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Technical and Economic Aspects of Environmentally Sustainable Investment in Terms of the EU Taxonomy

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Abstract: Removing impurities that occur in landfill gas, from sulphur and silicon compounds, is crucial for the energetic use of biogas in a cogeneration unit for energy purposes. The aim of this study was to analyse the shaped activated carbon, examining its structure and elemental composition as part of the biogas purification. The qualitative study of the purified landfill gas performed in this study showed a significant overshoot of hydrogen sulphide at 304.1 ppm with respect to the gas engine manufacturer's requirements, while the calculated hydrogen sulphide reduction efficiency was 24.58%. Examination of the surface of the spent carbon and its pores with a scanning microscope revealed a high level of clotting by sulphur compounds, which prevents proper reduction of this compound and reduces the efficiency of the treatment plant. Replacement of the activated carbon bed with a new one showed a hydrogen sulphide value of 7.5 ppm in the purified gas and a calculated reduction efficiency of 97.9%. The results of the study confirmed that continuous monitoring of the quality of the purified gas is necessary to control the adsorption properties of the activated carbon and can be used for the operation of gas engines in cogeneration units. The landfill gas treatment method described in this paper constitutes an environmentally sustainable project within the meaning of the EU regulation on the establishment of a framework to promote and facilitate this type of investment in terms of its financing and operation. The topic of the work fits into three key areas of broad research and implementation activities. The first, technological, is the transition to a low-carbon, sustainable and resource-efficient closed-loop economy; the second, environmental, pollution prevention and control. The third area is economics and finance in terms of making financial products available designed to reduce climate change and reporting on these activities.

Keywords: activated carbon; landfill gas; gas treatment; hydrogen sulphide removal; cogeneration

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1. Introduction

A landfill site, with its related facilities, is a building facility which, at the operation and reclamation stage, requires constant monitoring to determine its impact on individual environmental components. This is particularly true for monitoring water quality and emissions from the landfill surface into the air. Depending on the type of waste deposited, the eluate generated will be distinguished by its diverse chemical composition [1,2]. Of particular concern is the effluent generated in the waste deposit, which, in the event of leaks in the landfill insulation, poses a potential threat to surface and ground waters quality. Therefore, the wastewater generated in the landfill needs to be captured and purified according to its composition [3,4]. Containing a high load of inorganic and organic substances, heavy metals and toxic compounds, they pose a threat to individual and collective water intakes [5,6]. Landfill gas (LFG) generated in a landfill, which is not contained in an orderly manner, represents fugitive emissions of methane and carbon dioxide into the atmospheric air as the main greenhouse gases. The gas extracted using the degassing system is a renewable energy source and, as a gaseous fuel, can be converted to other energy carriers. Such activities are part of the measures affecting climate change mitigation as a result of environmentally sustainable projects [7,8]. The definition of biogas introduced for the purposes of billing energy generated from renewable sources is included in the Renewable Energy Sources Act (Journal of Laws 2015, item 478, as amended) [9]. Biogas, which originates from the anaerobic digestion of compounds of organic origin, can be produced, inter alia, in digesters at a wastewater treatment plant, bioreactors as agricultural or municipal biogas with full control and monitoring of this process [10,11]. In the case of LFG generation, the scenario is radically different, as the bioreactor operations are performed by the landfill, and the gas generation is out of control. The capture of biogas is achieved through a degassing system (plant), which is an integral part of the landfill both during its operation and after its reclamation [12,13]. The LFG generated in the landfill constitutes a gaseous fuel and should, therefore, be managed in an optimal way depending on its quality and quantity parameters [14,15]. The process that ensures efficient management of the gas is its purification and the generation of electricity and heat by burning the gas in gas engines that are part of a CHP (Combined Heat and Power) unit. This method represents the optimum use of the chemical energy contained in the gas and the highest efficiency in energy production [16,17].

A key element for the energetic use of biogas as well as natural gas in cogeneration units is the quality of the fuel to be combusted in the gas engine [18,19]. Where the operator of the landfill has no influence on the methanogenic process in the waste bed, they can only take care of the correct compression of the waste and the moisture content, e.g., by an irrigation system in the form of a return of eluate water to the landfill. Gas extracted from the waste bed from gas wells (vertical and horizontal) using pipelines should be subject to a treatment process of physical and chemical impurities before its energetic use in a CHP plant [20]. The quality testing of LFG is performed as a basis for the implementation of a proper purification system, and this concerns the removal or reduction of values of hydrogen sulphide, silicon and siloxanes [21,22]. The concentration of hydrogen sulphide in LFG is a resultant of the quality of waste accumulated in the landfill and inorganic sulphate content, which is consequently the cause of corrosion during combustion in a gas engine and numerous failures related to damage to moving parts of the engine [23]. In order to identify a sample of spent activated carbon, laboratory tests are used to determine the content of particular chemical compounds in the test sample. A method of handling such solutions was described by Feng et al., who used flotation separation of Cu-Fe sulfide minerals using selective depressors that interact with the pyrite surface [24].

Available and applied biogas desulphurisation licences allow the removal of hydrogen sulphide by, among others, adsorption using activated carbon, turf ore or biological filter beds [25]. The selection of appropriate technology should consider the hydrogen sulphide content of the biogas, the adsorption capacity of the filter, and the frequency of absorbent replacement, which has an impact on the operating costs of the plant [26,27]. Landfill gas further contains siloxanes, oxygen and methyl groups, commonly found in shampoos, deodorants, detergents, pharmaceuticals and paints, and adhesives [28]. When combusted in a gas engine, silicon is released, which, by combining with oxygen, forms permanent deposits containing silica and silicates [29]. The result of these formed deposits is abrasive wear between the moving parts of the engine, causing wear on the crankshaft, pistons, etc. [30,31].

Polymer resin, silica gel and activated carbon-based filters used in LFG treatment plants provide at an acceptable level the reduction of silicon compounds contained in the gas [32]. The method most commonly applied is the removal of sulphur compounds and siloxanes through the use of an adsorption bed based on activated carbon, and this is supported by its adsorption properties [33,34]. Activated carbon is composed of graphite-like microcrystallites, in which the ordering of the carbon atoms is similar to the structure of pure graphite. The porous structure of activated carbons determines the sorption properties and, thus, the possibility of using them in specific areas, including gas purification [35]. Carbon has versatile applications beyond adsorption. Carbon compounds, in the form of graphite, have found applications in conductivity to improve electrical charge transport. Graphitic carbon components are key to enhancing the transport efficiency of photogenerated charge carriers based on the g-C3N4 hetero-structure described in their work by Zhang et al. (2023). This type of solution may find application in photovoltaic cells in the conversion of solar radiant energy into electricity [36].

Depending on the type of storage site, there is also a high gas moisture content reaching above 80%. Such a condition obliges the plant operator to use equipment to dehydrate the untreated gas in in-line dehydrators and to remove the purified gas condensate [37,38]. The generation of energy from LFG, which is a source of renewable energy in a cogeneration system, is correlated with the generation of waste (including hazardous waste), which should be managed in a manner consistent with the waste hierarchy [39]. This concerns waste in the form of spent activated carbon used in the gas purification process [40,41]. The waste generated in the landfill gas utilisation plant, including the CHP unit, e.g., from gas treatment, used engine oils, and consumables, should be identified, balanced and assessed in order to determine precisely how these should be disposed of [33,42].

Activated carbon has been widely used as a pollutant sorbent in many industries for several decades [43,44]. It has been shown that both granular and dusty activated carbon can be used to adsorb pesticides as well as to remove various harmful compounds from wastewater, e.g., phenol, for landfill wastewater treatment [45,46]. The addition of activated carbon (AC) in the adsorption process helps to remove a wide range of pollutants and carcinogenic compounds such as pharmaceuticals, metallic and non-metallic impurities, dyes and even taste and odour from aqueous solutions [47–49]. Adsorption of pollutant gases by activated carbon has been recognised as a promising technology [50]. However, there is still a lack of comprehensive knowledge on the sustainable management of spent adsorbents loaded with pollutants [51–53].

Regeneration of spent activated carbon is based on thermal, chemical and electrochemical processes. Thermal volatilisation usually refers to the process of drying, thermal desorption and high-temperature heat treatment in the presence of a limited number of oxidising gases such as steam, flue gas and oxygen [54]. However, they are characterised by a carbon loss of 5–10% due to oxidation and abrasion and are highly energy-intensive [55,56]. Over the years, a wide range of reactivation techniques has been proposed and applied to deal with spent activated carbon, which can be thermal, wet oxidation [57,58], supercritical fluid extraction and electrochemical regeneration [59]. Chemical regeneration methods, such as wet oxidation and supercritical fluid regeneration, can be carried out by decomposing the adsorbates using oxidising chemicals under subcritical or supercritical conditions, but these techniques usually require high pressure and temperature, making them economically disadvantageous [60–62]. Literature reports support research into the regeneration of spent activated carbon by oxidation of adsorbed substances using hydrogen peroxide and the Fenton reaction, which are among the oxidants used in deep oxidation methods. It was shown that the action of hydrogen peroxide on spent carbon resulted in partial oxidation of the adsorbed substances, related to a significant weight loss and reduction in the diameter of the granules, as well as a change in the chemical nature of the surface [63]. The use of new materials in climate change mitigation installations and technologies is a challenge for researchers. A study of Cu–Fe alloy as a magnetic material was presented in their work by

Liu et al. (2019). The results showed that the alloy in question shows great potential for use as a soft magnetic material for wide industrial applications [64].

Landfill gas purification methods used to optimise the operation of cogeneration units, reducing gas and dust emissions into the environment, are dedicated installations for environmentally sustainable projects. These issues, fit strongly into the currently lively scientific as well as business discourse related to the environment, sustainability and taxonomy. The European Union (EU) taxonomy that has been developed is one step towards the development of environmental projects and the "greening" or "environmentalisation" of European countries. The taxonomy is a new EU law for classifying economic activities as environmentally sustainable. This is the colloquial name for a new piece of European Union legislation, i.e., Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on establishing a framework to facilitate sustainable projects [65]. The new legislation is intended to increase the level of environmental protection by diverting capital from environmentally damaging projects to greener alternatives. In other words, the Taxonomy does not prohibit investment in environmentally damaging activities but grants additional preference to green solutions, making research into the adsorption properties of activated carbon in the removal of hydrogen sulphide from landfill gas even more relevant and marketable. The analysis of the mentioned solution, in the opinion of the authors of this paper, should be considered in the context of the EU Taxonomy, as it affects the business model and capital raising opportunities, and regulatory changes in the financial sector contribute to redirecting capital towards sustainable activities. These changes promote the development of technologies using renewable fuels, e.g., landfill gas, to transform the energy sector [66].

The issue of taxonomy considerations has been of interest to a number of researchers in the literature, and it is interesting to find different conclusions. Implications of taxonomy implementation for small and medium-sized enterprises (SMEs), on the other hand, have been explored by O'Reilly and his team (2023). The researchers noted that the sustainability requirements that currently apply to larger companies could be extended to SMEs (small and medium-sized enterprises) by 2026 due to the increasing importance of issues in the environmental dimension. However, they also noted that SMEs may need support at that time, given the difficulty of meeting potential taxonomy requirements and the financial constraints of SMEs [67]. Och (2021), on the other hand, indicated that the taxonomy is particularly useful for defining sustainable activities. In particular, however, he noted that the taxonomy requires companies and financial market participants to disclose detailed environmental and social information, which can be quite difficult for companies and cause additional costs. However, in the long-term perspective, the negative impact of this element should be negated [68].

In their paper, Schutze and Stede (2021) described the features of the taxonomy, pointing out some of its shortcomings. For example, they pointed out that the targets for different industries (which have the highest negative environmental impact) are different, which can lead to complications in the comparison process. Therefore, it is worthwhile to ensure the development of single assessment indicators that could help to make cross-sectoral comparisons, if needed [69]. The features of the European Green Deal, of which the Taxonomy is a part, were also assessed by Sikora (2020). He noted that although the assumed course of action should help to achieve the set long-term environmental development goals, it also requires significant financial investment, which can be quite difficult to achieve [70]. Pacces (2021), on the other hand, analysed the potential of taxonomies to contribute to sustainable corporate governance. In particular, he draws attention to the competition between institutions to perform better on this taxonomy, which could further enhance its effectiveness [71]. The features of the EU taxonomy were also assessed by a team of researchers under Lucarelli (2020). The researchers noted that the legal framework is based on extensive scientific research over the past three decades, especially in relation to environmental and economic measures. Considering this, it is reasonable to expect their positive impact on the status of air pollutant emissions over time (as the implementation of the taxonomy is still ongoing) [72]. In their paper, Dusíka and Bond (2022) indicate that taxonomic approaches can change the decision-making rules of companies and thus lead to better financial performance. Consequently, the current economic literature in the context of the study of the taxonomy adopted in the European Union assumes that, over the long term, it should help solve many environmental problems [73].

