass waste have been studied by numerous researchers, such as Booneimsri et al. [49], Azhdari et al. [50], Ion et al. [51], Donaldson et al. [52], and others. Alcock et al. [53] revealed the following structure of greenhouse gas emissions: cultivation—62.16%, processing—25.41%, packing—11.35%, and transportation—1.08%. For this reason, the main focus of this study was on the cultivation and processing (the largest emission items).

In the processing of sunflower seeds, approximately 15% of the husk is formed, which can become a high-quality biofuel. Other types of by-products of sunflower seed production can also be used as energy biomass. Previous studies did not consider the relationship between the use of sunflower residues for biorefinery and circular economy indicators.

The purpose of this study was to examine the potential of sunflower residues-based biorefinery (primarily for power and heat production) and its impact on core circular economy indicators. In this study, we focused on the indicators related to used and produced energy (primarily from renewable sources) and carbon dioxide emissions.

To reach this purpose, the following objectives were set up:

- the identification of suitable indicators
- the review of existing technologies
- the determination of circular economy indicators and their comparison

2. Materials and Methods

We collected, summarized, and analyzed scientific articles and practical reports of agricultural activity in the central and southern part of Ukraine. Sunflower is one of the main cultivated crops for this region. Usually, its cultivation is multi-purpose. It is used for human nutrition and animal feed, and for technical, industrial, and, increasingly, for energy purposes. In the latter case, harvest residues, husks, and other post-processing waste are most often used as raw materials for the production of 1–2 generation biofuels (solid, liquid, biogas). In addition, the digestate is an extremely valuable by-product of biogas plants. It can completely replace synthetic fertilizers. It has not only an ecological effect on the quality of the soil, but also reduces the emission of greenhouse gases into the atmosphere during the production of mineral fertilizers. This study analyzed the energy and environmental indicators of the full technological cycle of sunflower cultivation and processing, including the utilization or reuse of waste and by-products, which may become important in the near future.

2.1. System Boundary

Sunflower residues can be used in different ways: the substitution of mineral fertilizers (indirect input energy) and heat and power generation (direct input energy) (Figure 4). In this study, we considered the following methods for energy conversion: anaerobic digestion of crop residues, fermentation of crop residues, and direct incineration of crop residues and husk.

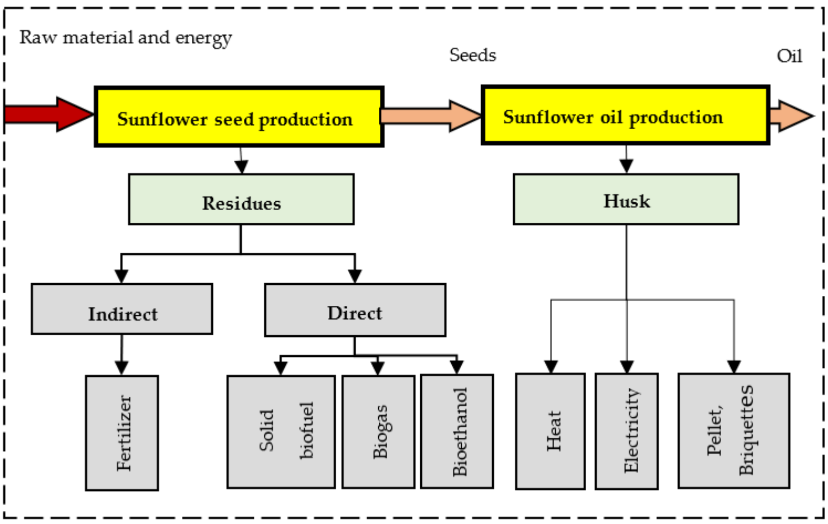

Figure 4. System boundaries for the pathway of residue utilization.

Briquettes and pellet made from sunflower husks are increasingly being used in private households and communal boiler houses. Their popularity is due to their ease of use and high rates of heat generation. They conquer not only the local market but are also exported.

Sunflower products are characterized by the highest heat output. This allows them to be used in more applications than just household boilers.

The traditional method is used for the production of this type of product. The crushed raw materials of a certain moisture level are pressed at a given temperature. What makes it possible to create briquettes of high strength and excellent quality characteristics:

- high density
- long burning time
- high level of heat capacity
- compactness

In addition, the products are not overly sensitive to storage conditions. Protection against direct moisture is enough for the briquettes or pellets to retain their properties for many years.

2.2. Circular Economy Indicators

Circular economy is a major topic, especially in the European Union. According to the Bellagio Principles, there are four groups of circular economy indicators: Environmental footprint, material and waste, socioeconomic impact, and policy as well as process implementation [54–58]. Only a few indicators of the first and second groups meet the objectives of this study. They concern renewable energy, greenhouse gas emissions, and recycling of materials. We selected relevant indicators to monitor the circular economy transition (Table 1) [59–61].

Table 1. Indicators to monitor the circular economy transition.

Classification	Indicator
Footprint	Renewable energy share Carbon dioxide emissions savings Energy recoverability benefit rate
Material and waste	Circular material use rate

The renewable energy share (RES) is calculated as

$$RES = \frac{DES + IDES}{EI} \cdot 100,\ \%, \tag{1}$$

where DES is the direct energy inputs substituted by bioenergy, MJ/t; $IDES$ is the indirect energy inputs substituted by bioenergy, MJ/t; and EI is the energy inputs, MJ/t.

The energy recoverability benefit rate ($ERBR$) is the share of residue-embodied energy that can be saved when the residues would be recycled

$$ERBR = \frac{0.01 \cdot \eta \cdot \alpha \cdot MR \cdot LHV_{\alpha} + 0.01 \cdot \beta \cdot EE_{BP}}{MR \cdot LHV_{MR}} \cdot 100,\ \ \%, \tag{2}$$

where η is the energy efficiency for the power and/or heat generation, %; α is the yield of biofuel, g/kg (l/kg, m^3/kg); LHV_{α} is the lower heating value of the derived fuel, MJ/kg (MJ/L, MJ/m^3); β is the yield of by-products, %; EE_{BP} is the embodied energy of an original product substituted by the by-products, MJ/kg; MR is the mass of the residue, kg/t; and LHV_{MR} is the lower heating value of the residue, MJ/kg.

