waste

Review

Value Chain Analysis of Rice Industry by Products in a Circular Economy Context: A Review

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Abstract: The quantity of organic waste generated by agricultural sectors is continually increasing due to population growth and rising food demand. Rice is the primary consumable food in Asia. However, many stakeholders follow a linear economic model such as the "take–make–waste" concept. This linear model leads to a substantial environmental burden and the destruction of valuable resources without gaining their actual value. Because these by-products can be converted into energy generating and storage materials, and into bio-based products by cascading transformation processes within the circular economy concept, waste should be considered a central material. This review examines the composition of rice straw, bran, and husks, and the procedures involved in manufacturing value-added goods, from these wastes. Moreover, starting with an extensive literature analysis on the rice value chains, this work systematizes and displays a variety of strategies for using these by-products. The future development of agricultural waste management is desirable to capitalize on the multi-functional product by circulating all the by-products in the economy. According to the analysis of relevant research, rice straw has considerable potential as a renewable energy source. However, there is a significant research gap in using rice bran as an energy storage material. Additionally, modified rice husk has increased its promise as an adsorbent in the bio-based water treatment industry. Furthermore, the case study of Sri Lanka revealed that developing countries have a huge potential to value these by-products in various sectors of the economy. Finally, this paper provides suggestions for researchers and policymakers to improve the current agriculture waste management system with the best option and integrated approach for economic sustainability and eco- and environmental solution, considering some case studies to develop sustainable waste management processes.

Keywords: rice straw; rice bran; rice husk; agricultural waste; valorization; circular economy; biomass; bioeconomy

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1. Introduction

Rice is an annual plant crop mainly cultivated in areas with high rainfall and rice is a primary edible food and crop in Asia [1,2]. Many South Asian countries have an agrarian economy and have been producing significant amounts of agricultural waste related to the rice industry. As a food crop, rice ranks first in consumption, second in total output, and third in total cultivation [1]. Most (around 90%) of the world's rice supply is grown in Asia; the world's two major rice producers, China and India, provide more than half of the world's rice supply [1,3]. The world increase in cultivated area from 120 million to 163 million ha (0.5%) each year and the increase in paddy yield from 1.8 to 4.6 t/ha (1.6%) between 1960 and 2018 caused a more than threefold increase in global rice output, from 221 million to 745 million metric tons (2.1% per year) [4] (Figure 1). The Green Revolution dramatically increased rice production, which helped stave off famines, feed millions of people, alleviate poverty and hunger, and improve the lives of countless people throughout Asia [1,5]. Since there is a limit on how much land may be devoted to rice cultivation, any future increases in output will have to come from higher yields. Most of the world's population relies on rice for sustenance. With a global per capita consumption of 64 kg per year, milled rice accounts for 19% of global daily calorie intake [1,3,4,6].

Agricultural wastes are biomass residues that can be grouped into two categories, i.e., crop residues and agro-industrial residues [7]. However, traditional approaches handling agricultural waste have been linked to environmental damage and financial losses. Many farmers and other agro-industry stakeholders engage in open field burning or open dumping to clear their land for future cultivation rather than extracting their total value. In developing countries, burning crop straws and other agricultural wastes in the open air or in the kitchen is a significant contributor to dangerously high levels of air pollution. According to estimates provided by the World Bank and the Institute for Health Metrics and Evaluation (2016), the welfare losses caused by exposure to air pollution cost the global economy around $5.11 trillion in 2013 [8]. For sake of example and comparison, the size of welfare losses in Belarus, Bulgaria, India, Romania, Kazakhstan, and Bangladesh as a share of regional gross domestic product (GDP) are as follows: 9.25%, 8.85%, 7.69%, 7.21%, and 6.81%. The cost of air pollution caused by open-air straw burning in mainland China in 2004 was estimated to be over 19.65 billion CNY or around 0.14% of the country's GDP [9]. Thus, it is possible to minimize these adverse effects by considering the valorization process for these potential feedstocks and using them as a valuable material or source for the national economy [10].

Considering their waste quantities and physical and chemical properties, rice industry by-products have a high potential for generating energy and extracting nutrients, minerals, and biochemicals through different valorization processes [10]. However, their potential still needs to be explored due to issues relating to their supply chain, appropriate technologies for pretreatment, and cost-effective methods. Therefore, it is necessary to combine them with feasible business models to facilitate the valorization methods for the rice industry by-products in many developed and developing countries [7,10].

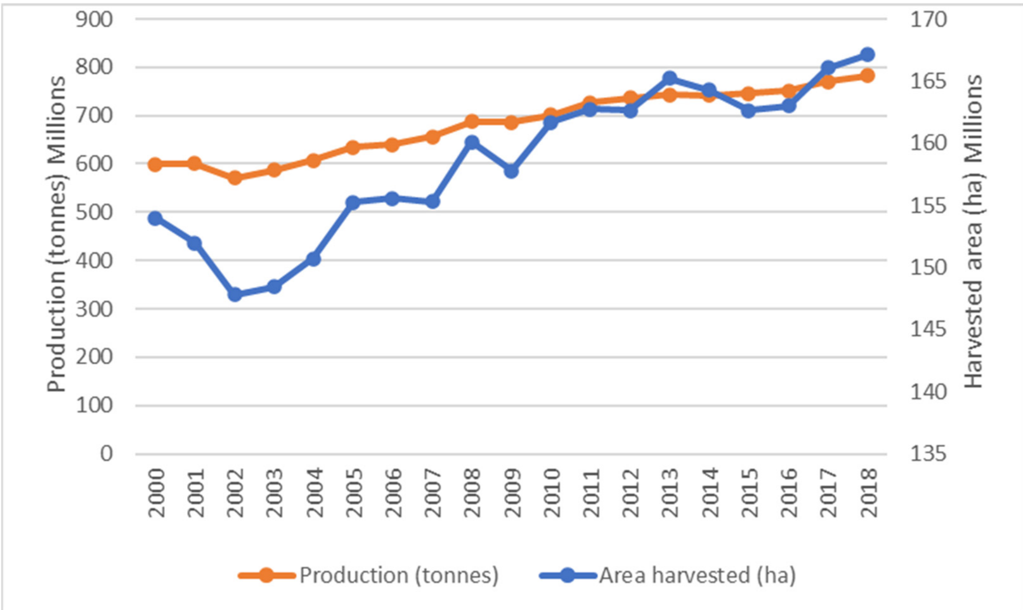

Figure 1. Rice production and area harvested, adopted from [11].

However, if wastes are valorized as raw materials to complete parts of equipment through disassembly and remanufacturing, they can create value for entire supply chains, allowing additional markets for used components beyond the raw materials market and developing new specialized professions. These openings are crucial because they establish an indirect market where resources, energy, and components from various waste streams in the rice value chain produce income for the communities [12].

Therefore, the primary purpose of this study is to consider current waste management practices for the main types of waste in the rice industry, namely rice straws, rice bran, and rice husk, including rice husk ash that remains from processes involving energy generation. Additionally, this review presents the strategies and potentialities of these by-products for developing full utilization in the economy. Therefore, the study is focused on the potentiality of all types of products, such as high-value low-volume products, high-volume low-value products, and value-added products (Figure 2). However, the implementation of these valorization options will be determined by practical feasibility. In addition, these options will be analyzed for compatibility with other factors such as economic feasibility and social acceptance.

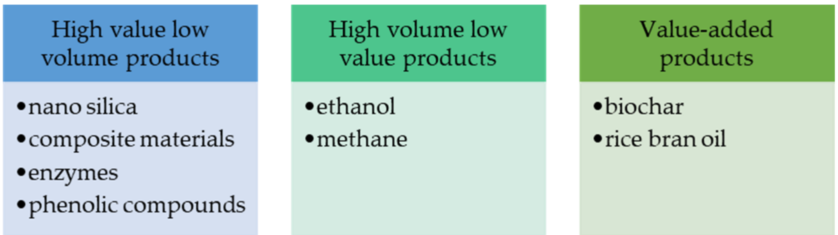

Figure 2. Focused valorization options.

2. Rice Industry Value Chain

Agricultural food processing consists of a variety of value chains and generates different types of agricultural waste through the value chain from farm to fork [13,14] (Figure 3). Large quantities of valuable wastes are produced during the harvesting and processing stages, and these wastes should be studied and analyzed to extract their valuable parts sustainably. For example, paddy straws are produced in large quantities during paddy harvesting. These straws are commonly found in the field and are often used as fodder for animals and as bedding for livestock [15]. The remaining part is burned by the farmers when ready for subsequent cultivation. Additionally, rice husk frequently becomes a material for burning and is discarded in landfills [16]. The destruction of this valuable biomass without proper use will cause irreversible damage to the environment and all living beings on the planet. Bran is another by-product of the rice processing value chain (Figure 3). After harvesting and milling, the by-products of the rice industry can be subjected to industrial symbiosis to exploit their full value [2,13].

Rice farming is integrated with geography, soil type, water availability, harvesting and processing techniques, and market behavior [17,18]. Farmers grow different types of rice in different regions because each grows best in specific soil types and climates. Additionally, access to water and proper irrigation systems boost agricultural production [19,20]. Many small and medium rice farmers still depend on labor [14]. Traditional techniques are slow and dependent on workability and experience. Modern technology and equipment are helpful in rice-producing areas but expensive [13,14,21,22]. Consequently, different production conditions affect the rice industry's waste [21,22]. Therefore, waste calculation should include unused rice and other waste due to harvesting and processing errors [2,13]. Consumer behavior and attitudes will determine how much rice is wasted at the end of the food value chain [23–25]. Edible rice wastage is due to bad taste, rotting, and leftovers [23–25].

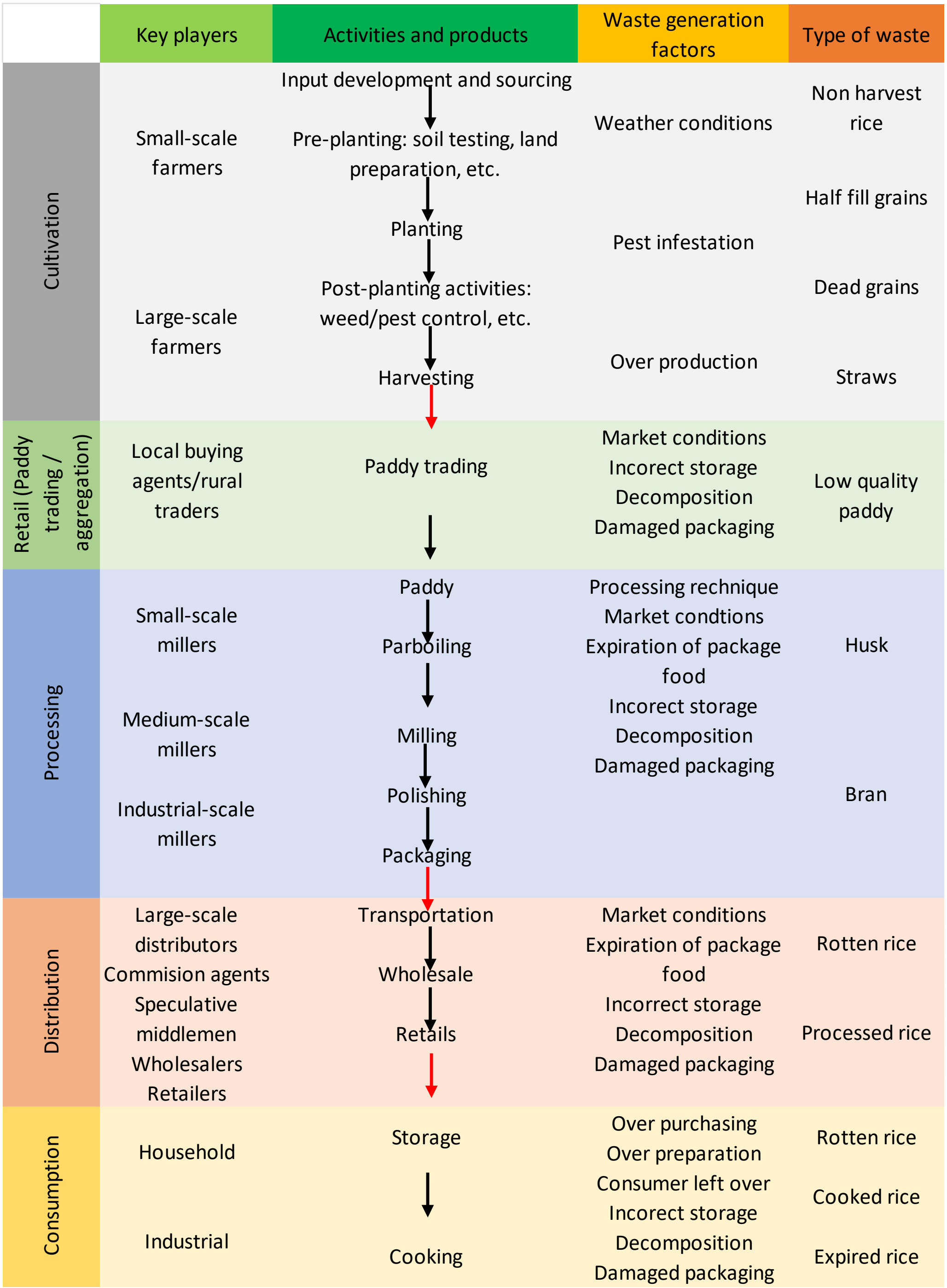

Figure 3. Conceptual model of the rice waste generated all along the food chain (red arrows represent the interaction points of each stage throughout the value chain) adopted from [14,26–29].