Elements of the circular economy that support sustainability and positively impact economic growth in the European Union have been examined by Hysa et al. (2020). The researchers found that the indicators they selected have a positive impact on EU economic growth (environmental tax revenues, municipal waste recycling rate, private investment, jobs, sustainability-related gross value added, and number of patents related to recycled products), with the exception of the recycled raw materials trade factor. All this is in line with previous studies highlighting the importance of using recycled materials, managing municipal waste, increasing labour productivity, the usefulness of implementing an environmental tax and encouraging environmental innovation to ensure GDP (gross domestic product) growth [74].

The taxonomy was also addressed in a study by Hoepner and Schneider (2022). They noted that the main purpose of the current taxonomy is to direct investment to those projects that best fit the definition of "sustainability". The results indicate a low level of compliance with the principles of the taxonomy among companies, with only 20% of companies actually adhering to its principles. The researchers argue, however, that such results are not a negative indicator in general, as they only show that the economy (and especially companies) are not yet fully prepared to move towards operating according to sustainability principles. In the future, the situation should change for the better if government authorities continue this policy [75].

Taxonomy as a high-quality tool for attracting investment has also been considered by Kirby et al.(2021). Those researchers believe that the creation of such a base of taxonomy measures will indeed achieve the intended result of attracting money to sustainable development projects. Nevertheless, they also report that there is scepticism about the extent to which this will actually be achieved. The researchers, therefore, suggest that investment funds should be examined in terms of the extent to which environmental factors are decisive for them in project selection [76]. The relationship between environmental, social and governance (ESG) assessments and the EU taxonomy was explored by M. Dumrose et al. (2022). The researchers observed that there is a significant positive relationship between the EU taxonomy and environmental ESG scores. This indicates that the two approaches have broadly common principles and are effective in the context of assessing the components of sustainability indices. This finding is particularly important given that both are now among the main pillars of public policy-making in the European Union [77]. Some features of the taxonomy were also considered by Ingre and Passburf (2020). They noted the considerable versatility of this framework and its applicability for different purposes. They also write about its impact on the performance of funds specialising in investing in companies that position themselves as "sustainable." The magnitude of the effect depends on the availability of third-party data and investor demand. Alignment with the EU taxonomy should lead to increased investment flows into companies that comply with it. The focus on the environmental dimension of the EU taxonomy narrows the definition of "sustainability" for companies, potentially causing a shift of investment from those considered sustainable under current criteria to those compliant with the EU taxonomy. This could threaten portfolio diversification and lead to a broader definition of "sustainability" among investors [78].

In their study, Papari et al. (2024) also considered the impact of the Taxonomy in supporting the financing of green urban solutions for sustainability in Europe. They noted that not all such projects are yet covered by the principles of the Taxonomy, so public authorities should take care to attract investment for their subsequent implementation. In addition, the study highlights a need for the EU to align its financial disclosure policies and environmental funding efforts with global initiatives in support of biodiversity [79].

The challenges and benefits associated with the adoption of the taxonomy by EU member states were also noted by Andersen et al. (2023). The researchers noted that adoption is indeed a key element of human development towards sustainability. The researchers believe that the adoption of this legislation will, in the long term, lead to the development of software, the development of artificial intelligence and the field of counselling [80]. As part of their study, Bogeanu-Popa and Man (2022) assessed the European Union's efforts to encourage investment in sustainable businesses. They described the taxonomy as an effective approach not only to raise funds but also to increase transparency among such companies and corporate disclosure [81].

However, the taxonomy is seen as a regulatory mechanism to guide investment in green projects and to set clear criteria for assessing the sustainability of economic activities, which may be of great importance in the context of research into the adsorptive properties of activated carbon in the removal of hydrogen sulphide from landfill gas. This is mainly because it fits in with the environmental goals of the taxonomy, which are, inter alia, to mitigate and adapt to climate change, to move towards a circular economy, to prevent and control pollution and to protect and restore biodiversity and ecosystems.

The aim of the study was to link research in the area of landfill gas treatment technology and waste management processes with economic mechanisms that promote environmentally sustainable solutions. The work can be used in decision-making and technology selection by entrepreneurs planning investments in landfill gas purification. The presented technology fits into green investments and can be shown (disclosed) as a green investment in taxonomy reporting. Finally, the information contained in the paper can also provide information material for the financial industry, from which the taxonomy requires transparency in the products offered, according to which the financial product must serve as an investment in a business activity that contributes to environmental objectives.

2. Materials and Methods

The purpose of the study was a landfill gas treatment plant, which is used to generate combined heat and power. The installation is located in an active municipal landfill equipped with an active landfill degassing system. The landfill gas treatment plant extracted from the waste bed uses a two-stage gas treatment system. The first stage is a pre-treatment, consisting of the removal of solid particles from the gas, the removal of water in the dehydrator and condensate that condenses in the pumping and regulating module (Pump Monitoring Relay), the carbon filter (CF) and in the gas path in the cogeneration unit. The second stage of gas purification, representing advanced purification, includes a filter filled with activated carbon dedicated to the removal of hydrogen sulphide and silicon compounds found in the LFG before its energetic use in the cogeneration unit. A schematic diagram of the landfill gas treatment and energy utilisation plant, together with the measurement points for its basic parameters, is shown in Figure 1.

The shaped impregnated activated carbon used in the gas treatment plant is a product with a porous structure and an extremely large specific surface area. It features enhanced adsorption properties for H_2S, SO_2, mercaptans and acidic compounds. The activated carbon particles have a diameter of 4 mm and are 2 to 15 mm long. The carbon filter has a capacity of 1 m^3, and the charge density of the carbon is 520 $kg \cdot m^{-3}$. Replacement of used activated carbon with new (fresh) carbon becomes necessary in the LFG treatment plant when the H_2S content of the purified gas exceeds the hydrogen sulphide limit set by the gas engine manufacturer of up to 200 ppm H_2S in the landfill gas.

2.1. Landfill Gas Measurements

A test of the basic parameters of landfill gas at the landfill gas extraction plant (untreated gas) was carried out at the PRM (point no. 1) and after its purification in a coal filter (point no. 2) before entering the cogeneration plant. The study involved measuring the content of the four basic parameters of LFG, i.e., methane, carbon dioxide, oxygen and hydrogen sulphide. The measurement was conducted using a portable gas analyser, which allows the measurement of four parameters: methane, oxygen, carbon dioxide and hydrogen sulphide. Three measurement series were planned and conducted at weekly intervals, each with 5 measurements for the four LFG parameters at a frequency of 3 h for raw and purified gas before carbon filter replacement and for raw and purified gas after carbon filter replacement.

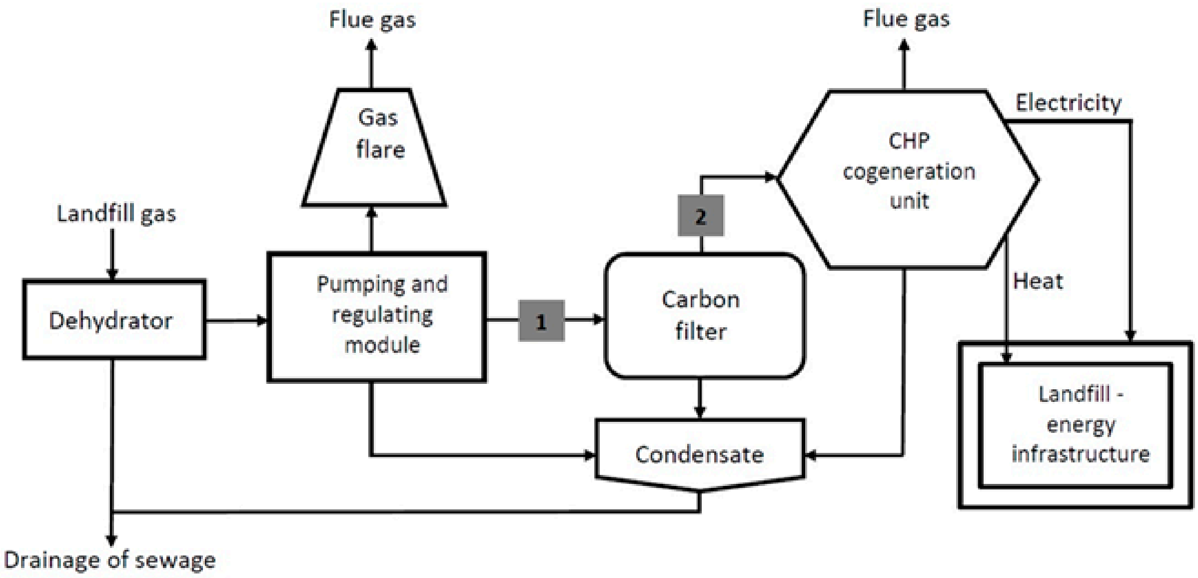

Figure 1. Diagram of a landfill gas energy utilisation facility. Own study.

2.2. Methods for Testing Activated Carbon

A sample of activated carbon from the landfill gas treatment plant filter was taken for testing in accredited laboratories of spent activated carbon operated in the LFG treatment plant. The collected carbon sample was then divided into three samples so that, Sample 1 was transferred to Laboratory A to determine the basic physical and adsorption parameters. For this purpose, activated carbon was assessed for particle size and grain size distribution, bulk density, mechanical strength, ash content, volatile matter content and iodine number.

Sample 2 was transferred to Laboratory B to verify the chemical compounds adsorbed by the activated carbon using a scanning electron microscope and EDS. Sample 3, on the other hand, was transferred to laboratory C for detailed analysis of the content of individual chemical compounds in relation to the applicable standards. A sample of the spent activated carbon taken from the landfill gas treatment plant and sent for testing and the fresh carbon replaced in the plant is shown in Figure 2.

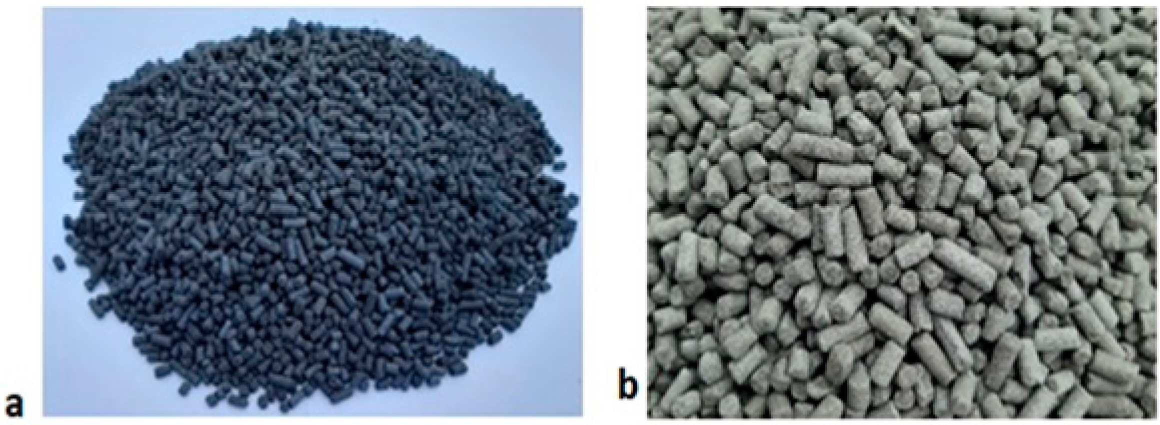

Figure 2. Shaped activated carbon: (**a**) fresh, (**b**) spent; transferred for laboratory testing.

Samples of spent activated carbon were transferred to two different accredited laboratories to assess the physico-chemical parameters of the carbon used in the cogeneration plant to purify landfill gas.