2.3. Carbon Dioxide Emission Savings

We analyzed direct and indirect carbon dioxide emission savings (Figure 5). Direct savings is the result of biomass combustion. Biomass substitutes fossil fuels and, therefore, reduces carbon dioxide emissions. Indirect savings is the application of field residues as biofertilizer, reducing the amount of mineral fertilizers used.

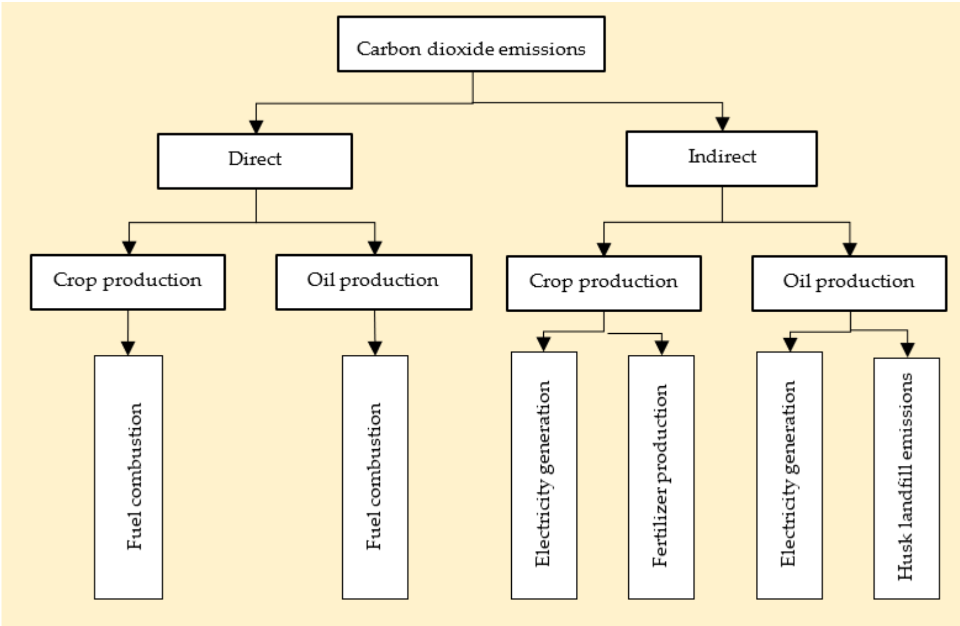

Figure 5. Carbon dioxide emissions in sunflower oil production.

Carbon dioxide emissions savings (*CDES*) is determined by the following formula

$$CDES = EE_e \cdot We + EE_h \cdot Wh + WTW_f \cdot MF,\ \text{kgCO}_2, \quad (3)$$

where EE_e is the emission factor for power generation, $kgCO_2/kWh$; EE_h is the emission factor for heat generation, $kgCO_2/kWh$; *We* is the power generated, kWh per residue obtained from a ton of seed; *Wh* is the heat generated, kWh per residue obtained from a ton of seed; WTWf is the well-to-wake carbon dioxide emissions of the mineral fertilizer, $kgCO_2/kg$; and *MF* is the mass of the mineral fertilizer substituted by biofertilizer, kg.

3. Results and Discussion

3.1. Sunflower Residues and Husk Availability

The flows of sunflower biomass growing are as follows: seeds—1000 kg, stalks—from 1400 to 1700 kg, and heads and chaffs—from 200 to 600 kg [45]. The by-products have acceptable calorific value and contain major nutrients, such as nitrogen, phosphorus, and potassium (Table 2) [62].

Table 2. The properties of sunflower stalks.

Indicator	Unit	Value		
		Minimum	Maximum	Average
Lower heating value	MJ/kg	15.2	24.4	17.7
Moisture content	%	2.3	18.0	9.1
Nitrogen [db]	%	0.31	2.0	1.11
Phosphorus [db]	%	0.01	0.23	0.09
Potassium [db]	%	0.80	6.78	2.75

db—dry base.

Since 2012, Ukraine has held a worldwide leadership position in sunflower seed production. Due to innovative technologies, Ukrainian farmers have achieved high yields that exceed the worldwide average. The calculations assumed 2150 kg/ha and the total energy inputs of 12,000 MJ/ha [63,64]. At this seed yield, residues are generated in the range of 3440 to 4945 kg/ha (fresh mass).

Husk is a by-product of sunflower oil production. Its output varies from 15.9 to 18.8% of sunflower seed consumption. In Ukraine, the average output is 17.5% [65]. This value was assumed for the calculations.

3.2. Indirect Energy Input and Carbon Dioxide Savings

Crop residues can be used as biofertilizer, which results in a decrease in the use of mineral fertilizers. The indirect energy input savings is the function of nutrient contents in the residues

$$IDE = 0.01 \cdot MR \cdot (1 - 0.01 \cdot WC) \cdot \sum_{i=1}^{n} (NC_i \cdot EE_i),\ \text{MJ/ha}, \quad (4)$$

where MR is the mass of the residues, kg/ha; WC is the water content of the residues, %; NC_i is the content of the *ith* nutrient component, %; and EE_i is the energy equivalent (embodied energy) of the *ith* nutrient component, MJ/kg.

The energy equivalent or embodied energy and well-to-wake (WTW) carbon dioxide emissions of mineral fertilizers are shown in Table 3 [66–69].

Table 3. Embodied energy and WTW carbon dioxide emissions of fertilizers.

Component	Embodied Energy, MJ/kg	WTW Carbon Dioxide Emissions, gCO_2/kg
Nitrogen	52.0–121.2	913–7108
Phosphorus	12.6–63.0	1051–1083
Potassium	6.7–16.8	583

The indirect energy inputs of mineral fertilizers substituted by residues range from 772.8 to 1864.0 MJ per ton of seeds. These values constitute 8.25% to 52.95% of the total energy inputs. In Ukraine, this indicator is approximately 23.6%. Carbon dioxide emission savings vary from 27.1 to 95.9 $kgCO_2$ per ton of seeds.