Waste Production throughout the Value Chain

After completion of the harvesting process, the paddy is transferred to the rice mills to be processed into white or brown rice. The paddy is subjected to a series of operational procedures during the rice milling process to remove straw particles, half-filled seeds, husks, bran, and germ. Several milling processes exist, such as one-stage milling and multi-stage milling [2,30]. Compared to multi-stage mills, the one-stage milling technique produces fewer by-products. The large-scale industrial milling process has several steps, such as cleaning (removing chaff, dead seeds, seeds that are only half full, and stones), parboiling, de-husking, peeling, polishing, and grading [2,30,31]. In addition, specific varieties of rice will be washed in hot water for a certain amount of time to remove the husk, enhance its size, and obtain a better shape of the grains [31].

There are several ways to remove rice husks from rice seeds. The germ particles and outer bran are removed after the husking in a series of huller reels and pearling cones, where the waxy cuticle is sheared off by friction between the high-speed abrasive cone and its casing [30–32]. As a result, rice bran is generated as a by-product [33]. The milling gap between the cone and the cover can be changed. Therefore, the grinding ratio can be changed by raising or lowering the cone [30,31]. Typically, in most rice mills, the rice passes through several cones, each with a higher milling rate than the previous one [30]. Since the milling space between the cone and the casing is adjustable [31], the milling rate can be varied by raising or lowering the cone [29]. The bran from the different stages is usually quantified as one product [33]. Next, rice from the pearlier is passed through polishers to get a finer appearance to the rice grains [2,26]. In this process, some parts of the starchy kernel are removed. This by-product is called fine bran if it is included within the inner bran layer. Finally, the mixture of whole and broken rice from the polishers are subjected to the sieving process and graded according to the standard at which the rice is sold [27].

According to previous research, the ratio of useable products to by-products is shown in Figure 4. Pollards are often a blend of polishings and bran. However, all these by-products are generated during the rice milling process, and their amount is roughly 60% rice husk, 35% rice bran, and 5% polishing from the whole rice mill waste stream [16,34–39].

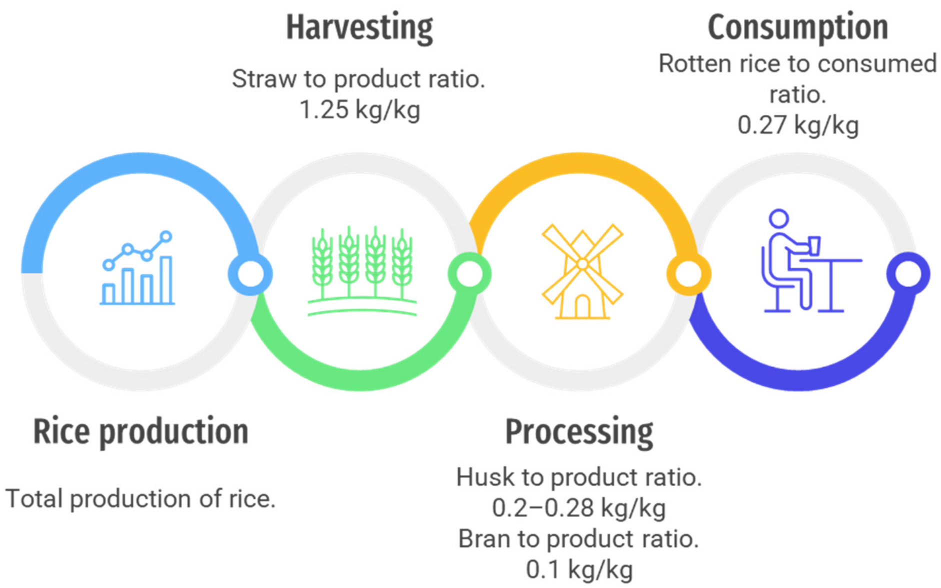

Figure 4. Quantity of rice processing by-products throughout the value chain adopted from [16,34–39].

Total rice consumption worldwide from 2008/2009 to 2021/2022 (in 1000 metric tons) is shown in Figure 5. The FAO Agricultural Outlook predicts that paddy production will rise to 52603 metric tons by 2027 compared to 2018 [40]. Due to factors including the increase in agriculturally usable land, technological advancements, and faster population growth in recent decades, global agricultural output has expanded dramatically [40].

Figure 5. Total rice consumption worldwide from 2008/2009 to 2021/2022 (in 1000 metric tons) adopted from [41]. ** estimate as of January 2022.

As agricultural waste generates economic benefits, agricultural waste recycling is not meant to degrade value like other industrial waste recycling does [42]. Due to the nature of systemically implemented operations, recycling must be compared to materials that remain the same or lose performance when recycled. Due to their inherent propensity for rapid spoiling, agri-food supply chain management may need to be more sustainable and efficient [43]. Having a systemic vision and viewpoint that prioritizes the concepts of complexity and networks is essential for solving this challenge [13,42–44]. According to this method of thinking, a system is a collection of interconnected individuals whose behaviors are determined by their connections. When all of these elements are considered, they form a holistic system with more worth than just the sum of its individual parts. From this point of view, designing the agri-food scenario using a systemic approach is a viable method to begin a paradigm shift that entails switching from linear to circular structures.

3. Analysis of Rice Supply Chain Waste

3.1. Rice Straw

Rice straw is the vegetative part of the rice plant (*Oryza sativa* L.). Rice straw consists of the plant's stem, leaves, and pods and is generated after being cut off during harvest. Rice straw comprises cellulose, lignin, waxes, silicates, and minerals. In general, animals are often fed with rice straw, and rice straw can be utilized for creating compost, paper, cow bedding, and crafts; it also offers energy to specific industries and covers agricultural areas [45,46]. The rice straw of the current year is usually burned before the subsequent plowing to prepare the field.

Composition of Rice Straw

Variety, cultivated area, seasons, nitrogen fertilizer, plant maturity, plant health, and several other environmental and human variables significantly impact the chemical composition of any biomass [15,47]. Changes in chemical and physical parameters affect the yield and quality of the final product. Heterogeneity is thus seen as detrimental to the manufacturing process. Additionally, this impacts how by-products are used at the end of their life cycle. Therefore, compositional analysis and structural characterization should be considered to enhance the effectiveness of the valorization options. Tables 1–3 provide the average values of various important parameters describing raw and processed rice straw (based on the energy, nutritional, and fertilizer properties, respectively) as obtained by the chemical analyses. Rice straw has a greater silica concentration but less lignin than the straws of other cereals [48]. In order to maximize silica amount in the stem ratio, it is advised that the rice straw be shortened as much as possible [2]. Cell walls may contain silica, or silica may be soluble in water. They are eliminated with urine, where they sometimes crystallize. Since rice straw has a high oxalate content (1–2% of dry matter) and is known to lower Ca concentrations, adding supplemental Ca is often recommended [49]. Variety, time duration between harvest and storage, amount of nitrogen fertilizer used, plant maturity (lignin content increases with maturity), plant health, and environmental conditions affect the quality of rice straw [15]. Although rice straw is a rich energy source, it contains only 2–7% protein and is indigestible due to its high silica content. Therefore, it is considered a coarse and low-quality food source [50]. Minerals such as sulfur may be a limiting factor when considering it as fodder [51]. Other conditions usually involve:

- Excessive amounts of neutral detergent fiber (NDF) lead to decreased feed consumption and fat-corrected milk output [52].
- There is not enough P, Cu, Zn, Ca, and NaCl to meet the needs of animals [53].
- In comparison to corn silage, it contains less energy, has an unpleasant taste, and uses nitrogen less effectively [54].

Table 1. Energy characteristics of rice straw [2,47,55–59].

Properties	**Average Values (MJ/kg)**				
	Rice Straw	**Rice Straw Urea Treated**	**Rice Straw Ammonia Treated**	**Rice Straw NaOH Treated**	**Other**
Higher heating value (HHV)	-	-	-	-	15.5
Lower heating value (LHV)	-	-	-	-	14.43
	Average values (% wt)				
Fixed carbon	-	-	-	-	14.6
Volatile matter	-	-	-	-	60.28
Ash	-	-	-	-	16.83
Moisture	7.2	6.00	29.1	30.6	8.47
Carbon	-	-	-	-	38.58
Oxygen	-	-	-	-	35.79
Hydrogen	-	-	-	-	4.97
Nitrogen	-	-	-	-	1.12
Sulphur	-	-	-	-	0.145

Table 2. Fodder characteristics of rice straw [2,47,55–59].

Properties	**Average Values (% wt)**				
	Rice Straw	**Rice Straw Urea Treated**	**Rice Straw Ammonia Treated**	**Rice Straw NaOH Treated**	**Other**
Dry matter	92.8	94.0	70.9	69.4	-
Crude protein	4.2	7.9	11.0	2.9	-
Crude fiber	35.1	34.2	-	36.2	39.00
Neutral detergent fiber (NDF)	69.1	68.6	67.5	63.4	67.10
Acid detergent fiber (ADF)	42.4	42.3	-	37.7	-
Lignin	4.8	5.2	-	-	12.50
Ether extract	1.4	1.3	-	0.9	-
Ash	18.1	19.3	15.2	19.0	18.6
Gross energy	15.5	16.0	-	15.2	-

Table 3. Fertilizer characteristics of rice straw [2,47,55–59].

Properties	Average Values (g/kg)				
	Rice Straw	Rice Straw Urea Treated	Rice Straw Ammonia Treated	Rice Straw NaOH Treated	Other
Nitrogen	6.72	12.64	17.6	4.64	11.2
Phosphorus	0.9	1.5	-	0.4	1.2
Potassium	18	17.5	-	-	20.2
Calcium	2.9	3.2	-	2.1	3.3
Magnesium	1.9	1.7	-	-	2.0
Sulphur	-	-	-	-	0.7
Silica	-	-	-	-	68.8
Manganese	454	387	-	-	-
Zinc	34	34	-	-	-
Copper	6	3	-	-	-
Iron	355	-	-	-	956.3

3.2. Rice Bran

A significant waste product in the value chain of rice processing is rice bran. It is mainly used as animal feed and is regarded as a healthy source of fiber for pets because of its high nutritional content. Additionally, farmers may get it at a significant discount because of its availability. Due to the high fat and fiber content of rice bran, up to 40% of it is added to the diets of cattle, dogs, pigs, and chickens [60–62]. Additionally, rice bran is a valuable feed for many animals since it contains 14–18% oil. Therefore, dehulled rice bran may be utilized in more value-added processes than ordinary rice bran [2].

Composition of Rice Bran

The composition of rice bran has a significant role in defining its possible valorization options. Rice bran's physical and chemical properties are influenced by several aspects concerning the grain and the milling procedure [63]. Rice variety, environmental circumstances, grain size and form, distribution, chemical components, strength of the outermost layer, and breaking resistance are the primary elements affecting rice grain [64]. Additionally, the type of grinding machine is the main factor related to the processing conditions, and the grinding process of different layers of rice grain at different depths shows different chemical compositions [63,64].

Rice bran contains various nutrients, including carbohydrates, proteins, minerals, and lipids. It has a high carbohydrate (cellulose and hemicellulose) content and is simple to employ to create microbial products with added value [65]. As a result, before the valuation procedure, it is required to assess the composition. Because rice bran is employed in value-added goods as a microbial product or as a food additive, it is generated during several phases of the rice milling process, which are eventually combined and discharged as rice bran. As a consequence, the chemical composition varies significantly [2]. In addition, the chemical composition of raw rice bran and de-oiled rice bran varies in fiber concentration [55]. Tables 4–7 reflect the chemical analyses regarding its energy-related parameters, fertilizer-related features, feed-related parameters, and bioactive-component qualities.

Rice bran stands out compared to other cereal grains due to the tocotrienol, tocopherol, γ-oryzanol, and β-sitosterol contents [66]. This is significant since there is mounting evidence that these substances may help to lower levels of total plasma cholesterol, triglycerides, and low-density lipoprotein while raising levels of high-density lipoprotein [66]. In addition, ferulic acid and soluble fiber (including β-glucan, pectin, and gums) are found in the indigestible cell walls of rice bran. While the United States Department of Agriculture (USDA) nutritional database values for crude rice bran are often utilized in animal diet formulation [67], caution must be taken since they may not account for changes across rice cultivars [68].

The variety of rice bran utilized determines the chemical content and quality of the end product. According to Hong and his co-workers [69], the fatty-acid content of rice bran oil varies based on the type of rice bran utilized. According to the same paper, rice bran oil, which includes a high concentration of free fatty acids, has several drawbacks when used as fuel in diesel engines in the winter season.

Table 4. Energy characteristics of rice bran [2,55,56,63–65,70–74].

Parameters	**Average Values (MJ/kg)**							
	Fiber < 4%	**Fiber 4–11%**	**Fiber 11–20%**	**Fiber > 20%**	**Defatted Fiber < 11%**	**Defatted Fiber 11–20%**	**Defatted Fiber > 20%**	**Other**
HHV	-	-	-	-	-	-	-	15.29
LHV	-	-	-	-	-	-	-	14.17
	Average Values (% wt)							
Fixed carbon	-	-	-	-	-	-	-	19.53
Volatile Mmatter	-	-	-	-	-	-	-	61.83 (organic)
Moisture	10.0	9.9	9.8	8.3	10.3	11.0	8.4	-
Carbon	-	-	-	-	-	-	-	38.92
Oxygen	-	-	-	-	-	-	-	36.77
Hydrogen	-	-	-	-	-	-	-	5.12
Nitrogen	-	-	-	-	-	-	-	0.55
Sulphur	-	-	-	-	-	-	-	0.0

Table 5. Fodder characteristics of rice bran [2,55,56,63–65,70–74].