2.3. Environmentally Sustainable Projects—LFG Purification

In order to analyse the feasibility of environmentally sustainable projects for entrepreneurs in the field of environmentally sustainable projects for LFG treatment plants, a survey of official documents, reports and a review of the existing legal acts that form the basis for the implementation and financing of such facilities was carried out. Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on establishing a framework to facilitate sustainable investments, amending Regulation (EU) 2019/2088, (OJ L 198, 22.6.2020, p. 13) [65] was analysed. In addition, the content of Commission Regulation (EU) 2023/2485 of 27 June 2023, establishing additional technical criteria for the eligibility of economic activities making a significant contribution to climate change mitigation, was checked [82]. With regard to national law guidelines, the Recommendations for a Roadmap for the Development of Sustainable Finance in Poland for the application of the EU Taxonomy [83] were used. With regard to economics and finance, the Report of the banks according to Article 8 of the Taxonomy: requirements and challenges [84] was used. Investments to protect the environment in waste management also include installations for the capture, purification and energy use of landfill biogas. Such investments are part of climate change mitigation efforts and can make an important contribution to achieving environmental objectives as environmentally sustainable projects according to the EU taxonomy.

2.4. Description of Analytical Methods

Sample 1

The parameters of selected physical indicators of the tested shaped activated carbon were determined according to the following standards: PN-C-97554:1990 [85], for determination of bulk density, PN-C-97555-03:1982 [86], for determination of iodine number, PN-C-97554:1990 [85], for mechanical strength, PN-EN 12902:2005 [87], for ash content, and PN-88/C-97555/01:1988 [88] for subfraction content <0.5 mm.

Sample 2

Testing of a sample of used activated carbon was carried out in the laboratory using a Scanning Electron Microscope (SEM) with an Energy Dispersive Spectroscopy (EDS) system. The aim of these studies was to analyse the state of the spatially varying coal surfaces to obtain a plastic image of them with considerable depth of field, including the extent of coal pore collimation, and to determine the type of elements adsorbed in order to perform a percentage balance. Statistica software (version no. 14.1.0.4) [89] was used to statistically process the results.

Sample 3

A detailed analysis of the content of individual chemical compounds contained in Sample 3 was carried out in an accredited laboratory according to the applicable standards. The content of individual elements was determined using inductively coupled plasma atomic emission spectrometry (ICP-OES). Total fluorine and total sulphur were determined by ion chromatography (IC) after prior incineration of the sample, while mercury was determined using an atomic absorption spectrometer. Determination of total sulphur and hydrogen was performed by combustion with infrared (IR) detection. The primary analyses of silicate (SiO_2) were performed by the weight method, and the determination of ammonium ion and ammonium nitrogen by spectrophotometry.

3. Results

3.1. Landfill Gas Testing

The landfill gas quality test involved the analysis of 240 measurement results, representing the contents of methane, carbon dioxide, oxygen and hydrogen sulphide. The average values of the measurements taken separately for raw and purified gas, before and after replacement of the activated carbon bed at 2-day intervals, are shown in Table 1. The other LFG parameters were nitrogen, ammonia, hydrogen, silicon compounds, chlorine and fluorine.

Table 1. Basic parameters of landfill gas treatment plant before and after carbon filter bed replacement.

Parameters	Unit	Before Replacing the Carbon Cartridge		After Replacing the Carbon Cartridge	
		Gas not purified	Gas purified	Gas not purified	Gas purified
CH_4	%	51.7	50.2	50.8	50.3
CO_2	%	39.2	38.5	40.1	40.9
O_2	%	0.4	0.3	0.3	0.2
H_2S	ppm	402.6	304.1	386.7	7.5
Other parameters	%	8.66	10.97	8.76	8.60

Measurements of the basic parameters of the raw gas before the treatment plant showed stable CH_4 values of 50.8 to 51.7% and CO_2 values of 39.2% to 40.1%. Oxygen content in the range of 0.3 to 0.4% indicates good compression (compaction) of the waste, resulting in a high methane content in the gas. These values indicate that the landfill is in a stable methanogenic phase of gas production. The results of H_2S measurements in landfill gas at point 1 and at point 2 before the replacement of the gas-purifying activated carbon are shown in Figure 3.

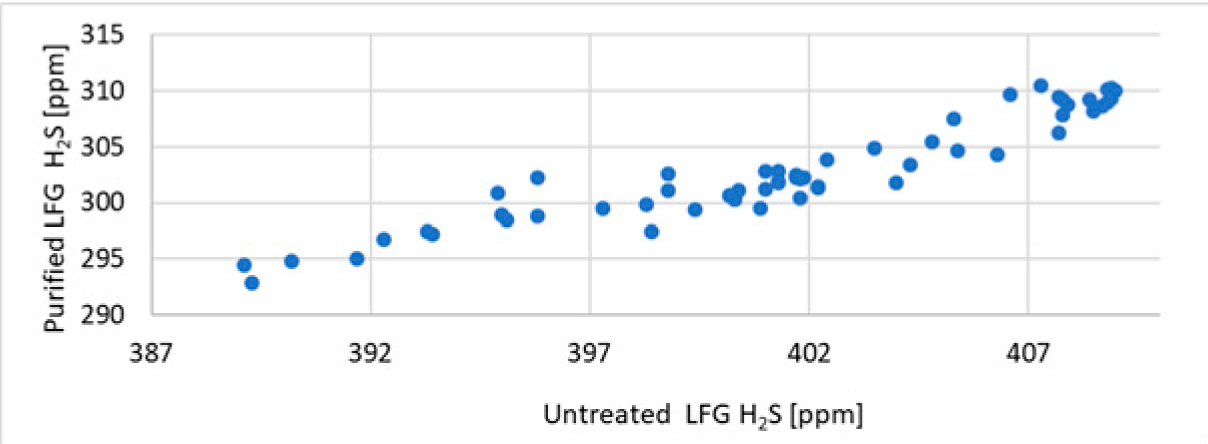

Figure 3. H_2S parameters before activated carbon replacement in the LFG treatment plant.

The H_2S content in the untreated gas (point 1) shows a value between 389.1 ppm and 409.0 ppm, with an average H_2S value of 401.5 ppm. This hydrogen sulphide content in the LFG for the landfill during the operational phase of the waste deposit represents the value for the stable phase of the landfill operation. On the other hand, analysis of the results of H_2S measurements in landfill gas after treatment at point 2 showed a hydrogen sulphide content ranging from 292.9 ppm to 310.5 ppm with an average value of 302.8 ppm. The calculated average hydrogen sulphide removal efficiency of the LFG was 24.58%, indicating high pore clogging of the activated carbon and low H_2S removal efficiency. In this situation, when the hydrogen sulphide limit was set to 200 ppm by the gas engine manufacturer, it became necessary to replace the spent activated carbon with a new one in order to protect the cogeneration unit from potential damage to the gas engine driving the electric generator. The results of measurements of the H_2S content in the landfill gas after replacing the gas-cleaning activated carbon at point 1 and at point 2 are included in Figure 4.

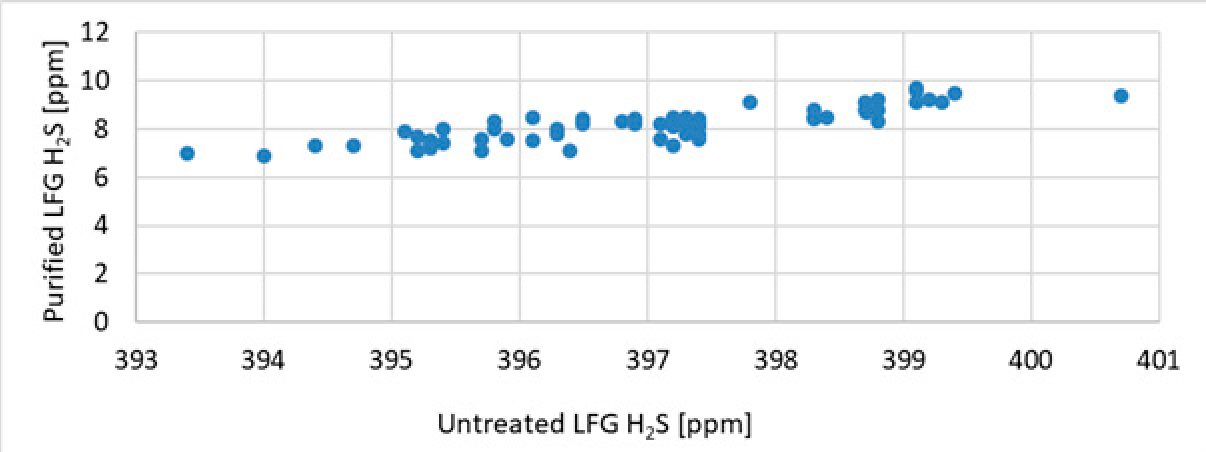

Figure 4. H_2S parameters after replacement of activated carbon in the LFG treatment plant.

Once the carbon filter cartridge had been replaced with a so-called fresh one, an analogous series of measurements were made after 2 days to stabilise the filter bed as before the carbon filter was replaced to check the H_2S content of the purified gas. The results of the raw gas measurements (point 1) ranged from 393.4 ppm to 400.7 ppm, with a mean value of 397.0 ppm. In contrast, the H_2S results at point 2 showed values ranging from 6.9 ppm to 9.7 ppm, with a mean value of 8.2 ppm. The calculated average hydrogen sulphide removal efficiency of the LFG was 97.9%, demonstrating the high efficiency of H_2S removal by fresh activated carbon.

3.2. Testing of Activated Carbon Sample 1

The performed testing of the physical parameters of the first sample of the spent activated carbon shaped in laboratory A showed a definite reduction in the adsorption properties of the spent activated carbon, resulting in a decrease in the efficiency of landfill gas treatment in its energy utilisation plant. A comparison of the physical parameters of the listed spent activated carbon with the fresh activated carbon used in the LFG treatment plant is shown in Table 2.

Table 2. Parameters of used and fresh-shaped carbon.

Parameters	Unit	Fresh Activated Carbon	Activated Carbon Spent in the LFG Treatment Plant
volatile matter	%	1.75	42.37
ash content	%	5.0	8.05
bulk density	$kg\cdot m^{-3}$	520	931
iodine number	$mg\cdot g^{-1}$	1000	38
mechanical resistance	%	96.0	99.9
3.5 mm grain size	%	93.0	98.4
2.75 mm grain size	%	7.0	1.4
average particle diameter of granules	mm	4.0	3.79

The tested volatile fraction values are 42.37%, which may indicate the presence of volatile sulphur compounds in the sample. An increase of almost 100% in the bulk density of the tested coal sample (from 520 $g\cdot dm^{-3}$ to 931 $g\cdot dm^{-3}$) indicates that the maximum level of adsorption of compounds in the structure of activated carbon was reached. Under the influence of exploitation, the ash content also increased from 5.0% to 8.05%. The activated carbon granules were slightly mechanically fragmented, as evidenced by the grain size and diameter of the granules. The spent activated carbon has an exceedingly high mechanical strength value of 99.9%. The strength even increased compared to fresh carbon (96.0%). It can be assumed that micropores of activated carbon, filled with adsorbed compounds, increase the stiffness of its grains by reducing the volume of free spaces, which results in an increase in the strength of activated carbon grains. This theory is also supported by the decrease in the iodine number for the spent carbon samples to a value of 38 mg·g^{-1} from a value of 1000 mg·g^{-1}, which also indicates an almost complete depletion of the adsorption properties.

The examined mechanical strength and ash content classify the active coal for further thermal regeneration, while an exceptionally low value of the iodine number indicates that it will not be possible to recover sufficiently high sorption properties of activated carbon during regeneration, i.e., regeneration of such coal will be unprofitable. The higher the value of the iodine number before the regeneration of the carbon, the more efficient the regeneration and the recovery of the adsorption properties.

3.3. Testing of Spent Activated Carbon Sample 2

Figures 5 and 6 below show electron microscope images at 250×, 500×, 1000× and 2000× magnification; the image clearly shows the porous structure and the impurities absorbed by the carbon. Figure 7 shows the examination of the spent carbon by EDS energy dispersive spectroscopy. Figure 8 shows a detailed quantitative and qualitative composition summary made using energy dispersive spectroscopy EDS.