3.3. The Energy Production from Sunflower Field-Based Residues

Sunflower residues can be converted into energy using several methods (Figure 6).

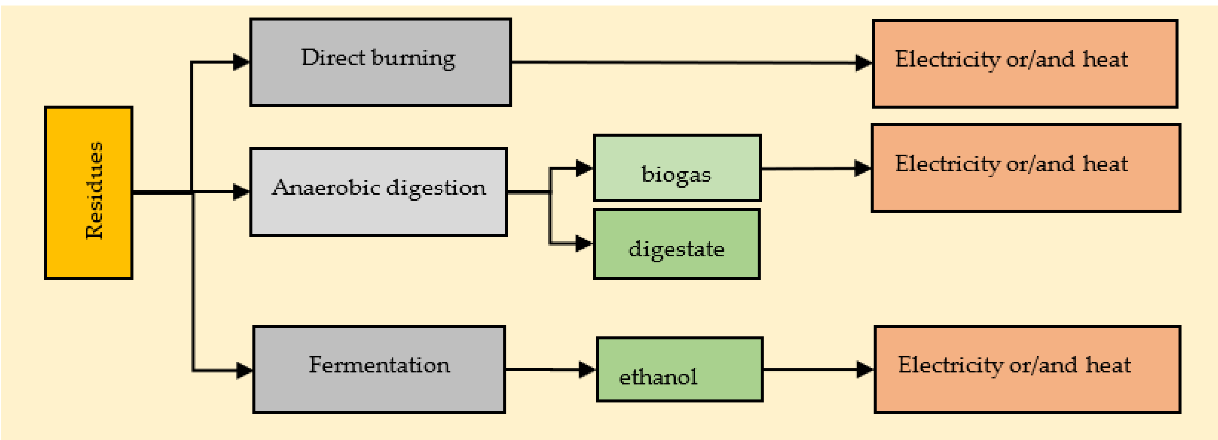

Figure 6. The transformation of residues into energy.

Direct combustion is the simplest pathway. It allows consumers to produce electricity and/or heat. Farmers harvest the sunflower seeds when the water content of the stalks is 60% [45]. Their lower heating value is approximately 7.78 MJ/kg. Sunflower residues should be dried before burning. Biomass-based power plants have an electric efficiency of

18% to 32% [70]. Sole heat generation has an efficiency of up to 85%. Combined heat and power plants can reach a total efficiency of 85% (including electricity efficiency) [45]. This technology is mature and, therefore, widespread. The direct combustion of residues can generate electricity, heat, or combined heat and power as follows: sole power generation—from 622.4 to 1590.5 kWh, and combined heat and power—from 2938.9 to 4224.8 kWh. The renewable energy share is 0% because the energy generated is not used for sunflower cultivation. Electricity and heat are delivered to external consumers.

Sunflower residues can be used as a substrate for anaerobic digestion. Due to the high content of cellulose, they need to be treated before digestion. The biomethane yield ranges from 127 to 210 m^3 per ton of volatile solids [45]. The by-product of biogas production is the digestate, which can be used as a biofertilizer [71]. Sunflower residues-based biogas plants can generate from 690.2 to 1642.2 kWh, including electricity (from 324.8 to 772.8 kWh). The use of the digestate as a biofertilizer increases the circular economy indicators.

Fermentation produces 101.4 L of bioethanol per ton of sunflower residues [72]. Ethanol can substitute fossil fuels for power generation [3]. There are different power generation devices suitable to be fueled by ethanol: internal combustion engines, gas turbine engines, and fuel cells. Their power efficiency varies in a wide range: gas turbine engines—up to 35%, internal combustion engines—from 25 to 44%, and fuel cells—up to 83% [73,74]. The application of internal combustion engine generators is a mature technology [75]. An ethanol-based power plant can generate electricity in the range of 238.9 to 604.2 kWh per ton of seeds.

The use of sunflower residues for power generation and the substitution of mineral fertilizers reduces carbon dioxide emissions. The carbon dioxide intensity of any national power generation system is a function of the following factors: the type of plant, conversion efficiencies, fuel or energy sources, and transmission and distribution losses in the grid. In European countries (top producers of sunflower seeds), this indicator varies from 98 (France) to 588 (Turkey) gCO_2eq/kWh [76]. The Ukrainian power generation system has an average carbon dioxide emission factor of 0.492 $kgCO_2/kWh$ [77–79].

Ukrainian heat supply systems mainly use natural gas as fuel. They have a carbon dioxide emission factor of 0.219 $kgCO_2/kWh$ (at 90% efficiency). Natural gas upstream emissions are the result of making the gaseous fuel ready for combustion. This process includes the extraction, refining, and transportation of natural gas for heat generation. Natural gas upstream emissions were estimated as 12.8 gCO_2eq/MJ [80]; for this reason, we used 0.128 $kgCO_2/kWh$. These factors allowed for the determination of carbon dioxide emission savings for different power supply systems. All derived biofuels can fuel cogeneration plants. This solution improves energy and environmental indicators.

The main circular economy indicators, such as the energy recoverability benefit rate, the renewable energy share, circular material use rate, and carbon dioxide savings, are calculated by the authors and presented in Table 4. The biomass-fired plants have the best indicator values. The ethanol-based plants have the worst indicator values.

To implement the above energy potential, farms should set up vertically integrated agro-energy companies. The utilization of all by-products produced by electricity generation increases their profitability [81,82]. However, despite the energy and environmental advantages, sunflower field-based residues are not widely used for energy production [83]. Sunflower residue pellets are primarily produced for livestock farming [84].

3.4. Sunflower Husk Utilization

The undeniable advantage of sunflower husk pellets and briquettes is their ease of use. These fuels have an even, smooth surface, so they do not leave splinters. In addition, they do not require specialized boilers. They can be burned in ordinary furnaces and any boilers designed for solid fuel. The duration of burning is at least one and a half hours or even much longer. If the briquettes are stacked correctly, they will emit heat for several hours—first during intense burning, and then when they are smoldering.