Parameters	**Average Values (% wt)**							
	Fiber < 4%	**Fiber 4–11%**	**Fiber 11–20%**	**Fiber > 20%**	**Defatted Fiber < 11%**	**Defatted Fiber 11–20%**	**Defatted Fiber > 20%**	**Other**
Dry matter	90.0	90.1	90.2	91.7	89.7	89.0	91.6	-
Crude protein	14.2	14.8	12.7	8.8	16.0	17.1	6.7	-
Crude fiber	4.1	8.6	16.3	28.3	9.8	14.8	30.8	-
NDF	12.4	25.2	34.4	48.7	26.6	32.6	51.7	-
ADF	3.2	11.2	19.6	32.7	12.5	18.0	35.4	25.2
Lignin	1.2	4.1	6.8	11.0	4.5	6.3	11.8	10.0
Ether extract	13.2	17.2	14.4	10.3	4.1	1.0	4.8	-
Ash	6.9	9.4	12.4	13.6	12.3	14.2	19.1	19.0
Starch	42.0	28.8	22.4	14.7	32.2	26.4	14.2	-
Total sugars	3.8	2.8	2.8	1.0	2.7	3.0	1.6	-
Gross energy	20.5	21.2	20.2	19.3	17.9	17.1	17.0	-
Lipids	-	-	-	-	-	-	-	-

Table 6. Fertilizer characteristics of rice bran [2,55,56,63–65,70–74].

Parameters	Average Values							
	Fiber < 4%	**Fiber 4–11%**	**Fiber 11–20%**	**Fiber > 20%**	**Defatted Fiber < 11%**	**Defatted Fiber 11–20%**	**Defatted Fiber > 20%**	**Other**
Nitrogen	22.7	23.68	2032	14.08	25.6	27.36	10.72	-
Phosphorus	13.9	17.0	13.8	7.4	12.1	19.2	4.9	-
Potassium	10.8	14.9	12.3	6.3	8.5	7.4	7.3	-
Calcium	0.6	0.7	0.7	4.7	0.8	2.5	1.0	-
Magnesium	6.1	7.8	6.5	2.1	4.6	4.4	2.4	-
Sulphur	-	-	-	-	-	-	-	-
	Average Values (mg/kg)							
Manganese	-	211.0	138.0	-	221.0	164.0	157.0	-
Zinc	-	63.0	55.0	-	80.0	80.0	34.0	-
Copper	-	8.0	9.0	-	14.0	13.0	7.0	-
Iron	-	106.0	-	-	297.0	556.0	443.0	-

Table 7. Biochemical characteristics of rice bran [2,55,56,63–65,70–75].

Parameters	Average Values (% wt)							
	Fiber < 4%	**Fiber 4–11%**	**Fiber 11–20%**	**Fiber > 20%**	**Defatted Fiber < 11%**	**Defatted Fiber 11–20%**	**Defatted Fiber > 20%**	**Other**
Protein	-	-	-	-	-	-	-	6.4
Aminoamides	% Protein							
Alanine	5.9	6.4	5.8	-	6.0	5.7	6.2	-
Arginine	7.7	6.6	7.2	-	7.0	6.2	7.4	-
Aspartic acid	7.9	9.0	9.3	-	8.7	8.8	8.1	-
Cystine	1.1	1.2	1.7	-	1.7	1.7	1.2	-
Glutamic acid	13.5	13.0	12.7	-	15.5	12.6	12.7	-
Glycine	4.9	5.3	5.2	-	5.1	5.0	5.4	-
Histidine	2.6	2.6	2.4	-	2.5	2.3	2.4	-
Isoleucine	5.8	5.9	5.3	-	4.8	4.2	6.7	-
Leucine	6.7	6.7	7.0	-	7.2	7.0	7.5	-
Lysine	4.5	4.7	4.4	-	4.4	3.9	4.6	-
Methionine	2.3	2.2	1.9	-	2.4	1.9	2.1	-
Phenylalanine	4.6	4.4	4.4	-	4.9	4.7	4.8	-
Proline	4.7	5.3	4.6	-	5.1	5.6	6.1	-
Serine	4.3	4.6	4.0	-	4.8	4.5	4.3	-

3.3. Rice Husk

Rice husk is the outer covering of the rice grain and is produced as a by-product of the rice milling process. It is also called hull and chaff [39,76]. In agricultural nations, this is the most prevalent agricultural by-product. In particular, rice husk is utilized as the primary source of energy in rice mills, poultry farming, and silica-rich cement [56,77,78]. Additionally, small quantities are used as construction materials and fertilizers [79]. However, most rice husks eventually wind up in landfills or are burned in the open air, significantly polluting the environment. The calorific value of rice husk is considerably high, roughly 16,720 kJ/kg [80]. As previously stated, many millers directly burn or gasify rice husk as their primary energy source [16]. Rice husk ash is another type of waste produced during this burning procedure. This additional waste, which makes up around 25% of the original volume of rice husks, has a significant adverse effect on the environment [38].

Composition of Rice Husk

Due to photosynthesis and biochemical interactions, silica and a barrier layer are formed on the rice plant's stem and husk surfaces [81]. These layers have developed to shield the rice plant and its grains from environmental changes such as temperature variations, excessive water evaporation, and microbial assault [81]. Approximately 20–30% of the rice husk is made up of mineral components, including silica and metallic residues containing magnesium (Mg), iron (Fe), and sodium (Na). Calcium (Ca), manganese (Mn), and potassium (K) are further examples of trace elements [82]. Rice husk mainly comprises organic compounds, including cellulose, lignin, and hemicellulose, making up around 70–80% of the total weight [37,83]. Rice husk is maturing into a raw material prospective in the manufacturing sector. However, when rice husk accumulates to the point that it poses a severe threat to the local ecosystem, it is classified as agro-waste. As a result, these adverse effects on the environment must be softened via a process of valorization or value addition. Therefore, it is crucial to conduct a physicochemical investigation and determine the composition of the material. Tables 8–11 show the characteristics of rice husks in terms of energy, fodder, fertilizer, and biochemical properties. The chemical components of rice husk ash are shown in Table 12.

Table 8. Energy characteristics of rice husks [2,16,35,55,56,84–86].

Parameter	Average Value (MJ/kg)
HHV	13.18
LHV	12.01
Parameter	**Average Value (% wt)**
Fixed carbon	24.62
Volatile matter	46.13
Ash	19.77
Moisture	9.01
Carbon	38.52
Oxygen	35.37
Hydrogen	4.79
Nitrogen	0.39
Sulphur	0.14

Table 9. Fodder characteristics of rice husks [2,16,35,55,56,84–86].

Parameter	Average Value (% wt)
Dry matter	91.9
Crude protein	3.7
Crude fiber	42.6
NDF	75.7
ADF	52.2
Lignin	25.05
Ether extract	1.5
Ash	20.52
Starch	5.3
Gross energy	16.3

Table 10. Fertilizer characteristics of rice husks [2,16,35,55,56,84–86].

Parameter	Average Value (g/kg)
Nitrogen	4.47
Phosphorus	0.74
Potassium	4.19
Calcium	1.96
Magnesium	0.43
Sulfur	1.84
Silica	95.4
	Average Value (mg/kg)
Manganese	442
Zinc	43
Copper	2
Iron	139.4

Table 11. Biochemical characteristics of rice husk in different rice varieties [2,55,56].

Bio-Active Compounds	Average Value			
	Gladio Variety	Carolina Variety	Creso Variety	Scirocco Variety
Total polar phenol (TPP) (mgGAE/kg)	27,898 ± 803	25,487 ± 1038	24,155 ± 797	19,662 ± 334
p-coumaric acid (mg/kg)	6367 ± 146	5692 ± 308	5565 ± 109	4879 ± 122
ferulic acid (mg/kg)	2037 ± 110	1752 ± 76	1771 ± 103	1510 ± 86

Table 12. Chemical composition of rice husk ash [87–89].

Parameter	Average Value (% wt)
SiO_2	93.4
Al_2O_3	0.05
Fe_2O_3	0.06
CaO	0.31
MgO	0.35
K_2O	1.4
Na_2O	0.1
P_2O_5	0.8

4. Valorization Potential of Rice Industry By-Products

4.1. Valorization of Rice Straw

Rice straw could also be valorized for four different purposes: energy production, animal feed, fertilizer, and other uses. By pyrolyzing rice straw, bio-oil, biochar, and syngas may be generated. Numerous chemical substances are found in rice straw bio-oil, including alcohols, acids, furans, aromatics, ketones, phenols, and pyranoglucose [47]. Alcohol and pyranoglucose are created as a consequence of the pyrolysis of cellulose, while hemicelluloses are used to create ketones [47]. The metabolic process through which carbohydrates are changed into alcohols or acids is known as fermentation, as shown in Equations (1) and (2). Second-generation biofuels are made from cellulose feedstock (Equation (1)). Physical, chemical, or biological pretreatment and fermentation are all viable routes to their production. While its lack of competition from other feedstock substrates is an advantage, its need for highly efficient lignohemicellulose enzymatic breakdown is a drawback. Although the commercialization of second-generation ethanol facilities shows promise, the longevity of these plants will primarily rely on the market availability of the feedstocks at affordable costs [90]. Bacteria convert carbohydrates into lactic acid (Equation (2)). Numerous chemical or physical pretreatments are required, followed by enzymatic hydrolysis to convert fermentable sugars from lignocellulosic materials into ethanol or lactic acid. In addition to its many uses in the food and beverage industries, lactic acid and its derivatives also have a wide range of applications in the pharmaceutical, cosmetic, and manufacturing industries [91,92]. Numerous studies have demonstrated that rice straw can be utilized to make second-generation biofuels [47,93–96]. Typically, bacteria and yeast turn carbohydrates into lactic acid and sugars into alcohol. *Trichoderma reesei*, which was derived from decaying rice straw waste, produces cellulases that break down cellulose in the rice straw to glucose, which is then fermented with yeasts such as *S. cerevisiae* to make ethanol [93,97,98].

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 \quad (1)$$

$$C_6H_{12}O_6 \rightarrow 2CH_3CHOHCOOH \text{ (lactic acid)} \quad (2)$$

The anaerobic digestion process may convert rice straw into biogas [75,99,100]. Anaerobic digestion is a sustainable process that converts organic waste into usable energy. Generating green energy from rice straw is an effective way to lessen the effects of global warming [75]. Around the globe, rice straw is utilized directly as an energy source for heating rooms by direct burning, firing clay pots, and cooking [101]. Additionally, small grids in certain nations such as Nigeria have a higher potential for using rice husks and straw as a source of rural power [102,103]. Umar and co-workers [102,103] claimed that rice straws have the potential to generate 1.3 million MWhy-1 energy in a country such as Nigeria. A 36 MW power plant in Sutton, Ely, Cambridgeshire, was constructed in 2000, producing more than 270 GWh annually while using 200,000 tons of rice straw [104]. Another work shows that Sri Lanka has a total energy capacity of 2129.24 ktoe/year of primary energy from rice straw and rice husk and a capacity of 977 Mwe, allowing it to produce 5.65 TWh of electricity per year [16].

According to literature, rice straw may be used efficiently for composite preparation [105–111]. Furthermore, rice straw microfibrils at 5% increase the characteristics of rice straw polypropylene composites [107]. Another study highlights many uses of rice-straw cement bricks for load-bearing walls [106]. Rice straw can also be used to lower the price of cement bricks with sufficient thermal insulation, appropriate mechanical qualities, and fire resistance [112–115]. Furthermore, rice straw-based composites with adhesives generated from starch can be used as ceiling panels and bulletin boards [109]. Finally, following proper pretreatment, rice straw could also be utilized to produce fiberboard [116].

Rice straw may be used to produce many kinds of enzymes in an industrial setting [47,57,58]. *Trichoderma harsanum* SNRS3 can generate cellulase and xylanase using alkali-pretreated rice straw [58]. According to this research, rice straw is a more effective inducer of the formation of cellulase and xylanase and does not need the inclusion of other chemicals. Lactic acid can be produced by using pretreated rice straw [117,118]. A Naviglio extractor and trifluoroacetic acid could transform rice straw into a unique bioplastic that can be used as shrink films, sheets, or for shape memory effects. Its mechanical characteristics are equivalent to polystyrene in the dry state, while in the wet state, the cast bioplastic performs equal to plasticized poly(vinyl chloride) [119].

Rice straw has a low value as a feeding material, despite its use as bedding for cattle [15]. In contrast to ruminants, which depend on symbiotic bacteria to break down cellulose in the gastrointestinal system, all vertebrates lack the enzymes necessary to dissolve β-acetyl bonds [52]. Additionally, dried rice straw contains low nutrient value owing to its low amount of protein and high amounts of lignin and silica. However, this may be addressed by pretreating it with ammonia or urea [48]. To increase the nutrient availability of rice straw, it can be converted into silage. Therefore, some researchers have focused on improving rice straw harvesting technologies for silage production [120]. Other studies have explored several practical examples of silage processing, including using different additives to enhance fermentation quality and adding yeasts such as *Candida tropicalis* [121–123]. Feed intake, digestibility, rumen fermentation, and microbial N synthesis efficiency are improved after urea treatment of rice straw [124].