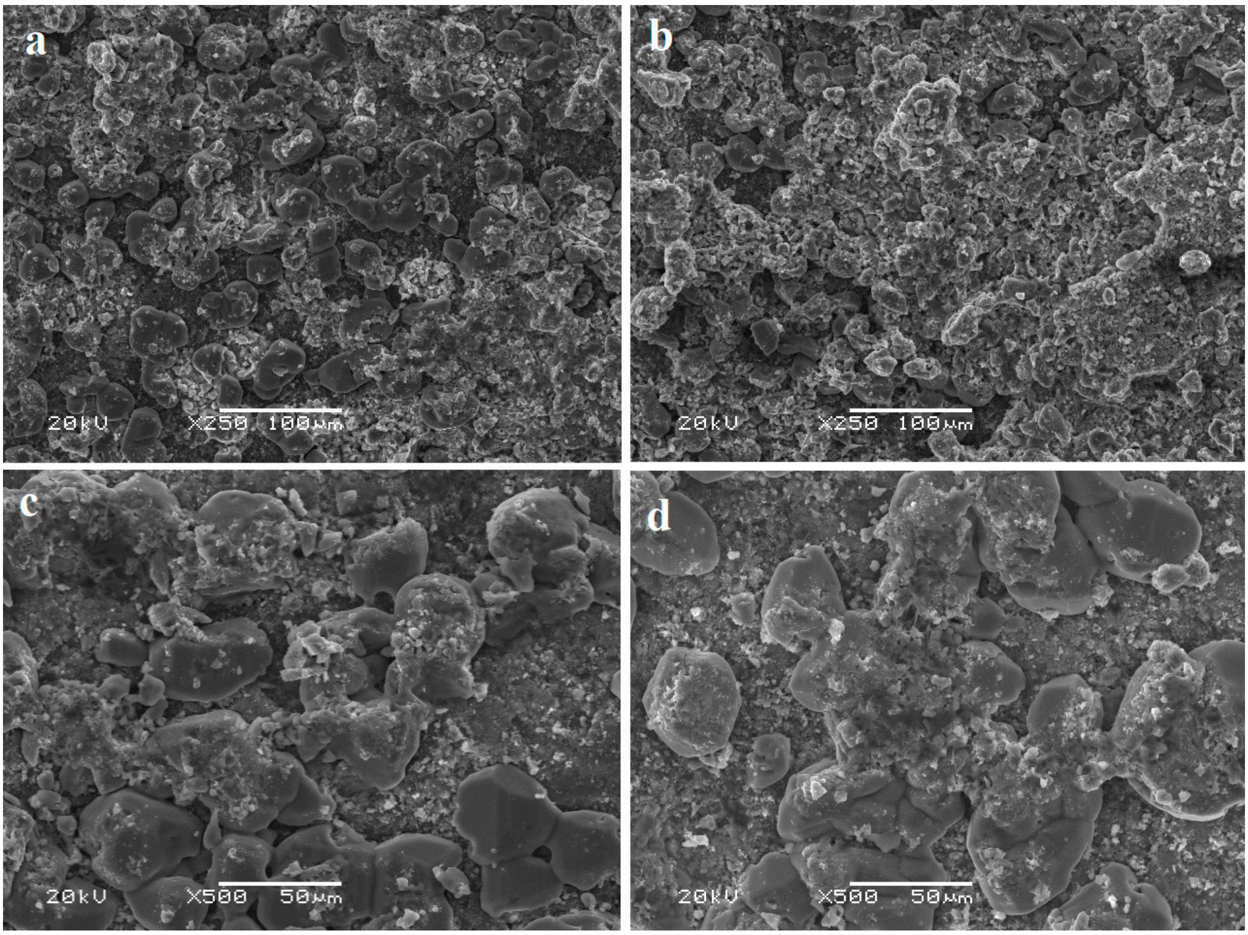

Figure 5. Surface images of the activated carbon sample at 250 (**a**,**b**) and 500 (**c**,**d**) magnification.

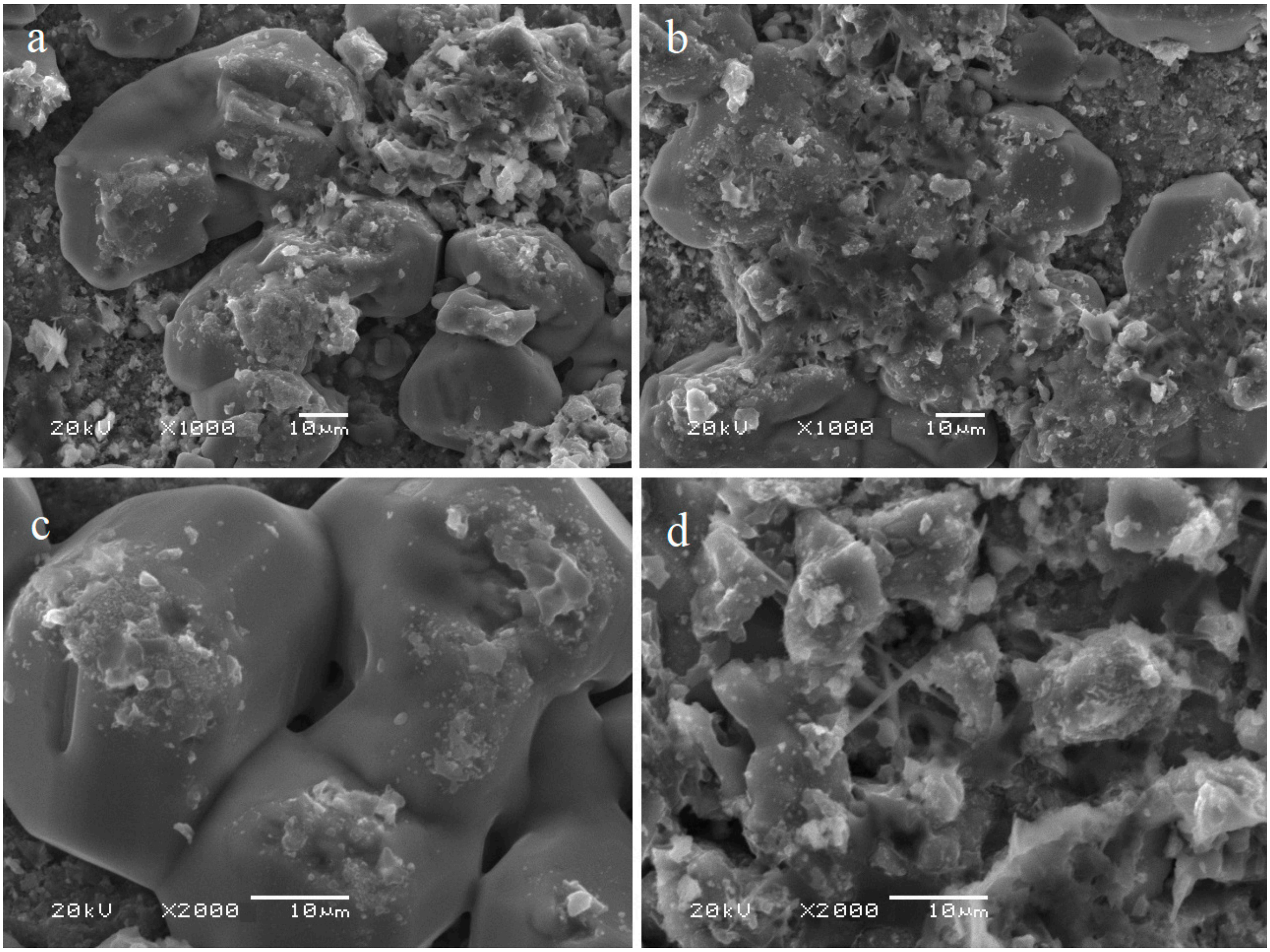

Figure 6. Surface images of the activated carbon sample at 1000 (**a**,**b**) and 2000 (**c**,**d**) magnification.

The use of a scanning electron microscope (SEM) in the study to examine the spatially varying surfaces of the samples makes it possible to obtain a plastic image of them with considerable depth of field. On the other hand, the EDS (energy dispersive spectroscopy) analysis used in the study allows the identification of the elemental composition of the materials. The main purpose of this analysis was to evaluate the degree of adsorption of activated carbon by impurities present in LFG. This mainly concerns sulfur compounds, silicon, including siloxanes, and calcium. The degree of colmation of the porous structure of the carbon and its pores will indicate the degree of efficiency of the gas treatment plant from these compounds. The micropores of activated carbon, filled with adsorbed compounds, will act as a barrier to contaminants that should potentially be used for LFG purification. Such a situation results in a decrease in gas purification efficiency, and lack of control can lead to bed breakthrough AND damage to the gas engine. This clogging can particularly be seen in Figure 6.

The elemental composition in points 1 to 5 in Figure 7a are presented in the remaining Figure 7b–f, in the following way: point No. 1 refers to Figure 7b, point No. 2 refers to Figure 7c, point 3 presents the composition of elements in activated carbon in Figure 7d, point 4 refers to Figure 7e, while the content of point 5 is shown in Figure 7f.

The process of regenerating spent carbon sorbents to restore their original sorptive properties and to reuse the regenerated carbons in the same or another process essentially involves the removal of adsorbed substances. This process can be carried out by desorption or decomposition of the adsorbed substances. One of the most widely used methods of regenerating spent activated carbons, including thermal removal of impurities, including sulfur compounds, by heating the sorbent bed, resulting in desorption of adsorbed impurities. Figure 8 shows the elemental percentage composition of spent activated carbon.

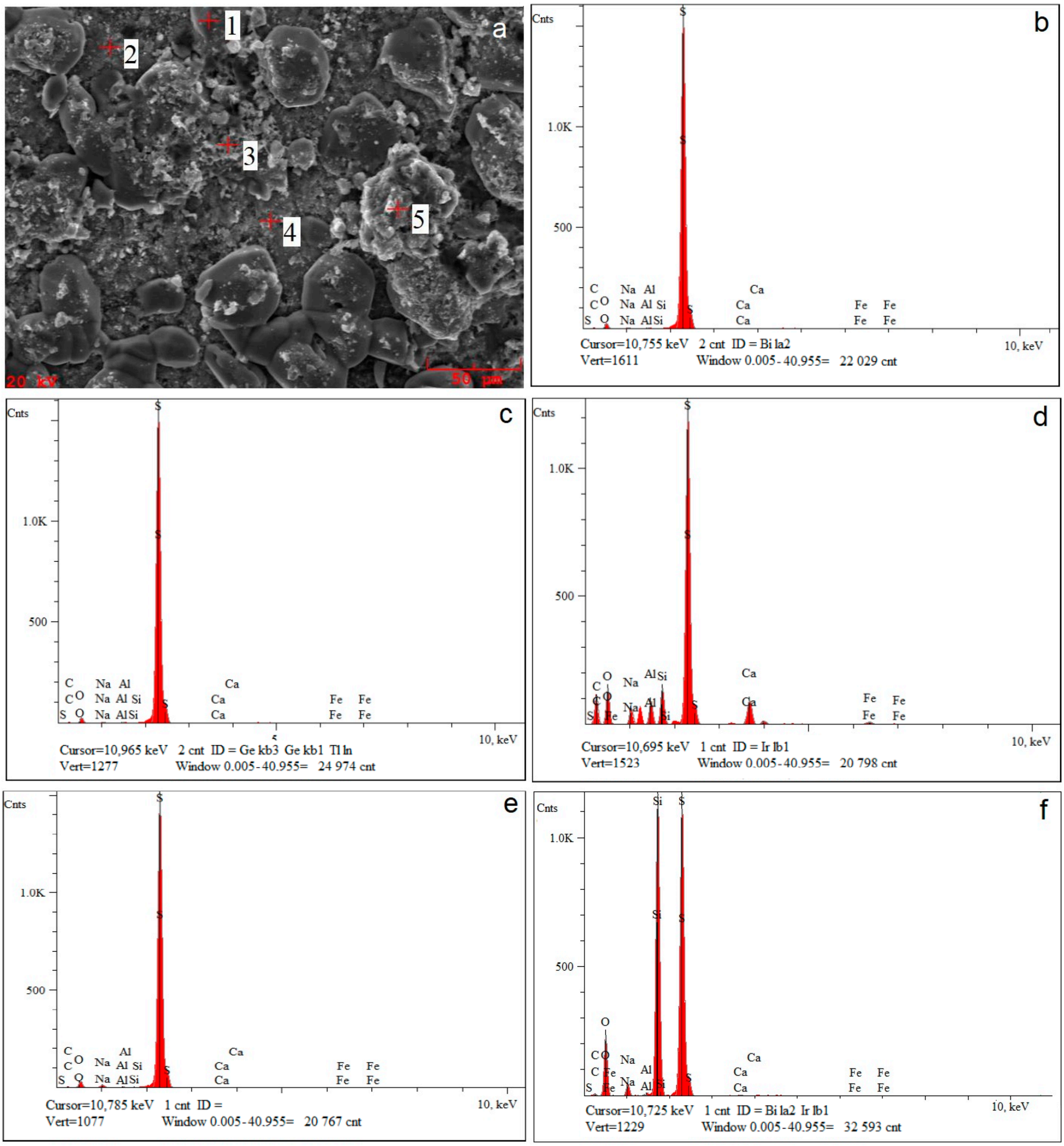

Figure 7. Five-point analysis of a sample of spent activated carbon performed by EDS.