Table 4. Indicators for sole power generation.

Technology	Indicator *			
	Energy Recoverability Benefit Rate, %	Renewable Energy Share, %	Carbon Dioxide Savings, $kgCO_2/t_{seed}$	Circular Material Use Rate, %
Biofertilizer	4.3–14.9	8.3–52.9	27.1–95.9	100
		Power generation		
Direct burning	18.0–32.0	0	306.2–782.5	100
Biogas	6.5–22.3	8.3–52.9	159.8–380.2	100
Ethanol	6.9–12.2	0	117.5–297.3	100
		Cogeneration		
Direct burning	85.0	0	1109.9–1696.6	100
Biogas	13.9–47.5	8.3–52.9	286.8–598.9	100
Ethanol	23.5	0	316.7–492.7	100

* the calculation error is within the relative standard error.

A small amount of waste remains after combustion. Ash is no more than 5% and is an excellent fertilizer with a high mineral content.

This product significantly exceeds the energy indicators of other types of solid biofuels. As a result of research, it was established that one kilogram emits up to 19,000 KJ and even more, depending on the quality. This is approximately the same as the best grades of hard coal, which have long been used for heating, water heating, and obtaining energy needed for other purposes.

2 tons of briquettes release as much energy as approximately
1 ton of diesel fuel,
1.3 tons of fuel oil,
3.2 tons of ordinary firewood,
and almost 1000 m^3 of natural gas.

The presence of natural vegetable oil residues contributes to greater heat release, which has a positive effect on the duration of combustion. On the other hand, the second emission of carbon dioxide during the burning of sunflower husks does not exceed 6–8 g (for comparison, the second emission of carbon dioxide during the burning of hard coal is not less than 20 g).

There are several methods for sunflower husk utilization. The first method is as follows. Many Ukrainian oil mills use husk as a solid fuel for heat generation. Cogeneration is a promising method. The results of the authors' calculations are presented in Table 5. The total energy requirement for sunflower seed cultivation and oil production ranges from 3520 to 9370 MJ per ton of seeds. We considered the most realistic scenario, which is the application of sunflower residues as a biofertilizer production and a husk-based energy supply system of an oil mill. The calculations show that the combination of biofertilizer and cogeneration has better indicators. Although, the improvement is not significant.

The share of power generation as a decrease in carbon dioxide savings is approximately 14.2%. It varies depending on the national carbon intensity. In European sunflower oil-producing countries, the carbon intensity ranges from 98 to 588 gCO_2eq/kWh. This variation is caused by the differences in the fuel sources and the type of power generation plants. In France, the share of renewable power generation decreases to 3.2%. In Romania, this indicator is approximately 16.5%. Carbon dioxide savings ranges from 178.8 (France) to 305.4 (Romania) $kgCO_2$ per ton of seeds.

Husk utilization for energy supply systems reduces fossil fuel consumption. Thus, this technology saves from 28.7 to 57.7 m^3 of natural gas per ton of seeds processed. A decrease in electricity supplied by the electric grid reduces the fossil fuels used for power generation. This decrease constitutes from 56.8 to 86.0 kWh per ton of seeds. Natural gas is typically used to manufacture nitrogen fertilizer. Its consumption ranges from 780 to 986 m^3 per ton of ammonia [80]. Thereby, the use of sunflower residues for fertilizer production saves from 7 to 8 m^3 per ton of seeds. The total decrease in fossil fuels may be from 35.7 to 88.7 m^3 of natural gas per ton of seeds or from 26.5 to 40.2 kg of hard coal per ton of seeds (for coal-based power plants).

Table 5. Indicators for husk utilization.

Pathway of Husk (Stalks) Utilization	Indicator *			
	Energy Recoverability Benefit Rate, %	Renewable Energy Share, %	Carbon Dioxide Savings, $kgCO_2$/t Seeds	Circular Material Use Rate (Processing/Total), %
		Oil production		
Heat generation	34.5–68.9	43.1–86.2	165.3–254.8	(43.1–6.2)/100
Cogeneration	42–80	100	193.2–297.1	(52.6–100)/100
		Sunflower cultivation		
Biofertilizer	4.3–14.9	8.3–52.8	27.1–95.9	100
		Sunflower cultivation and oil production		
Biofertilizer + heat generation	8.3–24.6	16.5–60.1	192.4–350.7	100
Biofertilizer + cogeneration	9.3–26.6	18.1–70.9	220.3–393.0	100

* the calculation error is within the relative standard error.

4. Conclusions

Agricultural residue-based biorefinery is a way towards sustainable development. It allows farmers to use by-products instead of fossil fuels to generate electricity and heat and reduce carbon dioxide emissions. Carbon dioxide emissions savings and the recycling of nutrients for plant growth are the environmental benefits. The recycling of crop residues improves circular economy indicators. In this study, we measured four indicators: the circular material use rate (sunflower stalks), the carbon dioxide emissions savings, the share of renewable energy, and the energy recoverability benefit rate.

Our investigation revealed that the recycling of sunflower husk for energy supply systems had the best indicators. The heat output of sunflower husk pellets and briquettes is much higher than that of traditional solid fuels such as firewood. They are needed much less. What also increases is the convenience of use—you do not need to constantly load the firebox. In addition, the duration of their burning is longer. Husk-based cogeneration can meet its own energy demands. The investigation showed that biomass-fired cogeneration plants provided the best circular economy indicators. The circular material use rate was the same for all pathways of residue utilization. Field-based and process-based residues can be recycled. Their combination can reach the following results: the circular material use rate—100%, the carbon dioxide emissions savings—up to 393 $kgCO_2$ per ton of seed, the share of renewable energy—up to 70.9%, and the energy recoverability benefit rate—26.6%.

The direction of further research should be to conduct a feasibility study of the above technologies based on the developed methodology for alternative fuels [85].