Rice straw has been proposed as a low-cost adsorbent for purifying contaminated water [125]. However, straw surface composition and metal speciation significantly impact the adsorption capacity, which changes with metal ions and water pH [126,127]. On the adsorbent surface of rice straw, methyl/methylene, hydroxyl, quaternary ammonium, ether, and carbonyl groups predominate; adding additional quaternary ammonium or incorporating carboxyl groups enhances its adsorption capability [128]. The existence of these groups is supported by the ATR–FTIR spectrum shown in Figure 6. However, competing cations and chelators in the solution are likely to result in decreased sorption capacities [129]. Furthermore, most heavy metal ions exhibit maximal adsorption capacities around pH 5. In contrast, very acidic circumstances promote Cr adsorption [130], which could be the result of the reduction of Cr(VI) to Cr(III). Moreover, cellulose phosphate derived from rice straw that has been treated with NaOH and then reacted with phosphoric acid in the presence of urea has a more remarkable ability to absorb heavy metals. This ability is increased when microwave heating is used to produce it [131]. The addition of epoxy and amino compounds to rice straw by reacting with epichlorohydrin and trimethylamine results in a high sulfate adsorption efficiency, demonstrating the material's anion exchangeability [132]. Like rice husk, straw can be used as an adsorbent for different water contaminants, such as alkali and phenolic chemicals, that can usually be recovered using anionic species [133]. Various adsorbents from rice straws have also been developed to remove dyes from wastewater. An example of cationic dye application is rice straw treated with citric acid, which increases the specific surface area and pore size. These treated straws have been used to absorb crystal violet or methylene blue from an aqueous phase [134]. It has been observed that the addition of activated rice straw causes a significant reduction in microalgae in water, which has been attributed to the synergistic effects of humic chemicals and H_2O_2 created by the straw breakdown [135]. According to a different investigation, water and methanol extracts from rice straw controlled the cyanobacterium *Anabaena* sp. but promoted *Chlorella* sp. To prevent the development of *Anabaena* sp., rice straw extraction is an economical and ecologically beneficial option, but it may not work as well on other cyanobacteria and microalgae [136].

Rice straw is utilized as organic fertilizer for various crops in many places throughout the globe. It can also be used as a soil conditioner to replace the organic matter in the soil [112]. In addition, rice straw is also a growth medium for mushrooms [137]. Adding biochar derived from rice straw to the soil makes it possible to enhance the characteristics of the soil by lowering its pH, cation exchange capacity (CEC), nutrient availability, and nitrate leaching [138–140]. Figure 7 displays an overview of all rice straw value-adding possibilities [2,47,53,57,58,75,100,106,110,130,137–139,141–144].

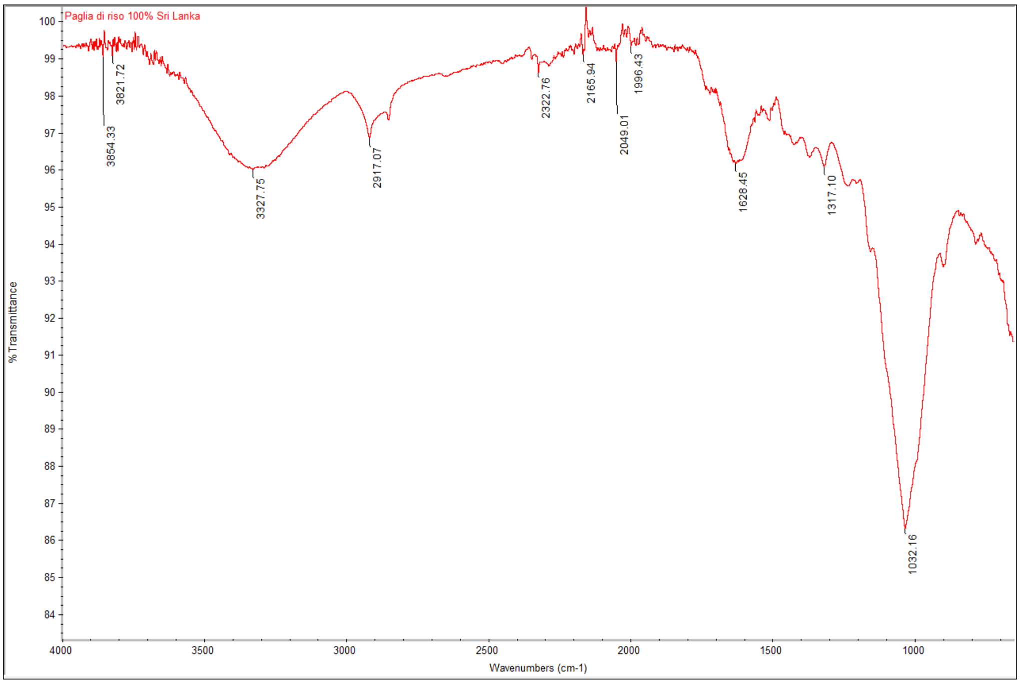

Figure 6. ATR–FTIR spectrum of Sri Lankan rice straw (own source) as-received sample acquired at room temperature using a Nicolet FTIR iS10 spectrometer (Nicolet, Madison, WI, USA) equipped with a Smart iTR with diamond plate. Straw was dried at 45 °C, milled, and sieved with a 1000 µm mesh sieve before analysis. Thirty-two scans in the 4000–600 cm^{-1} range at 4 cm^{-1} resolutions were co-added.

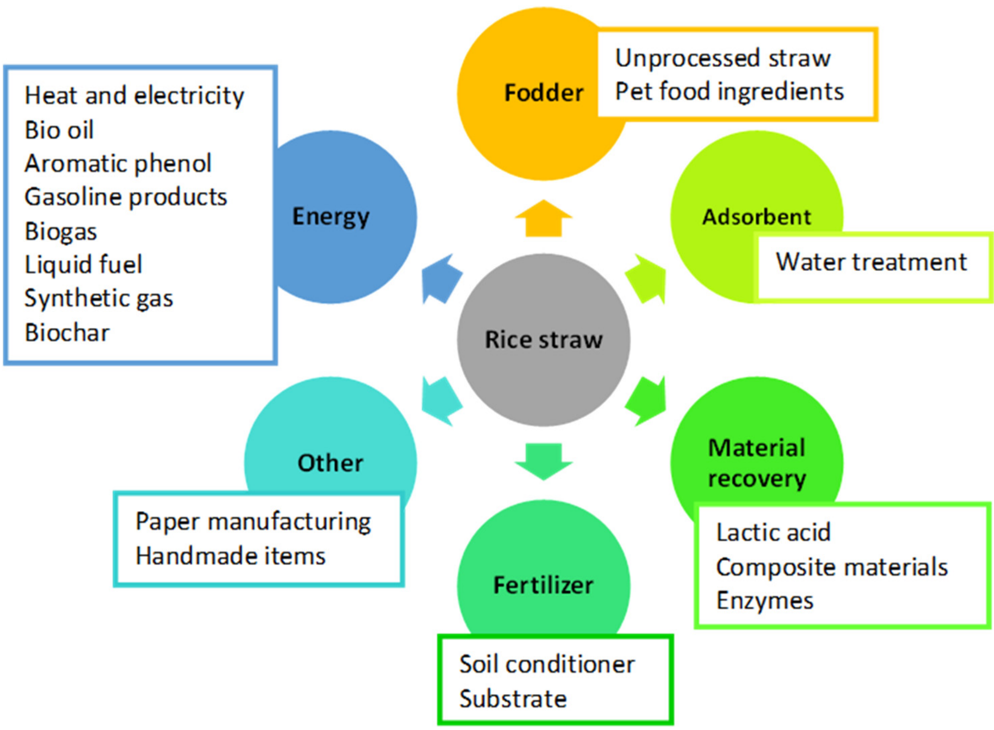

Figure 7. Summary of possible valorization options for rice straw.

4.2. Valorization of Rice Bran

Considering the concept of circular economy and green product technology, the biorefinery plan would be the best option for managing and utilizing rice bran [145]. In addition to providing more nutrients than other cereal grains, rice bran has more lipids, protein, and calories [146–148] (Table 5). Rice bran is vulnerable to oxidative rancidity; thus, heat stabilization is necessary to avoid spoilage and rancidity [149]. Rice bran oil is widely recommended around the world due to the presence of several beneficial natural and healthy bioactive ingredients. Companies have been encouraged to manufacture stabilized rice bran and rice bran products to improve the health of organisms because of the unique mix of lipids, minerals, and nutrients found in rice bran, including calcium, phosphorus, and magnesium [65]. In addition, several researchers have found that the manufacturing of de-oiled rice bran and rice bran oil is in great demand worldwide [62,150,151].

The production of biodiesel from rice bran is actively marketed all over the globe. However, rice bran oil must be removed from the rice bran to produce biodiesel via a transesterification process [152]. Several methods have purportedly been utilized to produce biodiesel from rice bran oil, including acid-catalyzed and base-catalyzed transesterification and lipase-catalyzed transesterification. However, each technique has different environmental effects as well as technological and economic benefits and drawbacks [153–156].

Some researchers have examined bioethanol synthesis from rice by-products such as rice bran, defatted rice bran, and rice washing drainage [157–160]. After pretreating stripped rice bran with diluted acid and detoxifying it, the *Pichia stipitis* NCIM 3499 strain generated an ethanol concentration of 12.47 g/L [161]. Additionally, another study found that biological pretreatment with the fungus *Aspergillus niger* increased ethanol output [162]. Numerous scientists have attempted to manufacture lactic acid from dehulled rice bran using various microbes [163–166]. Another study discovered that many *Bacillus coagulans* isolates could grow in denatured rice bran enzymatic hydrolysates without adequate nutrients, with the majority producing concentrations of lactic acid more significant than 65 g/L and yields greater than 0.85 g/g [163]. They stressed in the same paper that manufacturing lactic acid from dehulled rice bran might be economically viable.

Due to its numerous similarities to gasoline, biobutanol is the most ecologically benign substitute for traditional fossil fuels. Additionally, when HCl and enzyme treatments are used together, they can remove 41.18 g/L of sugar from dehulled rice bran and 36.2 g/L of sugar from rice bran [167]. Another study reported that both defatted rice bran hydrolysates and rice bran hydrolysates could be fermented in bioreactors with nutrients to make butanol at a rate of 12.24 g/L and 11.4 g/L, respectively [163].

Rice bran can be used as an adsorbent for polluting substances because it has a granular shape, is chemically stable, does not dissolve in water, and is easy to get. Its surface has several active sites that can remove pollutants [39]. How well these sites work depends on the chemical nature of the solution and whether or not there are other ions in the solution besides the ones to be trapped. Additionally, various functional groups on the surface of rice bran, such as hydroxyl and carbonyl groups, are responsible for its high adsorption effectiveness [39]. The existence of these groups is supported by the ATR–FTIR spectrum shown in Figure 8, which exhibits rice-straw-like peaks. Some researchers have tried to figure out the best way to remove arsenic from water using a fixed-bed column system made of rice bran. The objective of this study was to look at how different design parameters, such as flow rate, bed height, and initial concentration affected the adsorption process. The uptake capacities of As(III) and As(V) were found to be 66.95 μg/g and 78.95 μg/g, respectively [168].

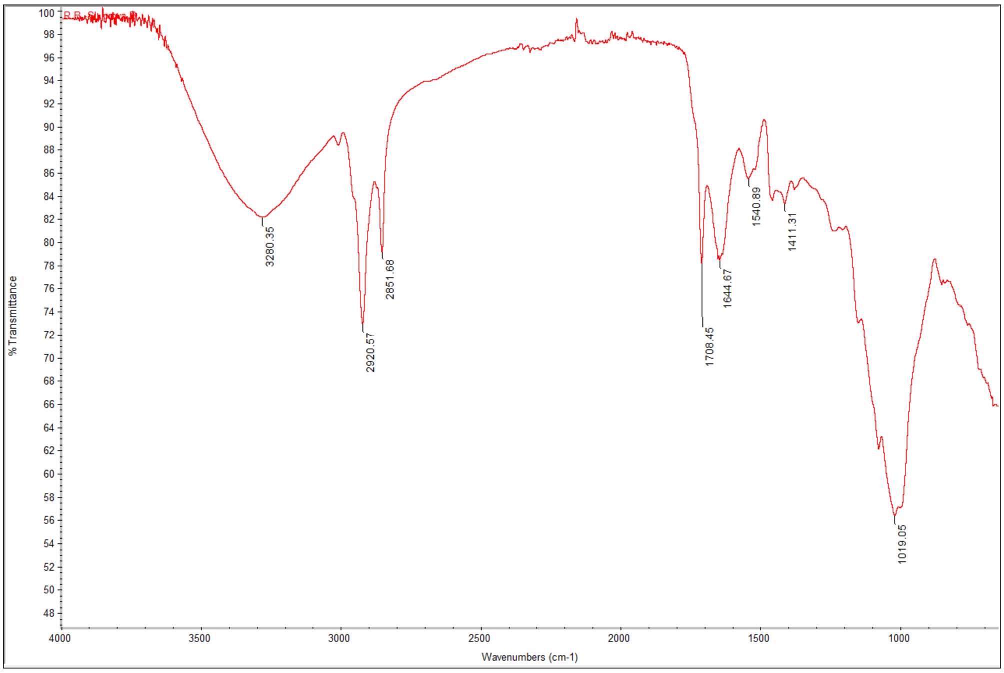

Figure 8. ATR–FTIR spectrum of Sri Lankan rice bran (own source) as-received sample acquired at room temperature using a Nicolet FTIR iS10 spectrometer (Nicolet, Madison, WI, USA) equipped with a Smart iTR with diamond plate. Bran was dried at 45 °C, milled, and sieved with a 1000 µm mesh sieve before analysis. Thirty-two scans in the 4000–600 cm^{-1} range at 4 cm^{-1} resolutions were co-added.