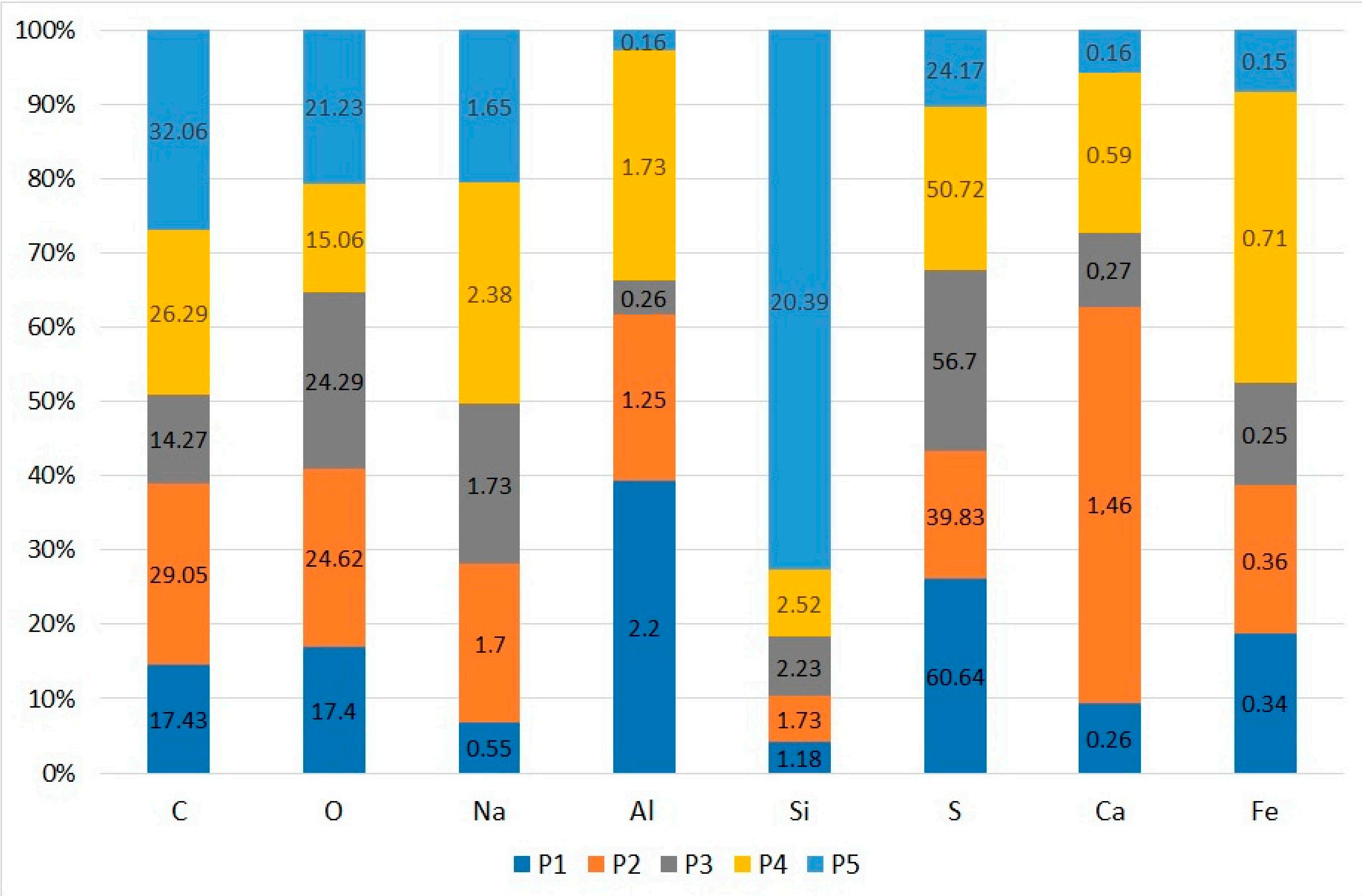

Figure 8. Percentage elemental composition of spent activated carbon.

3.4. Examination of Spent Activated Carbon Sample 3

Sample 3 was also analysed in detail for its physico-chemical properties and toxic compounds, which will help to determine the type of waste and how it should be disposed of. The detailed physico-chemical analysis of Sample 2 is shown in Table 3.

The study also aimed to determine further ways of handling spent activated carbon, depending on its physical properties, sorption capacity, mechanical strength and the type of impurities it contains. In the study carried out with IC-OES, the highest number of impurities in the spent activated carbon was sulphur at 51% on a dry weight basis, indicating a high efficiency in the carbon in capturing sulphur from hydrogen sulphide, which is also confirmed in Figures 3 and 4. The amount of ammonia in the waste carbon was formed at 9.93%. It is important to note the high efficiency of the removal of heavy metals from the biogas with coal, as evidenced by the high number of heavy metals adsorbed, such as lead 15.8%, chromium 8.44% and zinc 6.29%. Copper and nickel account for just over 3%. The other heavy metals examined, bismuth, cadmium, and mercury, are below 0.5%. The amount of absorbed fluorine of less than 0.1% should be emphasised. The spent activated carbon evaluated was analysed on the basis of the waste catalogue and was classified as hazardous waste under the code 06 13 02*—spent activated carbon. As it is a hazardous waste, it should be managed in accordance with the waste hierarchy [90]. Further handling of this waste depends on the decision of the plant operator, who decides whether to regenerate the coal or transfer it to disposal. In the case of a decision to regenerate, the operator chooses the entity to which it transfers the spent coal, bearing the cost of regeneration. After reclamation, the coal returns to the plant operator and can be reused for landfill gas treatment.

Table 3. Physico-chemical parameters of the spent moulded activated carbon.

Parameter	Unit	Results
Physical parameters		
dry mass in 105 °C	%	97.4
analytical water content	%	N/A
gross water content	%	2.65
total water content	%	2.65
Non-metal inorganic parameters		
SiO_2	% dry mass	1.6
Si	% dry mass	0.75
F total in dry mass	% dry mass	<0.1
S total in sample	%	49.7
S total in dry mass	% dry mass	51
F total in sample	%	<0.01
NH_4	$mg \cdot dm^{-3}$	12.8
N-NH_4	$mg \cdot dm^{-3}$	9.93
Extractable metals/mostly cations		
Bi	$mg \cdot kg^{-1}$ s.m.	<0.50
Cr	$mg \cdot kg^{-1}$ s.m.	8.44
Zn	$mg \cdot kg^{-1}$ s.m.	6.29
Cd	$mg \cdot kg^{-1}$ s.m.	<0.40
Cu	$mg \cdot kg^{-1}$ s.m.	3.64
Ni	$mg \cdot kg^{-1}$ s.m.	3.25
Pb	$mg \cdot kg^{-1}$ s.m.	15.8
Hg	$mg \cdot kg^{-1}$ s.m.	<0.30

4. Discussion

Purification of landfill gas from contaminants prior to its energy use in cogeneration units is necessary for the correct and safe operation of these systems. The LFG treatment systems in use often use moulded activated carbon to remove H_2S, SO_2, siloxanes and volatile organic compounds contained in the gas. The treatment of biogas using activated carbon from sulphur compounds, chlorine and siloxanes as a function of relative humidity for fuel cell microcogeneration systems was presented in their paper by Papurello et al. (2016). The results showed a relationship between relative humidity and the efficiency of H_2S gas purification, which, at humidities above 50%, showed a definite decrease in hydrogen sulphide removal [91]. The use of activated carbon in the purification of storage gas from VOCs was described by Gong et al. (2019) for the enrichment of landfill gas through CO_2 separation by pressure swing adsorption (PSA). The results showed the effectiveness of the need to remove VOCs and the efficiency of absorption using activated carbon [92]. Sevimoğlu and Tansel analysed the composition of sludge from gas engines burning landfill gas treated in an activated carbon filter and found a high level of silicon compound removal. However, for the removal of sulphur compounds, the sludge showed higher levels of sulphur compared to the raw gas. It indicates that activated carbon has released some sulphur during the cleaning process [93]. The purification of landfill gas for use in cogeneration modules was described by Dernbach and Henning, focusing on the removal of hydrogen sulphide, which caused corrosion on gas engine components. Applied absorption on activated carbon showed a high efficiency in removing hydrogen sulphide, which was confirmed by tests performed on a pilot plant [94].

The natural consequence of the use of activated carbons is that, once used, they become waste, which must be managed according to the waste hierarchy. The most favourable waste disposal direction, both from a social, economic, legal and environmental point of view, is disposal and recycling. The results of tests on used activated carbon showed a high content of sulphur compounds, silicon and heavy metals. With this in mind, the further handling of this waste should be determined [95]. Combusting and landfilling of waste should be considered as a last resort, to be implemented when others cannot be used. As far as the waste from the purification of landfill gas is concerned, reuse after appropriate treatment and recovery of the adsorbed substances is possible and preferable [96]. One of the most important advantages of activated carbon, making it a competitive sorbent compared to other porous materials, is that it can be regenerated repeatedly without losing its sorption capacity. Such a waste treatment of spent activated carbon fits into a closed-loop management system, and such a solution can be recommended [97,98]. However, an incredibly low iodine number value indicates that sufficiently high sorption properties of activated carbon will not be recovered during regeneration, i.e., regeneration of such carbon will be unprofitable. Heavy metals present in the spent carbon may also become a barrier during repeated use. It, therefore, substantiates the need to look for new methods of reusing spent coal. An idea as a continuation of the above research will be to try to incorporate it into lightweight aggregate, where the right choice of material proportions limits the leachability of heavy metals. Similar work has already been conducted [99] with good results, so it is reasonable to continue the research.

The results of the research on landfill gas purification using activated carbon should certainly be referred to issues related to the taxonomy and financing of sustainable development investments, especially in the context of the possibility of implementing and financing the presented solution. It should be emphasised that the role of financing in achieving sustainable development goals is insignificant. The authors recommend setting up mechanisms to combine market and public systems to finance sustainable development goals. They also recommend strengthening oversight of how companies comply with sustainability principles [100]. Solutions to encourage green financing of renewable energy projects have also been proposed by Taghizadeh-Hesary and Yoshino (2020). They highlighted the key problems associated with green project financing, namely the lack of long-term financing, numerous risks, low returns and reluctance to invest by market participants in general. As a result, they concluded that government intervention should be used in individual cases where market participants are unwilling to invest in projects, but this should only be performed on a case-by-case basis [101]. The performance of equity funds focused on renewable energy compared to traditional funds in the euro area was analysed by Ji et al. (2021). They showed that renewable energy funds tend to underperform traditional funds and outperform the market average, suggesting that investors may encounter negative performance when choosing environmentally friendly investment options. Despite the socio-economic and environmental benefits of renewable energy, the role of financial markets in financing these projects is crucial, yet such investments now appear less financially rewarding. Consequently, researchers also point to the need for a greater role for public authorities in ensuring the viability of such projects [102].