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References

1. WTRG Economics. Available online: https://wtrg.com/ (accessed on 20 December 2022).
2. EU Natural Gas. Available online: https://tradingeconomics.com/commodity/eu-natural-gas (accessed on 20 December 2022).
3. Yang, Y.; Tian, Z.; Lan, Y.; Wang, S.; Chen, H. An overview of biofuel power generation on policies and finance environment, applied biofuels, device and performance. *J. Traffic Transp. Eng. Engl. Ed.* **2021**, *8*, 534–553. [CrossRef]
4. Wang, T.; Qiu, P.; Liu, M.-Q.; Sun, Y.-H.; Zhang, Y. The Review of the Impact of Large Scale Photovoltaic Power Generation on Power System. In Proceedings of the 2016 International Conference on Material Science and Civil Engineering (MSCE 2016), Guangzhou, China, 17–19 June 2016; DEStech Publications Inc.: Lancaster, PA, USA, 2016. Available online: https://scholar.archive.org/work/nao4gvw73bhyfcjpkmiuz5przu/access/wayback/http://dpi-proceedings.com/index.php/dtmse/article/download/10527/10078 (accessed on 20 December 2022).
5. Geng, L.; Wang, Y.; Wang, Y.; Li, H. Effect of the injection pressure and orifice diameter on the spray characteristics of biodiesel. *J. Traffic Transp. Eng. Engl. Ed.* **2020**, *7*, 331–339. [CrossRef]
6. Alidrisi, H.; Demirbas, A. Enhanced electricity generation using biomass materials. *Energy Sources Part A Recovery Util. Environ. Eff.* **2016**, *38*, 1419–1427. [CrossRef]
7. Kussul, N.; Deininger, K.; Shumilo, L.; Lavreniuk, M.; Ali, D.A.; Nivievskyi, O. Biophysical Impact of Sunflower Crop Rotation on Agricultural Fields. *Sustainability* **2022**, *14*, 3965. [CrossRef]
8. Głąb, L.; Sowiński, J. Sustainable Production of Sweet Sorghum as a Bioenergy Crop Using Biosolids Taking into Account Greenhouse Gas Emissions. *Sustainability* **2019**, *11*, 3033. [CrossRef]
9. Brodt, S.; Six, J.; Feenstra, G.; Ingels, C.; Campbell, D. Sustainable Agriculture. *Nat. Educ. Knowl.* **2011**, *3*, 1. Available online: https://www.nature.com/scitable/knowledge/library/sustainable-agriculture-23562787/ (accessed on 28 December 2022).
10. EEA. *Trends and Projections in Europe 2022*; Tracking Progress towards Europe's Climate and Energy Targets; European Environment Agency report 10/2022; Publications Office of the European Union: Luxembourg, 2022. Available online: https://www.eea.europa.eu//publications/trends-and-projections-in-europe-2022 (accessed on 18 December 2022).
11. Plaza-Bonilla, D.; Nogué-Serra, I.; Raaillac, D.; Cantero-Martínez, C.; Justes, É. Carbon footprint of cropping systems with grain legumes and cover crops: A case-study in SW France. *Agric. Syst.* **2018**, *167*, 92–102. [CrossRef]
12. Yadav, G.S.; Das, A.; Lal, R.; Babu, S.; Meena, R.S.; Saha, P.; Singh, R.; Datta, M. Energy budget and carbon footprint in a no-till and mulch based rice–mustard cropping system. *J. Clean. Prod.* **2018**, *191*, 144–157. [CrossRef]
13. Bartocci, P.; Fantozzi, P.; Fantozzi, F. Environmental impact of Sagrantino and Grechetto grapes cultivation for wine and vinegar production in central Italy. *J. Clean. Prod.* **2017**, *140*, 569–580. [CrossRef]
14. Shen, Y.; Sui, P.; Huang, J.; Wang, D.; Whalen, J.K.; Chen, Y. Global warming potential from maize and maize-soybean as affected by nitrogen fertilizer and cropping practices in the North China Plain. *Field Crops Res.* **2018**, *225*, 117–127. [CrossRef]
15. Bernas, J.; Bernasová, T.; Nedbal, V.; Neugschwandtner, R.W. Agricultural LCA for Food Oil of Winter Rapeseed, Sunflower, and Hemp, Based on Czech Standard Cultivation Practices. *Agronomy* **2021**, *11*, 2301. [CrossRef]
16. Production of Major Vegetable Oils Worldwide from 2012/13 to 2021/2022, by Type. Available online: https://www.statista.com/statistics/263933/production-of-vegetable-oils-worldwide-since-2000/#:~:text=The%20production%20volume%20of%20vegetable,200%20million%20metric%20tons%20worldwide (accessed on 20 December 2022).
17. FAO. *World Food and Agriculture—Statistical Yearbook 2021*; FAO: Rome, Italy, 2021; p. 368. [CrossRef]
18. Debaeke, P.; Casadebaig, P.; Flenet, F.; Langlade, N. Sunflower crop and climate change: Vulnerability, adaptation, and mitigation potential from case-studies in Europe. *Oilseeds Fats Crops Lipids* **2017**, *24*, D102. [CrossRef]
19. Top Countries in Sunflower Oil Production. Available online: https://www.nationmaster.com/nmx/ranking/sunflower-oil-production (accessed on 20 December 2022).
20. World Agricultural Production, USDA Reports, February 2023. Available online: https://apps.fas.usda.gov/psdonline/circulars/production.pdf (accessed on 15 February 2023).
21. In the 2020–2021 MY, the Growth of World Sunflower Production is Expected. Available online: https://kaissaoil.com/en/in-the-2020-2021-my-the-growth-of-world-sunflower-production-is-expected/#:~:text=According%20to%20an%20updated%20report,areas%20by%201%2C100%2C000%2D1%2C200%2C000%20hectares (accessed on 20 December 2022).
22. Oguz, C.; Ogur, A.Y. Energy Productivity and Efficiency in Sunflower Production. *J. Agric. Sci. Technol.* **2022**, *24*, 767–777. Available online: http://jast.modares.ac.ir/article-23-49274-en.html (accessed on 18 December 2022).
23. Uzunoz, M.; Akcay, Y.; Esengun, K. Energy Input-output Analysis of Sunflower Seed (*Helianthus annuus* L.) Oil in Turkey. *Energy Sources Part B Econ. Plan. Policy* **2008**, *3*, 215–223. [CrossRef]
24. Yousif, L.A.; Mohamed, M.Y.; Ahmed, M.A.A. Energy use analysis for sunflower (*Helianthus annuus* L.) production in the mechanized rain fed schemes eastern Sudan. *Diyala Agric. Sci. J.* **2022**, *2*, 43–51. [CrossRef]
25. Avval, S.H.M.; Rafiee, S.; Keyhani, A. Energy Efficiency Analysis in Agricultural Productions: Parametric and Non-Parametric Approaches. In *Energy Efficiency—A Bridge to Low Carbon Economy*; IntechOpen: London, UK, 2012; pp. 135–158. [CrossRef]
26. Kallivroussis, L.; Natsis, A.; Papadakis, G. RD—Rural Development: The Energy Balance of Sunflower Production for Biodiesel in Greece. *Biosyst. Eng.* **2002**, *81*, 347–354. [CrossRef]
27. Yousefi, M.; Khoramivafa, M.; Damghani, A.M. Water footprint and carbon footprint of the energy consumption in sunflower agroecosystems. *Environ. Sci. Pollut. Res. Int.* **2017**, *24*, 19827–19834. [CrossRef]