Another excellent substitute for conventional fossil fuels is hydrogen, which, when oxidized, merely produces water vapor (H_2O). Additionally, hydrogen has a higher energy content for mass units than traditional fuels, ranging from 112 to 142 kJ/g [168,169]. Photo and dark fermentation and their combination are all capable of producing bio-hydrogen [170]. Some studies have investigated hydrogen generation from rice bran and defatted rice bran using isolated bacteria from the same substrates. They identified *E.ludwigli* IF2SW-B4 as the most promising strain. When rice bran was utilized as a substrate, 545 mL/L of bio-hydrogen was produced [171]. The whole biotechnology process will be more economical once enzymes are produced utilizing low-cost ingredients. For the environmentally friendly and more effective release of fermentable sugars from different affordable and sustainable biomasses such as rice bran, enzymatic hydrolysis is used [171]. Researchers have conducted several investigations to synthesize enzymes from defatted rice bran and rice bran [172–174]. Figure 9 displays an overview of all rice bran value-adding possibilities.

Figure 9. Possible valorization options for rice bran [39,145,146,150–153,157–174].

4.3. Valorization of Rice Husk

South Asian countries such as India, Pakistan, Bangladesh, and Sri Lanka were among the best in the world in utilizing rice husk from 1970 to 1985 [175]. In addition, governments and other organizations engaged in rice farming and the post-harvest process have provided essential direction and strong support for rice husk management. Rice husk differs from other agricultural wastes in several important physicochemical aspects, including high silica concentration, low density, high porosity, and a significant outer surface area [176]. Because of these qualities, rice husk is more valuable than other waste materials. As a result, it covers a range of industrial applications.

In water treatment, using activated carbon for the adsorption process to remove heavy metals from industrial effluents is appealing. Numerous functional groups, including hydroxyl, methyl/methylene, ether, and carbonyl are present on the rice husk's adsorbent surface, contributing to the material's enhanced adsorbent efficiency (Figure 10) [39]. The existence of these groups is supported by the ATR–FTIR spectrum shown in Figure 10, which mainly exhibits bands at 3307 cm^{-1}, 2921 cm^{-1}, 2000–2500 cm^{-1}, 1654 cm^{-1}, 1034 cm^{-1}, and 788 cm^{-1} representing hydroxyl groups, C–H groups, C≡C or C≡N bonds, C=O groups, C–O and C–H bonds, and Si–O bonds, respectively.

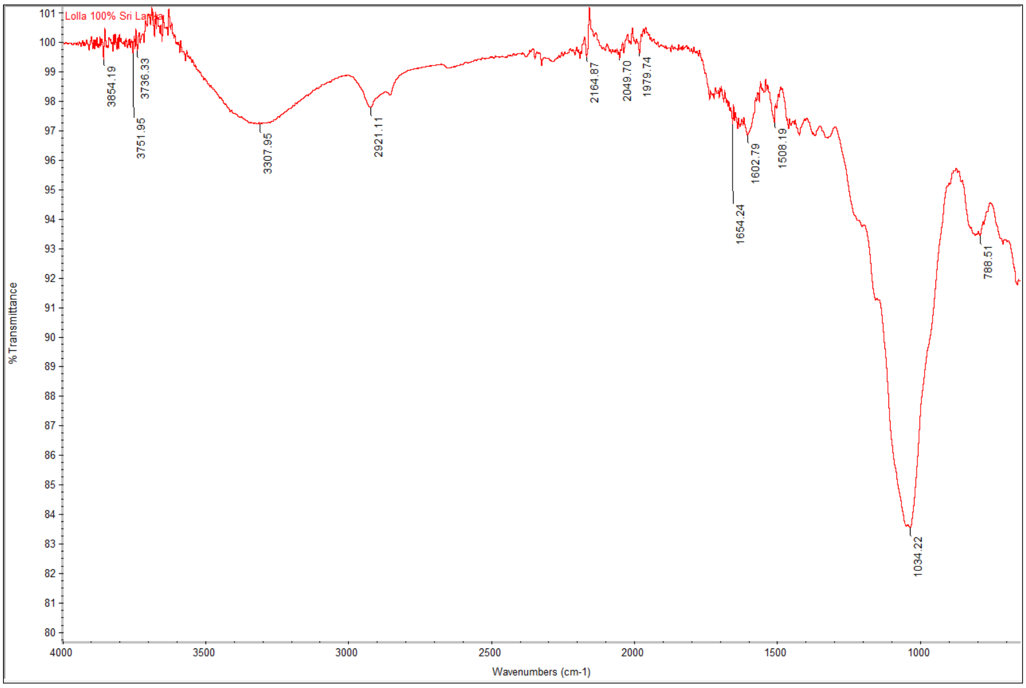

Figure 10. ATR–FTIR spectra of Sri Lankan rice husk (own source) as-received sample acquired at room temperature using a Nicolet FTIR iS10 spectrometer (Nicolet, Madison, WI, USA) equipped with a Smart iTR with diamond plate. Husk was dried at 45 °C, milled, and sieved with a 1000 µm mesh sieve before analysis. Thirty-two scans in the 4000–600 cm^{-1} range at 4 cm^{-1} resolutions were co-added.

The presence of several types of polar groups on the surface of rice husks results in a significant cation exchange capacity, indicating a potential efficacy in physisorption mode [177]. Rice husk treated with H_3PO_4 showed enhanced copper absorption capacity [178]. Some studies found that chemically treated rice husk can absorb cationic dyes such as methylene blue [179,180] and malachite green [181]. To study the absorption of fluoride from aqueous solutions, some researchers produced rice husk by chemically impregnating it with nitric acid, followed by physical activation [182]. According to their findings, the highest absorption of fluoride was 75% at a pH of 2, and the ability to absorb fluoride decreased as the pH rose from 2 to 10. Ahmaruzzaman and Gupta [183] confirmed this conclusion. When modified rice husk is cross-linked with poly(methyl methacrylate-co-maleic anhydride), nanoparticles are formed that can be used to absorb heavy metal ions (such as Pb(II)) and dyes (such as crystal violet) [184]. Researchers have discovered that novel green ceramic hollow fiber membranes made from rice husk ash can act as an adsorber and separator to remove heavy metals from water effectively [185]. Treating rice husk with H_2SO_4 and NaOH prior to heating enhances the product's capacity to absorb phenol [186].

Biomass derived from agricultural waste has been identified as a rich source of feedstock for biochar production; however, at present, farmers, and other stakeholders such as millers, practice open field burning or open dumping to dispose of these by-products. Compared to low-cost traditional treatment procedures (boiling, chlorination, sand filtration, and solar disinfection), biochar adsorbent offers various advantages. It is also suitable for low-income countries because of its availability, cheap cost, and accessible technology. Low-cost conventional approaches mainly destroy pathogens, while biochar can remove a wide range of pollutants from drinking water. Existing processes, such as chlorination, emit carcinogenic by-products, and boiling concentrates chemical contaminants. Pyrolysis temperature, vapor residence time, and other chemical and physical alteration variables influence the properties of biochar (Figure 11). Compared to conventionally activated biochar, rice husk biochar activated by a single phase of KOH-catalyzed pyrolysis under CO_2 has a larger surface area and greater capacity for phenol adsorption [187]. The gold-thiourea complex can be effectively adsorbed using biochar derived from rice husks that have been heated to 300 °C and have particular silanol groups and oxygen functional groups [188]. Rice husk-activated carbons are effective in removing phenol [189], chlorophenols [190], basic dyes [191,192], and acidic dyes [193,194] from water, as well as heavy metal ions such as Cr(VI) at low pH [195,196], Cu(II), and Pb(II) [197].

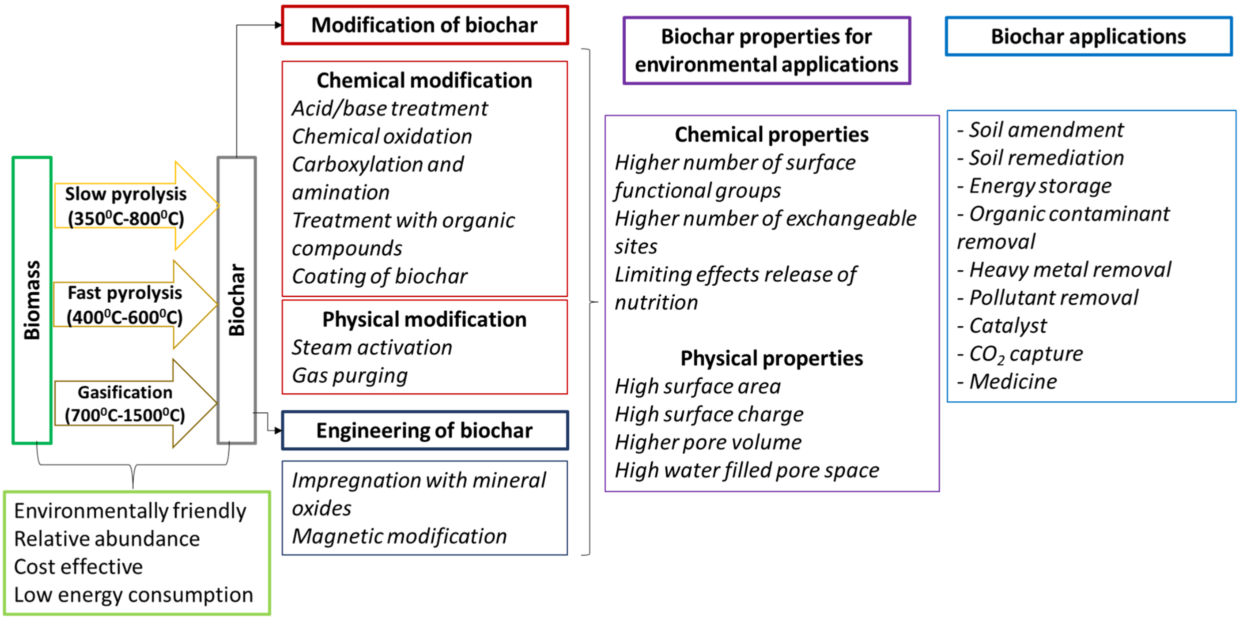

Figure 11. Strategic schematic diagram for biochar production, modification/engineering, characteristics, and water treatment applications adopted from [198–201].

Rice husk pellets provide an alternative to diesel oil and coal for energy generation in small-scale power plants. Through pyrolysis and gasification processes, they may also be used to produce biodiesel [202]. Rice husk, subjected to a thermochemical conversion process, may provide an inexhaustible supply of gaseous and liquid fuel. Thermochemical and biochemical processes are shown in Figure 12 as the two ways rice husk can be converted to energy. Thermochemical processes such as combustion, gasification, and pyrolysis are often regarded as the primary means of producing secondary energy substances. Fermentation and transesterification are also critical biochemical steps in ethanol and biodiesel production [175,203,204]. The briquettes made from rice husks with starch or gum arabic as binders burn stronger and more efficiently than timbers [205]. Another study describes a reactor that uses rice husk combined with sawdust or charcoal to generate high-grade fuel [206]. In order to obtain charcoal, which has a comparatively high calorific content, rice husk is subjected to carbonation using starch as a binder and either ferrous sulfate or sodium hypophosphite, which promote ignition [135]. Economically viable primary pyrolysis oil, suitable as boiler fuel oil and for the manufacture of catalytically treated, upgraded liquid products, can be obtained by fluidized-bed rapid pyrolysis with the catalytic treatment of rice husk [207].

Materials derived from rice husks have been used in the world's most advanced technical equipment and industries. For example, the Indian space agency has figured out how to extract high-quality silica from rice husk ash. This high-purity silica might also increase its use in the information technology sector [175]. In addition, the same publication has stated that other scientists have discovered how to extract and purify silica from rice husk ash to produce semiconductors. In addition, several researchers have pointed out the prospects of using silicon-based compounds extracted from rice husk and ash in various industries [208,209].