In his work, Lagoarde-Segot (2020) emphasises that access to finance for such projects can be improved through separate mechanisms such as green bonds. He also suggests that the Central Bank's policy should be changed to be more focused on financing companies whose activities are linked to the Sustainable Development Goals. Its feature is the inclusion of Central Bank indicators that track sector lending to companies that achieve the Sustainable Development Goals, as well as related financial assets. The policy aims to encourage investment while considering the impact of climate change on the country [103]. A review of methods for assessing the sustainability of investment funds was conducted by Mesonnier and Nguyen (2021). They evaluated different approaches and tools and found that the Paris Agreement Capital Transition Assessment (PACTA) tool, the Cambridge Institute for Sustainability Leadership Investment Impact Framework and the Net Environmental Contribution (NEC) were the most accurate, but also had their problems. Moreover, the researchers noted the problem of limited information on the activities of such funds and the availability of data on them, which complicates the ability to make assessments. They also point to the need for more reliable methods to assess the sustainability of funds. It follows that a draft of the tools needed is already available [104].

Generally speaking, the application of the EU Taxonomy in practice poses problems for both financial and non-financial enterprises, so the experts of the Working Group on the Application of the EU Taxonomy, which was established by a decision of the Sustainable Finance Platform at the Ministry of Finance, considered it important to develop a set of actions, measures or solutions that would improve the implementation of the EU Taxonomy in the Polish market and the adaptation of Polish enterprises to it. The key recommendations presented in the Report by the aforementioned Group include, inter alia, facilitating access to the taxonomy data, enhancing credibility in terms of making a significant contribution to environmental objectives in the sense of technical eligibility criteria, support in terms of calculating the carbon footprint and reducing the cost of reporting under the EU Taxonomy. Thus, as can be seen, the work on the Taxonomy will probably still be ongoing, as quite a number of problems and barriers are noted, but certainly, studies such as the ones presented in this publication can enrich the knowledge on the subject but also show the real chances of success of the planned transformation, which is not only an opportunity but even a necessity [82,105].

The obligations of entrepreneurs in relation to the Taxonomy can be divided into two groups: the first for entities in the financial industry and the second for other entrepreneurs in non-financial industries, including technical ones. In the case of the financial industry, the requirements relate to the transparency of the products offered, according to which if a financial product is used to invest in an economic activity that contributes to an environmental objective, the entrepreneur must disclose information about the objective, a description of the extent to which the project within the financial product qualifies as environmentally sustainable according to the Taxonomy [106,107]. On the other hand, if a financial product promotes an environmental aspect, it must additionally be accompanied by a statement indicating the following principle, "do not cause serious damage to the environment", and is only applicable to those projects within the financial product which consider the EU criteria for environmentally sustainable business. Other entrepreneurs, including those operating environmental installations, are obliged to publish non-financial information resulting from their business activities [108,109]. The taxonomy requires that as part of this obligation, information on the percentage of their turnover derived from products or services related to business activities that qualify as environmentally sustainable must be disclosed. In addition, they are required to report the percentage of their capital expenditures and operating expenditures corresponding to assets or processes related to business activities that qualify as environmentally sustainable. In the case of a group of entrepreneurs, however, the Taxonomy may be of great practical importance, not apparent from the content of its provisions. It is possible that some banks or other financial service providers will want to finance activities that only or largely comply with the Taxonomy. If this is the case, entrepreneurs wishing to obtain credit on favourable terms may, in practice, be required to demonstrate that their business complies with the Taxonomy. Otherwise, they may not obtain the funds they need or may obtain them on unfavourable terms. Reporting under the Taxonomy for, among other things, the reduction of greenhouse gas emissions as a result of the implementation of new climate protection technologies, including installations for the capture and energy use of methane produced at landfills [110,111].

With this in mind, landfill gas purification facilities and the products used in the process are environmentally sustainable projects for entrepreneurs and will be subject to reporting. The work has application value, indicating and justifying that installations for the extraction and energetic use of methane contained in LFG contribute to the reduction of greenhouse gas emissions and increase the energy efficiency of facilities. The use of activated carbon in landfill gas treatment facilities and its subsequent regeneration is part of a closed-cycle economy, which aims to maintain the value of products, materials and other resources in the economy for as long as possible. Such a state results in the minimisation of waste generation and the release of hazardous substances at all stages of their life cycle by applying the waste hierarchy [112,113].

Such projects are part of climate change mitigation efforts and can make an important contribution to achieving environmental goals not only locally but also globally.

5. Conclusions

In this paper, the efficiency of landfill gas purification using activated carbon is presented. The calculated average hydrogen sulphide removal efficiency of the LFG was 97.9%, demonstrating the high efficiency of H_2S removal by fresh activated carbon. In this study, spent carbon was also analysed by electron microscopy, EDS energy dispersive spectroscopy measurements and ICP-OES analyses. The analyses show that coal absorbs most sulphur, 51% on a dry weight basis, and a large number of heavy metals, especially lead, 15.8%, chromium, 8.44% and zinc, 6.29%. The high inertness of coal makes it classified as hazardous waste with the code 06 13 02*. This, in turn, makes it worth seeking new ways of managing it in order to meet the challenges of a closed-loop management system embedded in the European Green Deal. Climate change may affect all sectors of the economy, including waste management. The technical criteria for the qualification of environmentally sustainable projects should serve the objective of not causing harm to all economic activities in terms of climate change adaptation. The taxonomy is a new European Union law that defines which projects are environmentally sustainable. An economic activity qualifies as environmentally sustainable if it meets four cumulative conditions, i.e., it makes a significant contribution to at least one of the six environmental objectives, does not cause serious harm to any of the environmental objectives, is conducted in accordance with minimum guarantees and meets the technical qualification criteria. The financial industry will have to describe in detail whether the financial products it offers comply with the Taxonomy. Similarly, large entrepreneurs will, as part of their obligation to publish non-financial information, indicate the percentage of their activities that comply with the Taxonomy. Other entrepreneurs may, in practice, be required to specify whether their activities will comply with the Taxonomy, e.g., if they wish to obtain external financing.

This study has shown that landfill gas purification plants using activated carbon are environmentally sustainable installations. Hazardous waste generated in the process should be managed in accordance with the waste hierarchy as part of a closed-loop management system. The issues presented in the paper, have a practical application dimension that will allow investors, but also economists, to identify this type of plant as an environmentally sustainable investment. This applies primarily to the energetic use of methane contained in LFG as a way to reduce greenhouse gas emissions as a consequence of climate change mitigation. The use of filter material in the form of activated carbon makes a practical contribution to optimising the operation of the cogeneration unit in terms of the amount of energy produced. Studies of the chemical composition of spent organic carbon allow the use of processes for its regeneration, which are part of a circular economy. This type of investment will form the basis for reporting resulting from the EU taxonomy and include additional technical criteria for the eligibility of economic activities making a significant contribution to climate change mitigation.

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References

1. Di Giacomo, G.; Romano, P. Evolution and Prospects in Managing Sewage Sludge Resulting from Municipal Wastewater Purification. *Energies* **2022**, *15*, 5633. [CrossRef]
2. Sobiecka, E.; Cedzynska, K.; Smolinska, B. Vitrification of medical waste as an alternative method of wastes stabilization. *Fresenius Environ. Bull.* **2010**, *19*, 3045–3048.
3. Wysowska, E.; Kicińska, A. Assessment of health risks with water consumption in terms of content of selected organic xenobiotics. *Desalination Water Treat.* **2021**, *234*, 1–14. [CrossRef]
4. Gaska, K.; Generowicz, A.; Lobur, M.; Jaworski, N.; Ciuła, J.; Vovk, M. Advanced algorithmic model for poly-optimization of biomass fuel production from separate combustible fractions of municipal wastes as a progress in improving energy efficiency of waste utilization. *E3S Web Conf.* **2019**, *122*, 01004. [CrossRef]
5. Wysowska, E.; Wiewiórska, I.; Kicińska, A. Minerals in tap water and bottled waters and their impact on human health. *Desalination Water Treatm.* **2022**, *259*, 133–151. [CrossRef]
6. Smol, M.; Włodarczyk-Makuła, M. Effectiveness in the Removal of Organic Compounds from Municipal Landfill Leachate in Integrated Membrane Systems: Coagulation—NF/RO. *Polycycl. Aromat. Compd.* **2017**, *37*, 456–474. [CrossRef]
7. Generowicz, A.; Gronba-Chyła, A.; Kulczycka, J.; Harazin, P.; Gaska, K.; Ciuła, J.; Ocłoń, P. Life Cycle Assessment for the environmental impact assessment of a city' cleaning system. The case of Cracow (Poland). *J. Clean. Prod.* **2023**, *382*, 135184. [CrossRef]
8. Park, J.W.; Shin, H.C. Surface emission of landfill gas from solid waste landfill. *Atmos. Environ.* **2001**, *35*, 3445–3451. [CrossRef]
9. The Act of February 20, 2015 on Renewable Energy Sources (In Polish). Available online: https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20150000478/U/D20150478Lj.pdf (accessed on 6 October 2023).
10. Mukawa, J.; Pająk, T.; Rzepecki, T.; Banaś, M. Energy Potential of Biogas from Sewage Sludge after Thermal Hydrolysis and Digestion. *Energies* **2022**, *15*, 5255. [CrossRef]
11. Grosser, A.; Neczaj, E. Enhancement of biogas production from sewage sludge by addition of grease trap sludge. *Energy Convers. Manag.* **2016**, *125*, 301–308. [CrossRef]
12. Ciuła, J.; Kowalski, S.; Wiewiórska, I. Pollution Indicator of a Megawatt Hour Produced in Cogeneration—The Efficiency of Biogas Purification Process as an Energy Source for Wastewater Treatment Plants. *J. Ecol. Eng.* **2023**, *24*, 232–245. [CrossRef] [PubMed]
13. Ishchenko, V.; Pohrebennyk, V.; Kochanek, A.; Przydatek, G. Comparative Environmental Analysis of Waste Processing Methods in Paper Recycling. In Proceedings of the 17th International Multidisciplinary Scientific GeoConference SGEM, Vienna, Austria, 27–29 November 2017; Volume 17, pp. 227–234. Available online: https://www.researchgate.net/publication/319670927_Comparative_environmental_analysis_of_waste_processing_methods_in_paper_recycling (accessed on 1 May 2024).
14. Ajhar, M.; Travesset, M.; Yüce, S.; Melin, T. Siloxane removal from landfill and digester gas—A technology overview. *Bioresour. Technol.* **2010**, *101*, 2913–2923. [CrossRef] [PubMed]
15. Przydatek, G. Using advanced statistical tools to assess the impact of a small landfill site on the aquatic environment. *Environ. Monit. Assess* **2021**, *193*, 71. [CrossRef] [PubMed]
16. Sun, Q.; Wang, Y.; Liu, S. Biogas production via anaerobic digestion. In *Gas Biofuels from Waste Biomass: Principles ang Advances*; Liu, Z., Ed.; Nova Science Publishers: New York, NY, USA, 2014.
17. Tappen, S.J.; Aschmann, V.; Effenberger, M. Lifetime development and load response of the electrical efficiency of biogas-driven cogeneration units. *Renew. Energy* **2017**, *114*, 857–865. [CrossRef]
18. Generowicz, N. Overview of Selected Natural Gas Drying Methods. *Archit. Civ. Eng. Environ.* **2020**, *13*, 73–83. [CrossRef]
19. Manasaki, V.; Palogos, I.; Chourdakis, I.; Tsafantakis, K.; Gikas, P. Techno-economic assessment of landfill gas (LFG) to electric energy: Selection of the optimal technology through field-study and model simulation. *Chemosphere* **2021**, *269*, 128688. [CrossRef] [PubMed]
20. Dyachok, V.; Venhe, L.; Huhlych, S. The Biomethanization Gas Purification of Using Chlorophyll-Synthesizing Microalgae. *J. Ecol. Eng.* **2022**, *23*, 259–264. [CrossRef]
21. Álvarez-Flórez, J.; Egusquiza, E. Analysis of damage caused by siloxanes in stationary reciprocating internal combustion engines operating with landfill gas. *Eng. Fail. Anal.* **2015**, *50*, 9–38. [CrossRef]
22. Rasi, S.; Läntelä, J.; Rintala, J. Trace compounds affecting biogas energy utilisation-A review. *Energy Convers. Manag.* **2012**, *52*, 3369–3375. [CrossRef]
23. Kowalski, Z.; Kulczycka, J.; Verhé, R.; Desender, L.; De Clercq, G.; Makara, A.; Generowicz, N.; Harazin, P. Second-generation biofuel production from the organic fraction of municipal solid waste. *Front. Energy Res.* **2022**, *10*, 919415. [CrossRef]
24. Feng, Q.; Yang, W.; Chang, M.; Wen, S.; Liu, D.; Hang, G. Advances in depressants for flotation separation of Cu-Fe sulfide minerals at low alkalinity: A critical review. *Int. J. Miner Metall Mater.* **2024**, *31*, 1–17. [CrossRef]
25. Papurello, D.; Tomasi, L.; Silvestri, S.; Santarelli, M. Evaluation of the Wheeler-Jonas parameters for biogas trace compounds removal with activated carbons. *Fuel Process. Technol.* **2016**, *152*, 93–101. [CrossRef]
26. Khoiyangbam, R.; Gupta, N.; Kumar, S. Biogas Technology: Towards sustainable development. In *The Energy and Resources Institute*; TERI: 2011; pp. 1–18. Available online: https://www.researchgate.net/publication/261136066_Biogas_Technology_towards_sustainable_development (accessed on 7 March 2024).