28. Hamzei, J.; Seyyedi, M. Energy use and input-output costs for sunflower production in sole and intercropping with soybean under different tillage systems. *Soil Pollut. Res.* **2016**, *157*, 73–82. [CrossRef]
29. Nategh, N.A.; Banaeian, N.; Gholamshahi, A.; Nosrati, M. Optimization of energy, economic, and environmental indices in sunflower cultivation: A comparative analysis. *Environ. Prog. Sustain. Energy* **2021**, *40*, e13505. [CrossRef]
30. Maslikov, M. *Energy Efficiency Benchmarking in the Vegetable Oil Subsector of the Ukraine's Agro-Industrial Sector*; Report; UNIDO: Kyiv, Ukraine, 2012. Available online: https://open.unido.org/api/documents/3239314/download/2015_Energy%20Benchmarking%20Report_Oil_eng.pdf (accessed on 19 November 2022).
31. Havrysh, V.; Kalinichenko, A.; Mentel, G.; Mentel, U.; Vasbieva, D.G. Husk Energy Supply Systems for Sunflower Oil Mills. *Energies* **2020**, *13*, 361. [CrossRef]
32. Statistical Review of World Energy. 2021. Available online: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-full-report.pdf (accessed on 18 December 2022).
33. EDF's Power Generation Rebounded by 4.3% in 2021 (France). Available online: https://www.enerdata.net/publications/daily-energy-news/edfs-power-generation-rebounded-43-2021-france.html (accessed on 20 December 2022).
34. Distribution of Electricity Generation in Hungary in 2021, by Source. Available online: https://www.statista.com/statistics/1235432/hungary-distribution-of-electricity-production-by-source/#:~:text=Hungary%20sources%20most%20of%20its,production%20was%20fossil%20fuel%2Dbased (accessed on 20 December 2022).
35. Country Nuclear Power Profiles 2022 Edition. Available online: https://cnpp.iaea.org/countryprofiles/Romania/Romania_tables.htm (accessed on 20 December 2022).
36. Koplitz, S.N.; Jacob, D.J.; Sulprizio, M.P.; Myllyvirta, L.; Reid, C. Burden of Disease from Rising Coal-Fired Power Plant Emissions in Southeast Asia. *Environ. Sci. Technol.* **2017**, *51*, 1467–1476. [CrossRef]
37. Kushta, J.; Paisi, N.; Van Der Gon, H.D.; Lelieveld, J. Disease burden and excess mortality from coal-fired power plant emissions in Europe. *Environ. Res. Lett.* **2021**, *16*, 045010. [CrossRef]
38. Joint Implementation Project Design Document Form—Version 01. Available online: https://ji.unfccc.int/UserManagement/FileStorage/K1I6W5VRE27LF3PZUJGTHOCYDNMQB4 (accessed on 19 November 2022).
39. Petrillo, A.; Di Bona, G.; Forcina, A.; Silvestri, A. Building excellence through the Agile Reengineering Performance Model (ARPM): A strategic business model for organizations. *Bus. Process Manag. J.* **2018**, *24*, 128–157. [CrossRef]
40. Garofalo, P.; D'Andrea, L.; Tomaiuolo, M.; Venezia, A.; Castrignanò, A. Environmental sustainability of agri-food supply chains in Italy: The case of the whole-peeled tomato production under life cycle assessment methodology. *J. Food Eng.* **2017**, *200*, 1–12. [CrossRef]
41. Babu, S.; Rana, D.S.; Yadav, G.S.; Singh, R.; Yadav, S.K. A review on recycling of sunflower residue for sustaining soil health. *Int. J. Agro.* **2014**, *2014*, 601049. [CrossRef]
42. Srisa-Ard, K. Effects of crop residues of sunflower (*Helianthusannuus*), maize (*Zea mays* L.) and soybean (*Glycine max*) on growth and seed yields of sunflower. *Pak. J. Biol. Sci.* **2007**, *10*, 1282–1287. [CrossRef] [PubMed]
43. Babu, S.; Rana, D.S.; Yadav, G.S.; Singh, R. Influence of sunflower stover and nutrient management on growth, yield and energetics of sunflower (*Helianthus annuus*) in a pigeonpea (*Cajanus cajan*)-sunflower cropping system. *Indian J. Agric. Sci.* **2016**, *86*, 315–320. Available online: https://www.researchgate.net/publication/301621634_Influence_of_sunflower_stover_and_nutrient_management_on_growth_yield_and_energetics_of_sunflower_Helianthus_annuus_in_a_pigeonpea_Cajanus_cajan-_sunflower_cropping_system (accessed on 20 December 2022).
44. Nizami, A.S.; Rehan, M.; Waqas, M.; Naqvi, M.; Ouda, O.K.M.; Shahzad, K.; Miandad, R.; Khan, M.Z.; Syamsiro, M.; Ismail, I.M.I.; et al. Waste biorefineries: Enabling circular economies in developing countries. *Bioresour. Technol.* **2017**, *241*, 1101–1117. [CrossRef]
45. Geletukha, G.; Drahniev, S.; Zheliezna, T.; Bashtovyi, A. Prospects of Sunflower Residues Use for Energy. UABIO Position Paper, 2020, № 25. Available online: https://uabio.org/wp-content/uploads/2020/10/uabio-position-paper-25-en-1.pdf (accessed on 20 December 2022).
46. Marchenko, D.; Dykha, A.; Aulin, V.; Matvyeyeva, K.; Tishechkina, K.; Kurepin, V. Development of Technology and Research of Method of Electric Hydropulse Hardening of Machine Parts. In Proceedings of the IEEE Problems of Automated Electrodrive. Theory and Practice (PAEP), Kremenchuk, Ukraine, 1–25 September 2020. [CrossRef]
47. Dykha, A.V.; Marchenko, D.D.; Artyukh, V.A.; Zubiekhina-Khaiiat, O.V.; Kurepin, V.N. Study and development of the technology for hardening rope blocks by reeling. *East.-Eur. J. Enterp. Technol.* **2018**, *2*, 22–32. [CrossRef]
48. Silvestri, L.; Silvestri, C.; Forcina, A.; De Luca, C. A review of energy-based indicators for assessing sustainability and circular economy in the agri-food production. *Procedia Comput. Sci.* **2022**, *200*, 1756–1765. [CrossRef]
49. Booneimsri, P.; Kubaha, K.; Chullabodhi, C. Increasing power generation with enhanced cogeneration using waste energy in palm oil mills. *Energy Sci. Eng.* **2018**, *6*, 154–173. [CrossRef]
50. Azhdari, A.; Ghadamian, H.; Ataei, A.; Yoo, C.K. A New Approach for Optimization of Combined Heat and Power Generation in Edible Oil Plants. *J. Appl. Sci.* **2009**, *9*, 3813–3820. [CrossRef]
51. Ion, I.V.; Popescu, F. Improving the Energy Balance in a Sunflower Oil Mill. *Sci. Works Univ. Food Technol.* **2017**, *64*, 164–171. Available online: https://www.researchgate.net/publication/331168286_Improving_the_Energy_Balance_in_a_Sunflower_Oil_Mill (accessed on 8 January 2023).