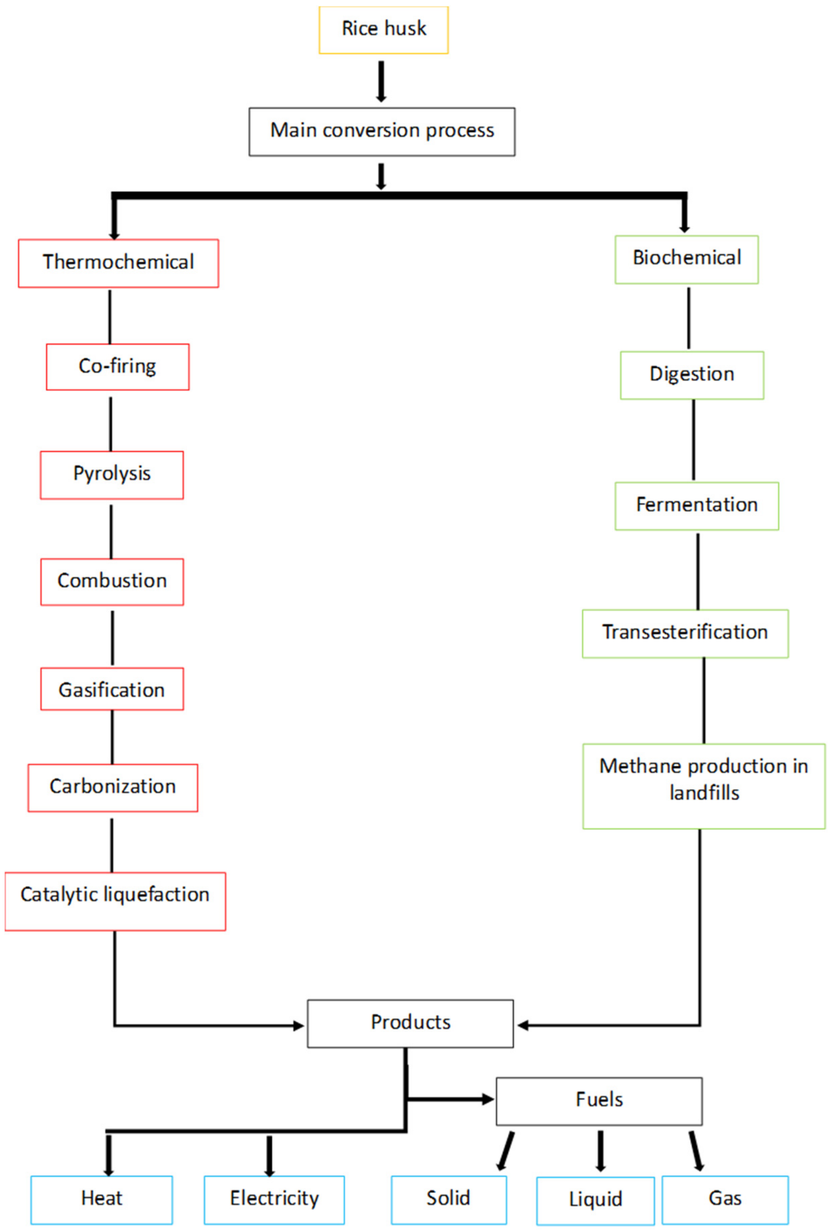

Figure 12. Energy conversion process of rice husk, adopted from [176,203,204].

Li et al. [210] stated that KOH-activated rice husk char could make porous carbons for CO_2 capture at low pressures. Low activation temperature and a small KOH/char ratio favor high CO_2 absorption and CO_2-over-N_2 selectivity. This is presumed to be due to the micropores' narrow size distribution. A similar investigation has been conducted using KOH-activated rice husk biochar for hydrogen storage. It revealed that 77 K/6 bars have a hydrogen storage capacity of 2.3%wt [211].

Due to its microscopic particle size, high solution pH, and low supportive electrolyte content, rice husk ash is an effective adsorbent for heavy metals, including lead and mercury [212,213]. In addition, the fluoride-absorption capacity of rice husk ash treated with aluminum hydroxide is enormous [214]. Both the effective removal of phenol from aqueous solutions and the adsorption of various dyes, including indigo carmine, Congo red, and methylene blue, has been accomplished using rice husk ash [180,215–218]. Due to its high silica concentration and the existence of mesopores and macropores, rice husk ash is a promising adsorbent for removing contaminants from biodiesel [219]. Zou and Yang [220] examined different approaches for generating silica and silica aerogel from rice husk ash.

Epoxy paints can use rice husk ash as a filler, and the inclusion of rice husk ash can improve a variety of qualities, including wear resistance, elongation, and scratch resistance [221]. In addition, a paper's printing quality might be enhanced by using rice husk ash. Because rice husk ash contains more silica, it can improve the paper's surface quality, and the coating layer it generates reduces the quantity of ink penetrating the paper [222]. Additionally, some researchers have studied pigments made from rice husk and ash [175].

Rice husk ash can improve the properties of cementitious materials such as concrete in resistance to corrosion. With the addition of rice husk ash, the cement particles are encased in a calcium silicate hydrate gel, making the cement denser and less porous. These characteristics are also helpful in protecting concrete against cracking, corrosion, and chemical breakdown caused by leaching agents [89,223–226]. The use of powdered rice husk ash derived under controlled burning conditions as a reinforcing filler for different rubbers has been researched. The authors discovered that substantially reinforced rice husk ash had no adverse effect on the vulcanization or aging behavior of certain rubber types, such as natural rubber, styrene–butadiene rubber, and ethylene–propylene–diene elastomers [227]. Moreover, the use of rice husk ash as a raw material in cement production has the potential to reduce production costs. Figure 13 displays an overview of all rice husk and rice husk ash value-adding possibilities.

Figure 13. Possible valorization options for rice husk and its ash [176–202,205–210,212–214,216–222, 224–226,228,229].

5. Circular Economy

The circular economy (CE) has gained attention as a way to overcome the current production and consumption model of "take, make and throw away" or the linear model based on continuous progress and increasing resource output [230]. CE aims to optimize resource usage and achieve an equilibrium between economy, environment, and society by supporting closed manufacturing processes [231,232]. Numerous studies have focused on political, environmental [233], economic, and corporate issues [13]. The "reduce, reuse and recycle" (3R) concept has nine steps from recovery to recovery (Figure 14). Industrial ecology, environmental economics, and environmental policy have influenced CE [13,232,233]. Some authors have claimed that broad systems theory is where CE first emerged [13,232]. Modern concepts including "sustainable design", "performance economy", "cradle-to-grave", "biomimicry", and "blue economy" are associated with developing CE [234,235]. CE was first introduced to Europe in 1976 with Germany's Waste Disposal Act [13,232]. Later, the European Union promoted CE through the Waste Directive 2008/98/EC and the Circular Economy Package [236]. "Reduce, reuse and recycle" is part of the European Waste Directive 2008/98/EC and has been part of the US Solid Waste Agenda since 1989 [236,237]. "CE includes corporate-level sustainable production practices, increasing producer and consumer awareness and responsibility, using renewable technology and materials (where possible), and adopting appropriate, consistent and clear policies and systems" [238].

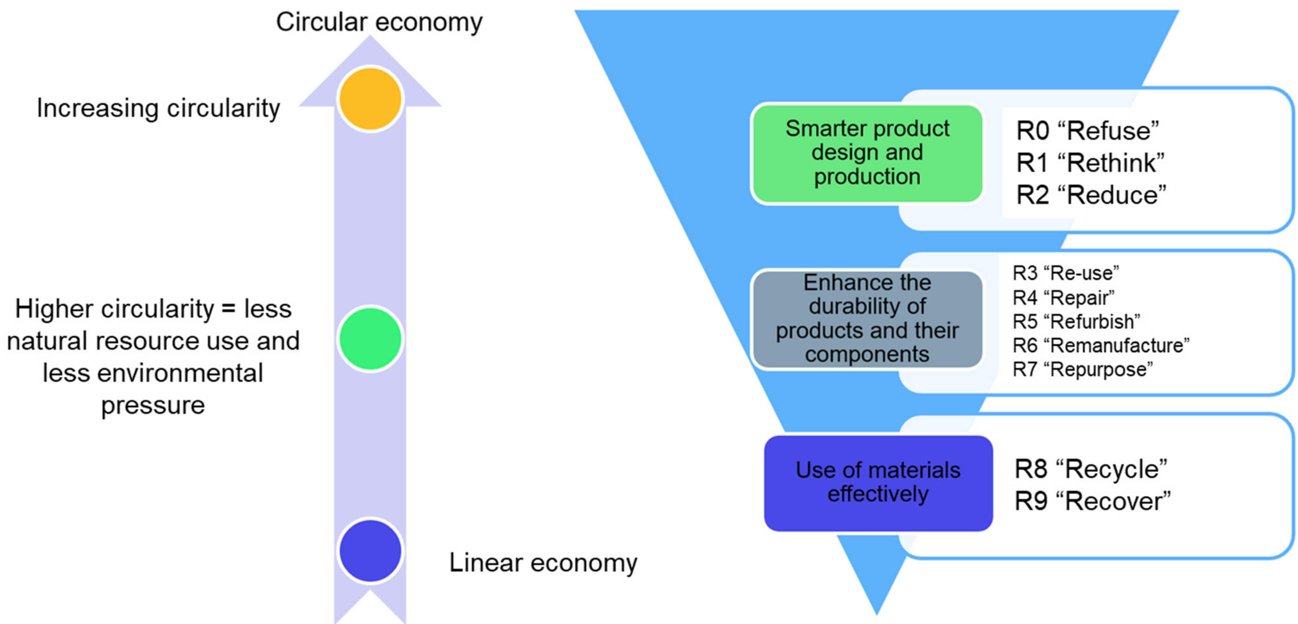

Figure 14. Priority order for circularity techniques within the production chain, adopted from [230–232].

A systemic perspective requires new solutions focusing on environmental processes and stakeholders in the relevant sectors. Agri-food waste management aims to increase resource efficiency and protect the environment. Innovative waste management solutions are needed to reduce waste or transform it into new raw materials. These management practices are part of the CE system, an industrial framework meant to be restorative or regenerative (producing no waste or pollution). Several studies have demonstrated the potential to produce bioenergy, biodegradable polymers, alcohols, and antioxidants from the food supply chain to manage agricultural wastes effectively. Thus, agricultural waste is a source of macronutrients, including proteins, carbohydrates, and fats, as well as micronutrients and bioactive chemicals used to generate new products. Biorefineries use agricultural waste to produce value-added energy and industrial goods. The scientific community considers this concept a sustainable alternative.

If a circular economy-based waste management system is successfully implemented, waste can become a source of wealth for a community or country. Sweden is a prime instance of this. They have made significant investments in infrastructure and imported a large percentage of Norway's waste to convert it into energy (electricity and heat). Thanks to this decision, Sweden can turn Norway's waste into money for its people. Consequently, it charges Norway for waste treatment, generates sufficient energy (electricity and heat) from Norway's waste to meet demand, and recycles or sells the metals it extracts from the bottom ash. In addition, the remaining bottom ash is taken to use in public infrastructure and precast concrete products, drastically reducing the need for mining operations. Because of its innovative approach to waste management within the context of the circular economy, Sweden is a standout among countries [12].

6. Case Study: Sri Lanka

6.1. Paddy and Rice Value Chain in Sri Lanka

Since 800 BC, rice has been grown in Sri Lanka [239]. Rice agriculture has grown throughout the nation due to ideal climatic conditions and geographic locations for paddy production (Figure 15). The low country dry zone has the highest rice production as this zone has had a well-planned irrigation system since ancient times. According to the Sri Lanka Rice Research Center, rice consumption per capita in 2019 was close to 107 kg. The Yala season (March to August) and the Maha season (September to December) are the two primary rice harvesting seasons in Sri Lanka. The paddy and rice value chain in Sri Lanka comprises public and private partners connecting rice producers such as small, medium, and industrial-scale farmers, millers (cooperative millers, rice marketing boards, and private millers), food processors, and consumers. In specific Sri Lankan mills, just one step of milling is performed [14]. Figure 16 represents the paddy and rice value chain in Sri Lanka.

Small-scale farmers in villages and semi-urban areas produce sufficient rice for personal use and store it throughout the season or the year. Mid-level farmers store for their consumption and sell excess paddy. Farmers sell these quantities directly to millers, and paddy collectors act as intermediaries in this buying and selling process. After collecting a substantial amount of paddy, they will sell it to co-operative or industrial-scale mills. Large rice farmers who grow rice on an industrial scale sell their crops directly to rice processing mills or process them in their mills. In most cases, small-scale private millers process only a small amount of waste in a particular area throughout the year or during a specific period.

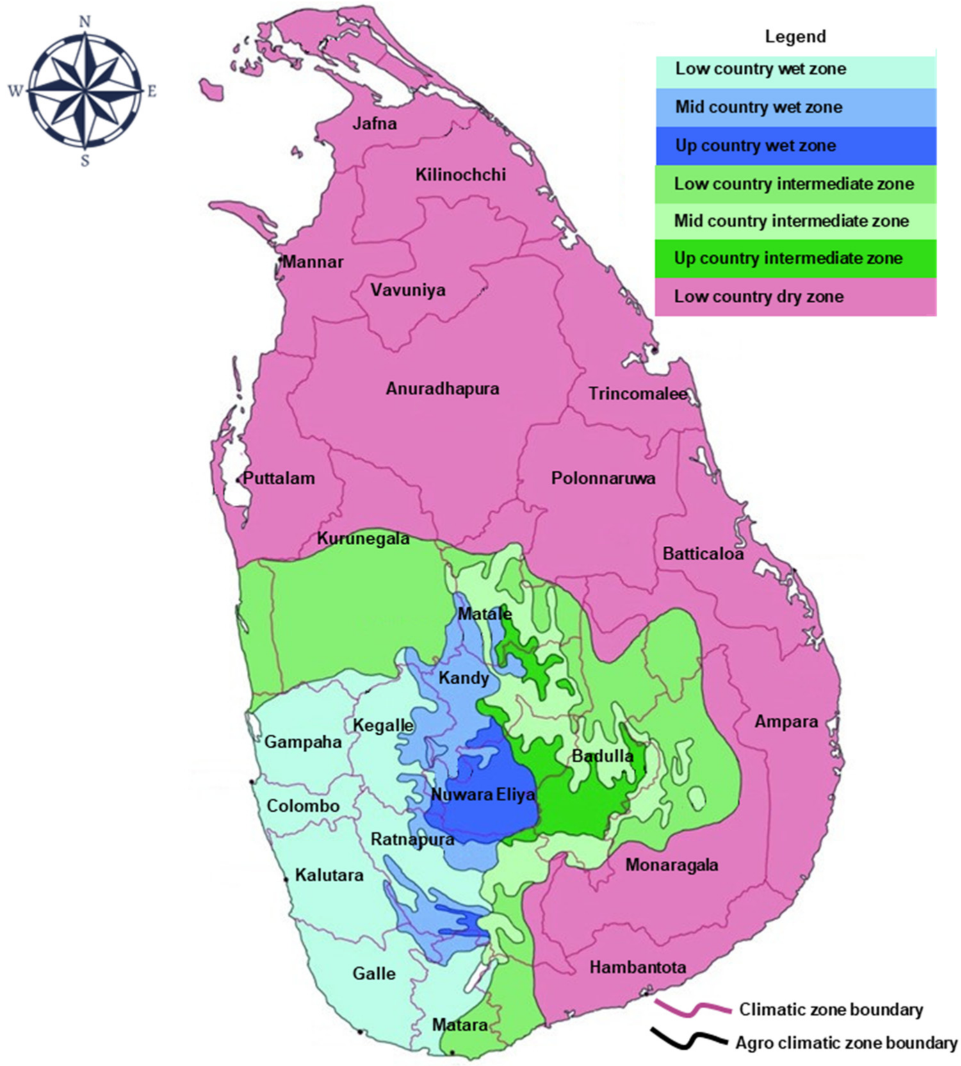

Figure 15. Map of Sri Lanka district distribution by climate zone and geographic regions adopted from [240].