27. Li, L.; Changda, C.; Yongming, S. Anaerobic processes and biogas technology. In *Bioenergy: Principles and Technologies*; Yuan, Z., Wu, C., Ma, L., Eds.; Boston: Berlin, Germany, 2017. [CrossRef]
28. Xu, J.; Tian, O.; Li, Y. Toward the truth of condensing-water membrane for efficient biogas purification: Experimental and modeling analyses. *J. Membr. Sci.* **2022**, *662*, 120967. [CrossRef]
29. Cinar, S.; Cinar, S.O.; Wieczorek, N.; Sohoo, I.; Kuchta, K. Integration of Artificial Intelligence into Biogas Plant Operation. *Processes* **2021**, *9*, 85. [CrossRef]
30. Amaraibi, R.J.; Joseph, B.; Kuhn, J. Techno-economic and sustainability analysis of siloxane removal from landfill gas used for electricity generation. *J. Environ. Manag.* **2022**, *314*, 115070. [CrossRef] [PubMed]
31. Kowalski, S.; Opoka, K.; Ciuła, J. Analysis of the end-of-life the front suspension beam of a vehicle. *Eksploat. I Niezawodn.–Maint. Reliab.* **2022**, *24*, 446–454. [CrossRef]
32. Zhang, D.; Zhang, R.; Zheng, Y.; Zhang, B.; Jiang, Y.; An, Z.; Bai, J. Carbon emission reduction analysis of CHP system driven by biogas based on emission factors. *Energy Build. Environ.* **2022**, *9*, 576–588. [CrossRef]
33. Stanuch, I.; Biegańska, J. Siloxane in the biogas. *Arch. Waste Manag. Environ. Prot.* **2014**, *16*, 1–8.
34. Malinowski, M.; Famielec, S. Impact of Biochar Addition and Air-Flow Rate on Ammonia and Carbon Dioxide Concentration in the Emitted Gases from Aerobic Biostabilization of Waste. *Materials* **2022**, *15*, 1771. [CrossRef]
35. Stoeckli, H.F. Microporous carbons and their characterization: The present state of the art. *Carbon* **1990**, *28*, 1–6. [CrossRef]
36. Zhang, X.; Yang, P. Role of graphitic carbon in g-C3N4 nanoarchitectonics towards efficient photocatalytic reaction kinetics: A review. *Carbon* **2023**, *216*, 118584. [CrossRef]
37. Zhang, Y.; Kawasaki, Y.; Oshita, K.; Takaoka, M.; Minami, D.; Inoue, G.; Tanaka, T. Economic assessment of biogas purification systems for removal of both H_2S and siloxane from biogas. *Renew. Energy* **2021**, *168*, 119–130. [CrossRef]
38. Malinowski, M. Impact of Air-Flow Rate and Biochar Addition on the Oxygen Concentration in Waste and Emitted Gases During Biostabilization of Undersized Fraction from Municipal Solid Waste. *J. Ecol. Eng.* **2021**, *22*, 136–144. [CrossRef]
39. Shin, H.C.; Park, J.W.; Park, K.; Song, H.C. Removal characteristics of trace compounds of landfill gas by activated carbon adsorption. *Environ. Pollut.* **2002**, *119*, 227–236. [CrossRef] [PubMed]
40. Pires, A.; Martinho, G. Waste hierarchy index for circular economy in waste management. *Waste Manag.* **2019**, *95*, 298–305. [CrossRef]
41. Alazzani, A.; Wan-Hussin, W.N. Global Reporting Initiative's environmental reporting: A study of oil and gas companies. *Ecol. Indic.* **2013**, *32*, 19–24. [CrossRef]
42. Regulation of the Minister of Climate of January 2, 2020 on the Waste Catalog. (In Polish). Available online: https://isap.sejm.gov.pl/isap.nsf/download.xsp/WDU20200000010/O/D20200010.pdf (accessed on 2 March 2024).
43. Leong, K.-Y.; Loo, S.-L.; Bashir, M.J.K.; Oh, W.D.; Rao, P.W.; Lim, J.W. Bioregeneration of spent activated carbon: Review of key factors and recent mathematical models of kinetics. *Chin. J. Chem. Eng.* **2018**, *26*, 893–902. [CrossRef]
44. Tran, V.T.L.; Gélin, P.; Ferronato, C.; Chovelon, J.M.; Fine, L.; Postole, G. Adsorption of linear and cyclic siloxanes on activated carbons for biogas purification: Sorbents regenerability. *Chem. Eng. J.* **2019**, *378*, 122152. [CrossRef]
45. Baskar, A.V.; Bolan, N.; Hoang, S.A.; Sooriyakumar, P.; Kumar, M.; Singh, L.; Jasemizad, T.; Padhye, L.P.; Singh, G.; Vinu, A.; et al. Recovery, regeneration and sustainable management of spent adsorbents from wastewater treatment streams: A review. *Sci. Total Environ.* **2022**, *822*, 153555. [CrossRef]
46. Molino, G.; Gandiglio, M.; Fiorilli, S.; Lanzini, A.; Drago, D.; Papurello, D. Design and Performance of an Adsorption Bed with Activated Carbons for Biogas Purification. *Molecules* **2022**, *27*, 7882. [CrossRef]
47. Mohammad-pajooh, E.; Turcios, A.E.; Cuff, G.; Weichgrebe, D.; Rosenwinkel, K.-H.; Vedenyapina, M.D.; Sharifullina, L.R. Removal of inert COD and trace metals from stabilized landfill leachate by granular activated carbon (GAC) adsorption. *J. Environ. Manag.* **2018**, *228*, 189–196. [CrossRef] [PubMed]
48. Din, M.I.; Ashraf, S.; Intisar, A. Comparative study of different activation treatments for the preparation of activated carbon: A mini-review. *Sci. Prog.* **2017**, *100*, 299–312. [CrossRef] [PubMed]
49. Reza, S.; Yun, C.S.; Afroze, S.; Radenahmad, N.; Abu Bakar, M.S.; Saidur, R.; Taweekun, J.; Azad, A.K. Preparation of activated carbon from biomass and its' applications in water and gas purification, a review. *Arab. J. Basic Appl. Sci.* **2020**, *27*, 208–238. [CrossRef]
50. Le-Minh, N.; Sivret, E.C.; Shammay, A.; Stuetz, R.M. Factors affecting the adsorption of gaseous environmental odors by activated carbon: A critical review. *Crit. Rev. Environ. Sci. Technol.* **2018**, *48*, 341–375. [CrossRef]
51. Chaukura, N.; Gwenzi, W.; Tavengwa, N.; Manyuchi, M.M. Biosorbents for the removal of synthetic organics and emerging pollutants: Opportunities and challenges for developing countries. *Environ. Dev.* **2016**, *19*, 84–89. [CrossRef]
52. Yang, Z.; Chen, Z.; Gong, H.; Wang, X. Copper oxide modified activated carbon for enhanced adsorption performance of siloxane: An experimental and DFT study. *Appl. Surf. Sci.* **2022**, *601*, 154200. [CrossRef]
53. Nath, K.; Bhakhar, M.S. Microbial regeneration of spent activated carbon dispersed with organic contaminants: Mechanism, efficiency, and kinetic models. *Environ. Sci. Pollut. Res.* **2011**, *18*, 534–546. [CrossRef] [PubMed]
54. Hwang, S.Y.; Lee, G.B.; Kim, J.H.; Hong, B.U.; Park, J.E. Pre-Treatment Methods for Regeneration of Spent Activated Carbon. *Molecules* **2020**, *25*, 4561. [CrossRef] [PubMed]
55. Ania, C.O.; Parra, J.B.; Menéndez, J.A.; Pis, J.J. Microwave-assisted regeneration of activated carbons loaded with pharmaceuticals. *Water Res.* **2007**, *41*, 3299–3306. [CrossRef]