52. Donaldson, A.; Kadakia, P.; Gupta, M. Production of Energy and Activated Carbon from Agri-Residue: Sunflower Seed Example. *Appl. Biochem. Biotechnol.* **2012**, *168*, 154. [CrossRef] [PubMed]
53. Alcock, T.D.; Salt, D.E.; Ramsden, S.J. A harmonised systems-wide re-analysis of greenhouse gas emissions from sunflower oil production. *bioRxiv* **2020**. [CrossRef]
54. Batsurovska, I.; Havrysh, V.; Novikov, O.; Hruban, V. Methods for Organising Conferences for Electrical Engineering Specialists via Distance Learning. In Proceedings of the IEEE International Conference on Modern Electrical and Energy Systems (MEES), Kremenchuk, Ukraine, 21–24 September 2021; pp. 1–6. [CrossRef]
55. Batsurovska, I. MOOCs in the system of e-learning of masters in Electrical Engineering. In Proceedings of the IEEE International Conference on Modern Electrical and Energy Systems (MEES), Kremenchuk, Ukraine, 21–24 September 2021; pp. 1–4. [CrossRef]
56. Philippidis, G.; Bartelings, H.; Smeets, E. Sailing into Unchartered Waters: Plotting a Course for EU Bio-Based Sectors. *Ecol. Econ.* **2018**, *147*, 410–421. [CrossRef]
57. Soloviev, V.N.; Lytvynova, S.H.; Batsurovska, I.V.; Dotsenko, N.A.; Gorbenko, O.A.; Kim, N.I.; Haleeva, A.P. Technology of application of 3D models of electrical engineering in the performing laboratory work. In Proceedings of the 9th Workshop on Cloud Technologies in Education (CTE 2021), Kryvyi Rih, Ukraine, 17 December 2021; pp. 323–335. Available online: http://ceur-ws.org/Vol-3085/paper09.pdf (accessed on 8 January 2023).
58. Urmetzer, S.; Lask, J.; Vargas-Carpintero, R.; Pyka, A. Learning to change: Transformative knowledge for building a sustainable bioeconomy. *Ecol. Econ.* **2020**, *167*, 106435. [CrossRef]
59. Measuring and Monitoring the Circular Economy and Use of Data for Policy-Making. October 2021. Available online: https://unece.org/sites/default/files/2021-10/Background%20report%20on%20measuring%20circular%20economy_ENG.pdf (accessed on 8 January 2023).
60. UNECE. *In-Depth Review of Measuring the Circular Economy Prepared by Finland (Lead), Belarus, Canada, Colombia, Netherlands, EEA, Eurostat, UNECE, UNSD, UNEP and OECD-ECE/CES/BUR/2020/OCT/2*; United Nations Economic Commission for Europe (UNECE): Geneva, Switzerland, 2020. Available online: https://unece.org/sites/default/files/2021-02/S3_1_In-depth_review_CE_EN.pdf (accessed on 8 January 2023).
61. OECD. *Global Material Resources Outlook to 2060: Economic Drivers and Environmental Consequences*; Organisation for Economic Co-operation and Development (OECD): Paris, France, 2019. Available online: https://www.oecd.org/environment/waste/highlights-global-material-resources-outlook-to-2060.pdf (accessed on 8 January 2023).
62. Characterisation of Agricultural Waste Co- and By-Products. Report of AgroCycle Project. Available online: http://www.agrocycle.eu/files/2017/10/D1.2_AgroCycle.pdf (accessed on 8 January 2023).
63. Plant Growing in Ukraine 2020; State Statistics Service of Ukraine: Kyiv, Ukraine, 2021. Available online: http://www.ukrstat.gov.ua/druk/publicat/kat_u/2021/zb/05/zb_rosl_2020.pdf (accessed on 8 January 2023).
64. World Agricultural Production, USDA Report, July 2022. Available online: https://downloads.usda.library.cornell.edu/usda-esmis/files/5q47rn72z/3197zt68h/cz30r0703/production.pdf (accessed on 8 January 2023).
65. JI Project "Utilization of Sunflower Seeds Husk for Steam and Power Production at the Oil Extraction Plant OJSC Kirovogradoliya". 2009. Available online: https://secbiomass.com/en/projects/546/ (accessed on 6 January 2022).
66. Aguilera, E.; Guzmán, G.I.; Infante-Amate, J.; García-Ruiz, R.; Herrera, A.; Villa, I. Embodied Energy in Agricultural Inputs. Incorporating a Historical Perspective. DT-SEHA 15. 2015. Available online: http://hdl.handle.net/10234/141278 (accessed on 8 January 2023).
67. Skowrońska, M.; Filipek, T. Life cycle assessment of fertilizers: A review. *Int. Agrophys.* **2014**, *28*, 101–110. [CrossRef]
68. Ledgard, S.F.; Boyes, M.; Brentrup, F. Life Cycle Assessment of Local and Imported Fertilisers Used on New Zealand Farms. In *Adding to the Knowledge Base for the Nutrient Manager*; Occasional Report No. 24. Christensen; Massey University: Auckland, New Zeland, 2011. Available online: https://www.massey.ac.nz/~flrc/workshops/11/Manuscripts/Ledgard_2011.pdf (accessed on 8 January 2023).
69. Wood, S.; Cowie, A. A Review of Greenhouse Gas Emission Factors for Fertiliser Production. June 2004. For IEA Bioenergy Task 38. Available online: https://www.sciencetheearth.com/uploads/2/4/6/5/24658156/2004_wood_a_review_of_greenhouse_gas_emission_factors.pdf (accessed on 8 January 2023).
70. Biomass for Heat and Power Technology Brief. IEA-ETSAP and IRENA Technology Brief E05. 2015. Available online: https://biomasspower.gov.in/document/Reports/IRENA_Biomass%20for%20Heat%20and%20Power.pdf (accessed on 8 January 2023).
71. Havrysh, V.; Kalinichenko, A.; Mentel, G.; Olejarz, T. Commercial Biogas Plants: Lessons for Ukraine. *Energies* **2020**, *13*, 2668. [CrossRef]
72. Ruiz, E.; Cara, C.; Ballesteros, M.; Manzanares, P.; Ballesteros, I.; Castro, E.E. Ethanol production from pretreated olive tree wood and sunflower stalks by an SSF process. *Appl. Biochem. Biotechnol.* **2006**, *130*, 631–643. [CrossRef]
73. Seljak, T.; Buffi, M.; Valera-Medina, A.; Chong, C.; Chiaramonti, D.; Katrašnik, T. Bioliquids and their use in power generation—A technology review. *Renew. Sustain. Energy Rev.* **2020**, *129*, 109930. [CrossRef]
74. Jiao, K.; Alaefour, I.E.; Karimi, G.; Li, X. Cold start characteristics of proton exchange membrane fuel cells. *Int. J. Hydrogen Energy* **2011**, *36*, 11832–11845. [CrossRef]
75. Pacheco, R.; Silva, C. Global Warming Potential of Biomass-to-Ethanol: Review and Sensitivity Analysis through a Case Study. *Energies* **2019**, *12*, 2535. [CrossRef]