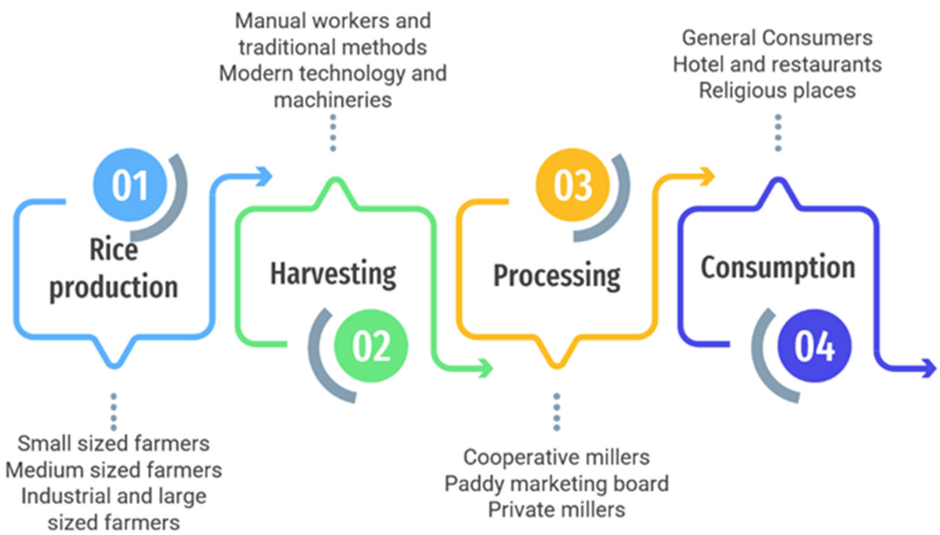

Figure 16. Paddy and rice value chain of Sri Lanka adopted from [14].

6.2. Rice Waste Availability in Sri Lanka

The vegetative portion of the rice plant is called rice straw (*Oryza sativa* L.). After the grain has been harvested or sliced, rice straw is produced. According to several researchers, the ratio of rice straw to grain is between 1.0 and 1.5 kg [2,16,39]. Previous studies have shown that 0.1 kg of rice bran is produced for every kilogram of rice [2,78]. Various scholars have revealed that approximately 20–28% wt of rice husk generates greater grain weight [2,35,37,38]. Abbas and Ansumali [79] noted that around 50% of the country's rice mill husk is burned to fulfill its energy needs for steam production. According to some literature [38], approximately 25% of rice husk ash is generated during the burning process. According to the data gathered from Sri Lanka Rice Research Center, in the 2019 Yala season, Sri Lanka produced 1,519,475 metric tons of rice, 1,899,343.75 metric tons of rice straw, 151,947.5 metric tons of rice bran, 364,674 metric tons of rice husk, and 45,584.25 metric tons of rice husk ash as shown in Figure 17. Because of varying weather conditions and several other variables, rice production differs among districts.

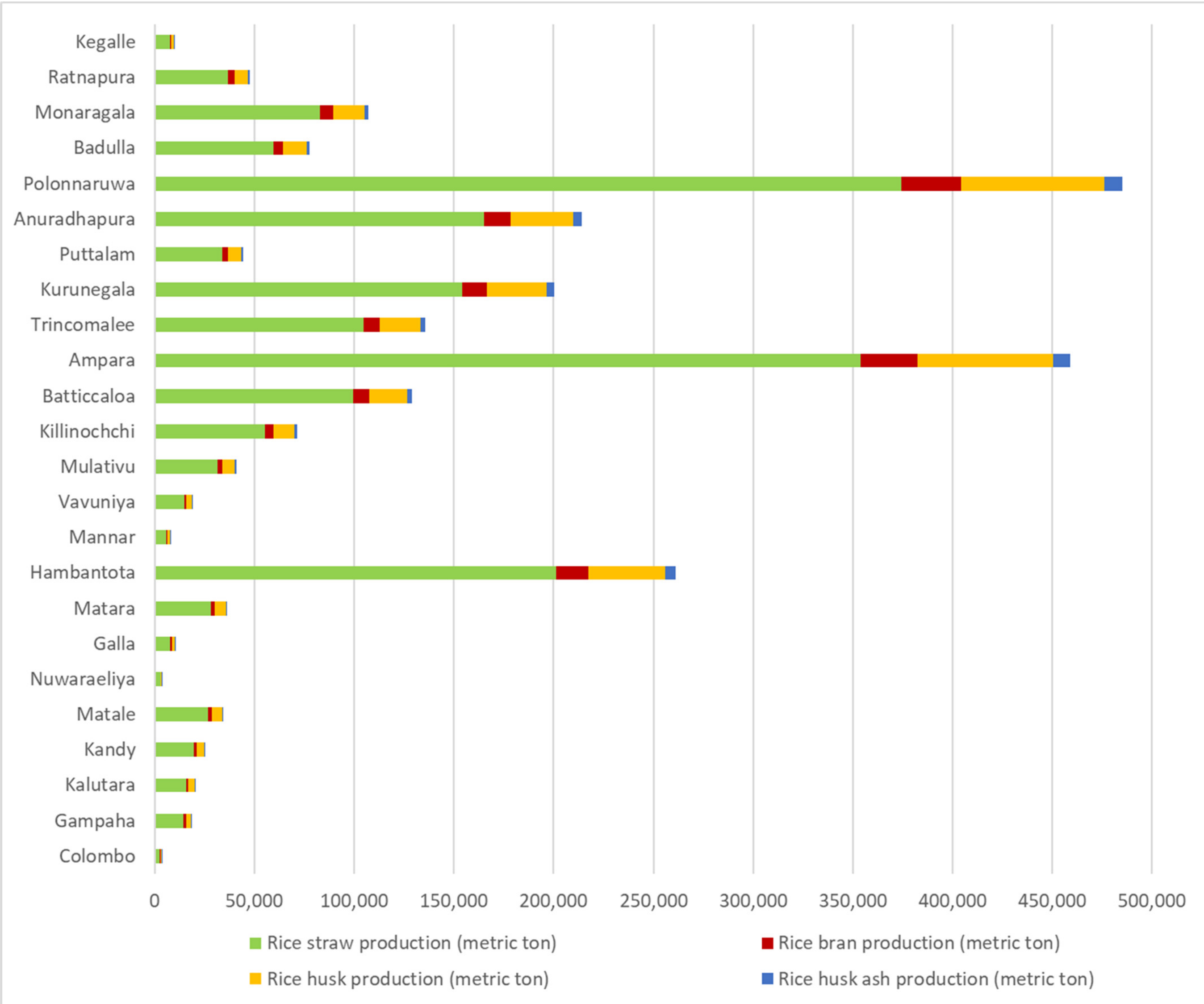

Figure 17. Rice straw, Rice bran, rice husk, and rice husk ash availability in each district of Sri Lanka (Source: Sri Lanka Rice Research Center).

6.3. Potentiality of Rice Waste Valorization in Sri Lanka

Currently, rice industry by-products are resold and recycled but have yet to be fully utilized. They are high in nutrients and have chemical–physical properties, making them useful in various sectors of the economy (food, fertilizer, building materials, energy, etc.). Therefore, sustainable and efficient agricultural waste management has emerged as a critical concern for all parties involved in the agricultural value chain in Sri Lanka. According to Figure 17, massive volumes of waste are discharged into the environment at every point along the value chain, permanently harming the air, water, and land. Proper management and implementation of a sustainable valorization system is a complex transformation for developing countries. It needs more funding, laws, and regulations to enhance the capabilities and techniques for agricultural waste management and coordinated efforts by local, regional, and global stakeholders. Therefore, any waste management system that applies to this industry should be founded on value principles and promote the circular economy throughout the process. Figure 18 displays the challenges that should be overcome to implement a sustainable valorization waste management system. The authors have found some feasible valorization techniques for rice processing by-products in the Sri Lankan context:

- Animal feed: Rice straw and rice bran can be used as animal feed, and a fitting technology can be used to produce nutritious and high-quality goods.
- Energy generation: Rice straw and rice husk can be used in grate-fired combustion boilers using steam turbine cycle technology to produce energy.
- Energy storage: activated porous rice husk and bran biochar can be used as hydrogen-storing carbon-based material with significant added value.
- Adsorbent in water treatment: Activated carbon from rice husk and rice straw can be utilized for wastewater treatment.
- Anaerobic co-digestion: A more efficient method of valorizing rice-related waste to produce green energy.
- Fertilizer production: Rice waste has a high potential for producing biochar and fertilizer to improve soil structure and organic matter content.
- Adsorption: The industrial production of adsorption by rice husks has enormous potential.
- Construction sector: Waste from the rice value chain can be effectively used in the building industry without affecting the end product negatively.
- Rice husk can be used in the ceramics sector, according to several studies.
- Rubber industry: Rice can may be used as filler in the rubber industry since Sri Lanka is one of the greatest rubber-producing nations in the world.

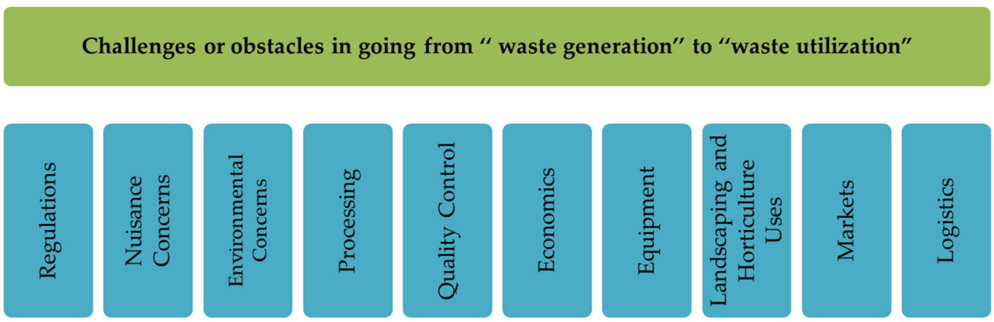

Figure 18. Challenges of valorization of rice industry by-products.

7. Management Issues for Handling Rice Industry By-Products

Lastly, the authors would like to stress the importance of taking precautions around rice husk remnants since they always include small dust particles created during processing. Breathing filters should be worn while working with these substances since they may irritate the upper respiratory tract and trigger allergic responses, including rhinitis, asthma, bronchitis, COPD, and extrinsic allergic alveolitis. Moreover, the dust from rice husk and straw may be readily ignited due to the small size of the dust particles. They can produce explosive concentrations in the air and may smolder when exposed to heat [241,242]. As a result, when working with rice wastes the same precautions should be followed as when working with other flammable dust.

8. Conclusions and Outlook

Rice husk, bran, and straw are often considered low-value waste. However, agriculture, energy generation and storage, pollution control and water treatment, construction materials, and many other vital valorization processes have already been adopted for them. Consequently, to implement these options, the legal requirements governing their disposal methods should be considered. Figures 7, 9 and 13 illustrate rice straw, bran, and husk valorization options. These lignocellulosic materials do, however, have further potential applications. As science and technology improve, identification of many more applications is anticipated as the scientific community and societies become more concerned with sustainability. According to the analysis of relevant research that has already been carried out, rice straw has considerable potential as a renewable energy source. However, there is a significant research gap in using rice bran biochar as an energy storage material. Additionally, modified rice husk biochar has a high promise as an adsorbent in the bio-based water treatment industry. Therefore, further research and development are needed to fill these gaps permanently. In the future, these by-products are expected to be used in fields such as the pharmaceutical industry, space science, etc. Most approaches are anticipated to take place in very small-scale operations, particularly if governments adopt a rural development strategy to halt urbanization, and non-scientific variables might judge the usefulness of research. Therefore, the present review mainly discusses the economics of different procedures. However, in the end, the conclusions about specific applications must be made by politics. For example, taxes or laws can be used to encourage each type of activity, while traditional activities such as burning straw and husk are intended to be discontinued. This will lead to laws that make alternative ways of doing things more fascinating.

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References

1. Bhandari, H. keynote speech Global Rice Production, Consumption and Trade: Trends and Future Directions. In *Proceedings of the Korean Society of Crop Science Conference*; The Korean Society of Crop Science: Suwon, Republic of Korea, 2019.
2. Patsios, S.I.; Plakas, K.V.; Kontogiannopoulos; Mitrouli, S.T.; Karabelas, A.J. *Characterisation of Agricultural Waste Co- and By-Products*; Chemical Process & Energy Resources Institute: Thessaloniki, Greece, 2016.