56. Liu, C.; Li, C.; Shan, Y.; Sun, Z.; Chen, W. Comparison of two typical regeneration methods to the spent biological activated carbon in drinking water. *Environ. Sci. Pollut. Res.* **2020**, *27*, 16404–16414. [CrossRef]
57. Xin-hui, D.; Srinivasakannan, C.; Qu, W.-W.; Xin, W.; Jin-hui, P.; Li-bo, Z. Regeneration of microwave assisted spent activated carbon: Process optimization, adsorption isotherms and kinetics. *Chem. Eng. Process. Process Intensif.* **2012**, *53*, 53–62. [CrossRef]
58. Nunes, K.G.P.; Sfreddo, L.W.; Rosset, M.; Féris, L.A. Efficiency evaluation of thermal, ultrasound and solvent techniques in activated carbon regeneration. *Environ. Technol.* **2021**, *42*, 4189–4200. [CrossRef] [PubMed]
59. Zhang, Z.; Peng, J.; Qu, W.; Zhang, L.; Zhang, Z.; Li, W.; Wan, C.R. Regeneration of high-performance activated carbon from spent catalyst: Optimization using response surface methodology. *J. Taiwan Inst. Chem. Eng.* **2009**, *40*, 541–548. [CrossRef]
60. Park, J.E.; Lee, G.B.; Hong, B.U.; Hwang, S.Y. Regeneration of Activated Carbons Spent by Waste Water Treatment Using KOH Chemical Activation. *Appl. Sci.* **2019**, *9*, 5132. [CrossRef]
61. Hwang, S.Y.; Lee, G.B.; Park, J.E.; Kim, J.H.; Kim, S.; Hong, B. Removal and recycling of volatile organic compounds (VOCs) adsorbed on activated carbons using in situ vacuum systems. *Int. J. Environ. Sci. Technol.* **2019**, *16*, 7827–7836. [CrossRef]
62. Trellu, C.; Oturan, N.; Keita, F.K.; Fourdrin, C.; Pechaud, Y.; Oturan, M.A. Regeneration of Activated Carbon Fiber by the Electro-Fenton Process. *Environ. Sci. Technol.* **2018**, *52*, 7450–7457. [CrossRef] [PubMed]
63. Çalişkan, E.; Bermúdez, J.M.; Parra, J.B.; Menéndez, J.A.; Mahramanlioĝlu, M.; Ania, C.O. Low temperature regeneration of activated carbons using microwaves: Revising conventional wisdom. *J. Environ. Manag.* **2012**, *102*, 134–140. [CrossRef]
64. Liu, S.; Jie, J.; Guo, A.; Yue, S.; Li, T. A comprehensive investigation on microstructure and magnetic properties of immiscible Cu-Fe alloys with variation of Fe content. *Mater. Chem. Phys.* **2019**, *238*, 121909. [CrossRef]
65. Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the Establishment of a Framework to Facilitate Sustainable Investment, and Amending Regulation (EU) 2019/2088 (Dz.U. L 198 z 22.6.2020, s. 13). Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32020R0852&from=EN (accessed on 18 March 2024).
66. Lenarczyk, A.; Jaskólski, M.; Bućko, P. The Application of a Multi-Criteria Decision-Making for Indication of Directions of the Development of Renewable Energy Sources in the Context of Energy Policy. *Energies* **2022**, *15*, 9629. [CrossRef]
67. O'Reilly, S.; Gorman, L.; Bhaird, C.M.A.; Brennan, N.M. Implementing the European Union Green Taxonomy: Implications for small—And medium-sized enterprises. *Account. Forum* **2023**, *1*, 1–26. [CrossRef]
68. Och, M. Sustainable Finance and the EU Taxonomy Regulation—Hype or Hope? *Jan Ronse Inst. Co. Financ. Law Work. Pap.* **2021**, *5*, 1–19. [CrossRef]
69. Schutze, F.; Stede, J. The EU sustainable finance taxonomy and its contribution to climate neutrality. *J. Sustain. Financ. Invest.* **2021**, *14*, 128–160. [CrossRef]
70. Sikora, A. European Green Deal—Legal and financial challenges of the climate change. *ERA Forum* **2020**, *21*, 681–697. [CrossRef]
71. Pacces, A.M. Will the EU Taxonomy Regulation Foster Sustainable Corporate Governance? *Sustainability* **2021**, *13*, 12316. [CrossRef]
72. Lucarelli, C.; Mazzoli, C.; Rancan, M.; Severini, S. Classification of Sustainable Activities: EU Taxonomy and Scientific Literature. *Sustainability* **2020**, *12*, 6460. [CrossRef]
73. Dusíka, J.; Bond, A. Environmental assessments and sustainable finance frameworks: Will the EU Taxonomy change the mindset over the contribution of EIA to sustainable development? *Impact Assess. Proj. Apprais.* **2022**, *40*, 90–98. [CrossRef]
74. Hysa, E.; Kruja, A.; Rehman, N.U.; Laurenti, R. Circular Economy Innovation and Environmental Sustainability Impact on Economic Growth: An Integrated Model for Sustainable Development. *Sustainability* **2020**, *12*, 4831. [CrossRef]
75. Hoepner, A.G.F.; Schneider, F.I. EU Green Taxonomy Data—A First Vendor Survey. *Econ. Voice* **2022**, *19*, 229–242. [CrossRef]
76. Kirby, D.; Thompson, S.; Macmahon, C. Shifting the EU Taxonomy from Theory to Practice: A Review of the Literature highlighting Potential Academic Contributions to its Adoption, Implementation, and Impact. Presented at the 1 st Annual Academy of Sustainable Finance. *Account. Account. Gov.* **2021**, *1*, 1–38. Available online: https://www.researchgate.net/publication/364051088_Shifting_the_EU_Taxonomy_from_Theory_to_Practice_A_Review_of_the_Literature_highlighting_Potential_Academic_Contributions_to_its_Adoption_Implementation_and_Impact (accessed on 4 March 2024).
77. Dumrose, M.; Rink, S.; Eckert, J. Disaggregating confusion? The EU Taxonomy and its relation to ESG rating. *Financ. Res. Lett.* **2022**, *48*, 102928. [CrossRef]
78. Ingre, G.; Passburf, C.V. The Impact of the EU Taxonomy. Stockholm: KTH Royal Institute of Technology School of Industrial Engineering and Management. 2020. Available online: https://www.diva-portal.org/smash/get/diva2:1456396/FULLTEXT01.pdf (accessed on 19 March 2024).
79. Papari, C.A.; Toxopeus, H.; Polzin, F.; Bulkeley, H.; Menguzzo, E.V. Can the EU taxonomy for sustainable activities help upscale investments into urban nature-based solutions? *Environ. Sci. Policy* **2024**, *151*, 103598. [CrossRef]
80. Andersen, J.; Seppanen, M.; Lahteenmaki, I. EU Taxonomy Market Study. Tampere: Tampereen Yliopisto Tampere University. 2023. Available online: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4369700 (accessed on 21 March 2024).
81. Bogeanu-Popa, M.M.; Man, M. The European Union Taxonomy—The Revolution of Sustainable Activities. *Analele Univ. Ovidius Constanta* **2022**, *22*, 818–826. Available online: https://www.researchgate.net/publication/375952350_The_European_Union_Taxonomy_-The_Revolution_of_Sustainable_Activities (accessed on 22 March 2024). [CrossRef]

82. Commission Delegated Regulation (EU) 2023/2485 of 27 June 2023 Amending Delegated Regulation (EU) 2021/2139 Establishing Additional Technical Screening Criteria for Determining the Conditions under Which Certain Economic Activities Qualify as Contributing Substantially to Climate Change Mitigation or Climate Change Adaptation and for Determining Whether Those Activities Cause no Significant Harm to any of the Other Environmental Objective. Available online: https://eur-lex.europa.eu/eli/reg_del/2023/2485 (accessed on 20 March 2024).
83. Recommendations for the Road Map for the Development of Sustainable Finance in Poland Regarding the Application of the EU Taxonomy (In Polish). Available online: https://www.gov.pl/attachment/fcc19949-dab2-485c-9524-c11d30a0354d (accessed on 22 March 2024).
84. Banks' Report in Accordance with Art. 8 Taxonomies: Requirements and Challenges. (In Polish). Available online: https://assets.ey.com/content/dam/ey-sites/ey-com/pl_pl/article/taksonomia-ujawnienia-za-rok-2023-wymogi-i-wyzwania.pdf (accessed on 2 March 2024).
85. *PN-C-97554:1990*; Formulated Activated Carbons. Sklep PKN: Warsaw, Poland, 1990.
86. *PN-C-97555-03:1982*; Activated Carbons. Test Methods. Sklep PKN: Warsaw, Poland, 1982.
87. *PN-EN 12902:2005*; Products for the Treatment of Water Intended for Consumption. Inorganic Carrier and Filtration Materials. Test Methods. Sklep PKN: Warsaw, Poland, 2005.
88. *PN-88/C-97555/01:1988*; Activated Carbons. Test Methods. Sieve Analysis. Sklep PKN: Warsaw, Poland, 1988.
89. *Statistica*, version 14.1.0.4; TIBCOI Software Inc.: Santa Clara, CA, USA, 2023.
90. Sarquah, K.; Narra, S.; Beck, G.; Bassey, U.; Antwi, E.; Hartmann, M.; Derkyi, N.S.A.; Awafo, E.A.; Nelles, M. Characterization of Municipal Solid Waste and Assessment of Its Potential for Refuse-Derived Fuel (RDF) Valorization. *Energies* **2023**, *16*, 200. [CrossRef]
91. Przydatek, G.; Kochanek, A.; Basta, M. Analysis of changes in municipal waste management at the county level. *J. Ecol. Eng.* **2017**, *18*, 72–80. [CrossRef] [PubMed]
92. Gong, H.; Zhou, S.; Chen, Z.; Chen, L. Effect of volatile organic compounds on carbon dioxide adsorption performance via pressure swing adsorption for landfill gas upgrading. *Renew. Energy* **2019**, *135*, 811–818. [CrossRef]
93. Sevimoğlu, O.; Tansel, B. Composition and source identification of deposits forming in landfill gas (LFG) engines and effect of activated carbon treatment on deposit composition. *J. Environ. Manag.* **2013**, *128*, 300–305. [CrossRef] [PubMed]
94. Dernbach, H.; Henning, K.D. Purification steps for landfill gas utilization in cogeneration modules. *Resour. Conserv.* **1987**, *14*, 273–282. [CrossRef]
95. Márquez, P.; Benítez, A.; Chica, A.F.; Martín, M.A.; Caballero, A. Evaluating the thermal regeneration pro-cess of massively generated granular activated carbons for their reuse in wastewater treatments plants. *J. Clean. Prod.* **2022**, *366*, 132685. [CrossRef]
96. Santadkha, T.; Skolpap, W. Economic comparative evaluation of combination of activated carbon generation and spent activated carbon regeneration plants. *J. Eng. Sci. Technol.* **2017**, *12*, 3329–3343.
97. Dąbek, L. *Regeneration of Used Active Carbons*; Wydawnictwo Politechniki Świętokrzyskiej: Kielce, Poland, 2007. (In Polish)
98. Kwon, Y.; Lee, S.; Bae, J.; Park, S.; Moon, H.; Lee, T.; Kim, K.; Kang, J.; Jeon, T. Evaluation of Incinerator Per-formance and Policy Framework for Effective Waste Management and Energy Recovery: A Case Study of South Korea. *Sustainability* **2024**, *16*, 448. [CrossRef]
99. Gronba-Chyła, A.; Generowicz, A.; Alwaeli, M.; Mannheim, V.; Grąz, K.; Kwaśnicki, P.; Kramek, A. Municipal waste utilization as a substitute for natural aggregate in the light of the circular economy. *J. Clean. Prod.* **2024**, *440*, 140907. [CrossRef]
100. Ziolo, M.; Bak, I.; Cheba, K. The role of sustainable finance in achieving sustainable development goals: Does it work? *Technol. Econ. Dev. Econ.* **2021**, *27*, 45–70. [CrossRef]
101. Taghizadeh-Hesary, F.; Yoshino, N. Sustainable Solutions for Green Financing and Investment in Renewable Energy Projects. *Energies* **2020**, *13*, 788. [CrossRef]
102. Ji, X.; Chen, X.; Mirza, N.; Umar, M. Sustainable energy goals and investment premium: Evidence from renewable and conventional equity mutual funds in the Euro zone. *Resour. Policy* **2021**, *74*, 102387. Available online: https://www.sciencedirect.com/science/article/abs/pii/S0301420721003962 (accessed on 20 March 2024). [CrossRef]
103. Lagoarde-Segot, T. Financing the Sustainable Development Goals. *Sustainability* **2020**, *12*, 2775. [CrossRef]
104. Mesonnier, J.S.; Nguyen, B. Showing off Cleaner Hands: Mandatory Climate-Related Disclosure by Financial Institutions and the Financing of Fossil Energy. *Available SSRN* **2021**, *1*, 1–38. [CrossRef]
105. Laktionova, O.; Kovalenko, Y.; Myhovych, T.; Zharikova, O. Transforming Financial Outsourcing Services for Sustainable Business Development: A Review on Green Finance. *Econ. Ecol. Socium* **2022**, *6*, 37–50. [CrossRef]
106. Tryhuba, A.; Hutsol, T.; Kuboń, M.; Tryhuba, I.; Komarnitskyi, S.; Tabor, S.; Kwaśniewski, D.; Mudryk, K.; Faichuk, O.; Hohol, T.; et al. Taxonomy and Stakeholder Risk Management in Integrated Projects of the European Green Deal. *Energies* **2022**, *15*, 2015. [CrossRef]
107. Koval, V.; Fostolovych, V.; Kubai, O.; Tkachyk, F.; Prystupa, L.; Laktionova, O. Financial Outsourcing in the Analysis of Environmental Fiscal Revenue Management. *Financ. Credit Act. Probl. Theory Pract.* **2023**, *6*, 112–127. [CrossRef]
108. Reis, I.F.G.; Gonçalves, I.; Lopes, M.A.R.; Antunes, C.H. Business models for energy communities: A review of key issues and trends. *Renew. Sustain. Energy Rev.* **2021**, *144*, 111013. [CrossRef]
109. Koval, V.; Olczak, P.; Hakova, M.; Bilyi, M.; Kretov, D.; Laktionova, O. Analysis of Financial Outsourcing Management in Regional Environmental Systems. *Sustainability* **2023**, *15*, 11966. [CrossRef]

110. Hwang, H.; Kweon, T.; Kang, H.; Hwang, Y. Resource and Greenhouse Gas Reduction Effects through Recycling of Platinum-Containing Waste. *Sustainability* **2024**, *16*, 80. [CrossRef]
111. Stupnytskyi, V.; Filipishyna, L.; Chumak, O.; Gonchar, V.; Komandrovska, V.; Iefimova, G. Environmental Compliance and Business Strategies Practices of Entrepreneurial Ventures. *E3S Web Conf.* **2023**, *408*, 01025. [CrossRef]
112. Kowalski, Z.; Kulczycka, J.; Makara, A.; Verhé, R.; De Clercq, G. Assessment of Energy Recovery from Municipal Waste Management Systems Using Circular Economy Quality Indicators. *Energies* **2022**, *15*, 8625. [CrossRef]
113. Sechi, S.; Giarola, S.; Leone, P. Taxonomy for Industrial Cluster Decarbonization: An Analysis for the Italian Hard-to-Abate Industry. *Energies* **2022**, *15*, 8586. [CrossRef]