76. Scarlat, N.; Prussi, M.; Padella, M. Quantification of the carbon intensity of electricity produced and used in Europe. *Appl. Energy* **2022**, *305*, 117901. [CrossRef]
77. *In 2020, the Installed Capacity of WPPs and SPPs Increased by 41% and Their Share in the Generation Mix Doubled*; Ukrenergo: Kyiv, Ukraine, 2021. Available online: https://ua.energy/general-news/in-2020-the-installed-capacity-of-wpps-and-spps-increased-by-41-and-their-share-in-the-generation-mix-doubled/ (accessed on 8 January 2023).
78. Moro, A.; Lonza, L. Electricity carbon intensity in European Member States: Impacts on GHG emissions of electric vehicles. *Transp. Res. Part D* **2018**, *64*, 5–14. [CrossRef]
79. Havrysh, V.; Kalinichenko, A.; Szafranek, E.; Hruban, V. Agricultural Land: Crop Production or Photovoltaic Power Plants. *Sustainability* **2022**, *14*, 5099. [CrossRef]
80. Prussi, M.; Yugo, M.; De Prada, L.; Padella, M.; Edwards, R.; Lonza, L. *JEC Well-to-Tank report v5*; EUR 30269 EN; Publications Office of the European Union: Luxembourg, 2020; ISBN 978-92-76-19926-7. [CrossRef]
81. Bilan, Y.; Nitsenko, V.; Havrysh, V. Energy aspect of vertical integration in agriculture. *Rynek Energii* **2017**, *5*, 98–110. Available online: https://www.researchgate.net/publication/331212173_Energy_aspect_of_vertical_integration_in_agriculture (accessed on 5 January 2023).
82. Pinczynski, M.; Kasperowicz, R. Overview of Electricity Market Monitoring. *Econ. Soc.* **2016**, *9*, 153–167. [CrossRef]
83. Biomass Heating. Available online: https://uabio.org/en/biomass-heating/ (accessed on 9 January 2023).
84. Sunflower Pellets. Available online: https://www.cargohandbook.com/Sunflower_Pellets#Applications (accessed on 9 January 2023).
85. Kalinichenko, A.; Havrysh, V.; Atamanyuk, I. The Acceptable Alternative Vehicle Fuel Price. *Energies* **2019**, *12*, 3889. [CrossRef]