3. Muthayya, S.; Sugimoto, J.D.; Montgomery, S.; Maberly, G.F. An Overview of Global Rice Production, Supply, Trade, and Consumption. *Ann. N. Y. Acad. Sci.* **2014**, *1324*, 7–14. [CrossRef]
4. Bandumula, N. Rice Production in Asia: Key to Global Food Security. *Proc. Natl. Acad. Sci. India Sect. B Biol. Sci.* **2018**, *88*, 1323–1328. [CrossRef]
5. Toenniessen, G.; Adesina, A.; DeVries, J. Building an Alliance for a Green Revolution in Africa. *Ann. N. Y. Acad. Sci.* **2008**, *1136*, 233–242. [CrossRef]
6. Papademetriou, M.K. Rice Production in the Asia-Pacific Region: Issues and Perspectives. Available online: https://www.fao.org/3/X6905e/x6905e04.htm (accessed on 24 November 2022).
7. Yevich, R.; Logan, J.A. An Assessment of Biofuel Use and Burning of Agricultural Waste in the Developing World. *Glob. Biogeochem. Cycles* **2003**, *17*. [CrossRef]
8. Kim, J.Y. *Transport for Health: The Global Burden of Disease from Motorized Road Transport*; World Bank Group: Washington, DC, USA, 2014.
9. He, K.; Zhang, J.; Zeng, Y. Knowledge Domain and Emerging Trends of Agricultural Waste Management in the Field of Social Science: A Scientometric Review. *Sci. Total Environ.* **2019**, *670*, 236–244. [CrossRef]
10. Koul, B.; Yakoob, M.; Shah, M.P. Agricultural Waste Management Strategies for Environmental Sustainability. *Environ. Res.* **2022**, *206*, 112285. [CrossRef]
11. Crops and Livestock Products. Available online: https://www.fao.org/faostat/en/#data/QCL/visualize (accessed on 8 October 2022).
12. Kalkanis, K.; Alexakis, D.E.; Kyriakis, E.; Kiskira, K.; Lorenzo-Llanes, J.; Themelis, N.J.; Psomopoulos, C.S. Transforming Waste to Wealth, Achieving Circular Economy. *Circ. Econ. Sustain.* **2022**, *2*, 1541–1559. [CrossRef]
13. Fiore, E.; Stabellini, B.; Tamborrini, P. A Systemic Design Approach Applied to Rice and Wine Value Chains. The Case of the InnovaEcoFood Project in Piedmont (Italy). *Sustainability* **2020**, *12*, 9272. [CrossRef]
14. Senanayake, S.M.P.; Premaratne, S.P. An Analysis of the Paddy/Rice Value Chains in Sri Lanka. *Asia Pac. J. Rural Dev.* **2016**, *26*, 105–126. [CrossRef]
15. Drake, D.J.; Nader, G.; Forero, L. *Feeding Rice Straw to Cattle*; ANR Publication: Davis, CA, USA, 2002; Volume 8079.
16. Illankoon, W.A.M.A.N.; Milanese, C.; Girella, A.; Rathnasiri, P.G.; Sudesh, K.H.M.; Llamas, M.M.; Collivignarelli, M.C.; Sorlini, S. Agricultural Biomass-Based Power Generation Potential in Sri Lanka: A Techno-Economic Analysis. *Energies* **2022**, *15*, 8984. [CrossRef]
17. Bhat, S.A.; Huang, N.-F. Big Data and AI Revolution in Precision Agriculture: Survey and Challenges. *IEEE Access* **2021**, *9*, 110209–110222. [CrossRef]
18. Gupta, R.; Sharma, A.K.; Garg, O.; Modi, K.; Kasim, S.; Baharum, Z.; Mahdin, H.; Mostafa, S.A. WB-CPI: Weather Based Crop Prediction in India Using Big Data Analytics. *IEEE Access* **2021**, *9*, 137869–137885. [CrossRef]
19. Hoffman, G.J.; Martin, D.L. Engineering Systems to Enhance Irrigation Performance. *Irrig. Sci.* **1993**, *14*, 53–63. [CrossRef]
20. Aslam, M. Agricultural Productivity Current Scenario, Constraints and Future Prospects in Pakistan. *Sarhad J. Agric.* **2016**, *32*, 289–303. [CrossRef]
21. Barker, R.; Herdt, R.W.; Rose, B. *The Rice Economy of Asia*; Routledge: London, UK, 2014; ISBN 9781315060521.
22. Hobbs, P.R.; Gupta, R.K. Resource-Conserving Technologies for Wheat in the Rice-Wheat System. In *Improving Productivity and Sustainability of Rice-Wheat Systems: Issues and Impact*; American Society of Agronomy Special Publication: Madison, WI, USA, 2015; pp. 149–171.
23. Priefer, C.; Jörissen, J.; Bräutigam, K.-R. Food Waste Prevention in Europe—A Cause-Driven Approach to Identify the Most Relevant Leverage Points for Action. *Resour. Conserv. Recycl.* **2016**, *109*, 155–165. [CrossRef]
24. Mesterházy, Á.; Oláh, J.; Popp, J. Losses in the Grain Supply Chain: Causes and Solutions. *Sustainability* **2020**, *12*, 2342. [CrossRef]
25. Beitzen-Heineke, E.F.; Balta-Ozkan, N.; Reefke, H. The Prospects of Zero-Packaging Grocery Stores to Improve the Social and Environmental Impacts of the Food Supply Chain. *J. Clean. Prod.* **2017**, *140*, 1528–1541. [CrossRef]
26. Mohidem, N.A.; Hashim, N.; Shamsudin, R.; Man, H.C. Rice for Food Security: Revisiting Its Production, Diversity, Rice Milling Process and Nutrient Content. *Agriculture* **2022**, *12*, 741. [CrossRef]
27. Wilson, R.T.; Lewis, I. *The RICE Value Chain in Tanzania*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2015.
28. Soullier, G.; Demont, M.; Arouna, A.; Lançon, F.; Mendez del Villar, P. The State of Rice Value Chain Upgrading in West Africa. *Glob. Food Sec.* **2020**, *25*, 100365. [CrossRef]
29. Hong, B.H.; How, B.S.; Lam, H.L. Overview of Sustainable Biomass Supply Chain: From Concept to Modelling. *Clean. Technol. Environ. Policy* **2016**, *18*, 2173–2194. [CrossRef]
30. Afzalinia, S.; Shaker, M.; Zare, E. Comparison of Different Rice Milling Methods. *Can. Biosyst. Eng.* **2004**, *46*, 363–366.
31. Dhankhar, P. Rice Milling. *IOSR J. Eng.* **2014**, *4*, 34–42. [CrossRef]
32. Kamari, S.; Ghorbani, F. Extraction of Highly Pure Silica from Rice Husk as an Agricultural By-Product and Its Application in the Production of Magnetic Mesoporous Silica MCM–41. *Biomass Convers. Biorefin.* **2021**, *11*, 3001–3009. [CrossRef]

33. Wiboonsirikul, J.; Kimura, Y.; Kanaya, Y.; Tsuno, T.; Adachi, S. Production and Characterization of Functional Substances from a By-Product of Rice Bran Oil and Protein Production by a Compressed Hot Water Treatment. *Biosci. Biotechnol. Biochem.* **2008**, *72*, 384–392. [CrossRef]
34. Migo-Sumagang, M.V.P.; van Hung, N.; Detras, M.C.M.; Alfafara, C.G.; Borines, M.G.; Capunitan, J.A.; Gummert, M. Optimization of a Downdraft Furnace for Rice Straw-Based Heat Generation. *Renew. Energy* **2020**, *148*, 953–963. [CrossRef]
35. Vaskalis, I.; Skoulou, V.; Stavropoulos, G.; Zabaniotou, A. Towards Circular Economy Solutions for The Management of Rice Processing Residues to Bioenergy via Gasification. *Sustainability* **2019**, *11*, 6433. [CrossRef]
36. Magnago, R.F.; Costa, S.C.; de Assunção-Ezirio, M.J.; de Godoy Saciloto, V.; Cremona Parma, G.O.; Gasparotto, E.S.; Gonçalves, A.C.; Tutida, A.Y.; Barcelos, R.L. Briquettes of Citrus Peel and Rice Husk. *J. Clean. Prod.* **2020**, *276*, 123820. [CrossRef]
37. Payá, J.; Monzó, J.; Borrachero, M.V.; Peris-Mora, E.; Ordóñez, L.M. Studies on Crystalline Rice Husk Ashes and the Activation of Their Pozzolanic Properties. *Waste Manag. Ser.* **2000**, *1*, 493–503.
38. Hossain, S.S.; Mathur, L.; Roy, P.K. Rice Husk/Rice Husk Ash as an Alternative Source of Silica in Ceramics: A Review. *J. Asian Ceram. Soc.* **2018**, *6*, 299–313. [CrossRef]
39. Collivignarelli, M.C.; Sorlini, S.; Milanese, C.; Illankoon, W.A.M.A.N.; Caccamo, F.M.; Calatroni, S. Rice Industry By-Products as Adsorbent Materials for Removing Fluoride and Arsenic from Drinking Water—A Review. *Appl. Sci.* **2022**, *12*, 3166. [CrossRef]
40. FAO. *OECD-FAO Agricultural Outlook 2021–2030*; FAO: Paris, France, 2021.
41. World Production Volume of Milled Rice from 2008/2009 to 2021/2022. Available online: https://www.statista.com/statistics/271972/world-husked-rice-production-volume-since-2008/ (accessed on 2 October 2022).
42. Belc, N.; Mustatea, G.; Apostol, L.; Iorga, S.; Vlăduţ, V.-N.; Mosoiu, C. Cereal Supply Chain Waste in the Context of Circular Economy. *E3S Web Conf.* **2019**, *112*, 03031. [CrossRef]
43. Parfitt, J.; Barthel, M.; Macnaughton, S. Food Waste within Food Supply Chains: Quantification and Potential for Change to 2050. *Philos. Trans. R. Soc. B Biol. Sci.* **2010**, *365*, 3065–3081. [CrossRef] [PubMed]
44. Thyberg, K.L.; Tonjes, D.J. Drivers of Food Waste and Their Implications for Sustainable Policy Development. *Resour. Conserv. Recycl.* **2016**, *106*, 110–123. [CrossRef]
45. Rosmiza, M.Z.; Davies, W.; Aznie, C.R.; Mazdi, M.; Jabil, M.J. Farmers' Knowledge on Potential Uses of Rice Straw: An Assessment in MADA and Sekinchan, Malaysia. *Malays. J. Soc. Space* **2014**, *10*, 30–43.
46. Singh, G.; Arya, S.K. A Review on Management of Rice Straw by Use of Cleaner Technologies: Abundant Opportunities and Expectations for Indian Farming. *J. Clean. Prod.* **2021**, *291*, 125278. [CrossRef]
47. Abraham, A.; Mathew, A.K.; Sindhu, R.; Pandey, A.; Binod, P. Potential of Rice Straw for Bio-Refining: An Overview. *Bioresour. Technol.* **2016**, *215*, 29–36. [CrossRef]
48. Van Soest, P.J. Rice Straw, the Role of Silica and Treatments to Improve Quality. *Anim. Feed Sci. Technol.* **2006**, *130*, 137–171. [CrossRef]
49. McManus, W.R.; Choung, C.C. Studies on Forage Cell Walls: 2. Conditions for Alkali Treatment of Rice Straw and Rice Hulls. *J. Agric. Sci.* **1976**, *86*, 453–470. [CrossRef]
50. Jackson, M.G. Rice Straw as Livestock Feed. Available online: https://www.fao.org/3/X6512E/X6512E07.htm (accessed on 12 October 2022).
51. Djajanegara, A.; Doyle, P.T. Urea Supplementation Compared with Pretreatment. 1. Effects on Intake, Digestion and Live-Weight Change by Sheep Fed a Rice Straw. *Anim. Feed Sci. Technol.* **1989**, *27*, 17–30. [CrossRef]
52. Kanjanapruthipong, J.; Thaboot, B. Effects of Neutral Detergent Fiber from Rice Straw on Blood Metabolites and Productivity of Dairy Cows in the Tropics Center. *Asian-Australas. J. Anim. Sci.* **2006**, *19*, 356–362. [CrossRef]
53. Prasad, C.S.; Gowda, N.K.S. *Importance of Trace Minerals and Relevance of Their Supplementation in Tropical Animal Feeding System: A Review*; Directorate of Knowledge Management in Agriculture: New Delhi, India, 2005.
54. Nishida, T.; Suzuki, T.; Phaophaisal, I.; Pholsen, P.; Narmsilee, R.; Indramanee, S.; Oshio, S. Research on Feeding Standard of Beef Cattle and Feedstuff Database in the Indochinese Peninsula. In *Education for Sustainable Development (ESD) on Relationships between Agriculture and Global Environmental Issues*; Dairy Japan Co., Ltd.: Tokyo, Japan, 2008.
55. Phyllis2, Database for (Treated) Biomass, Algae, Feedstocks for Biogas Production and Biochar. Available online: https://phyllis.nl/ (accessed on 13 November 2022).
56. Animal Feed Resources Information System. Available online: https://www.feedipedia.org/ (accessed on 13 November 2022).
57. Zahari, N.I.; Shah, U.K.M.; Asa'ari, A.Z.M.; Mohamad, R. Selection of Potential Fungi for Production of Cellulase Poor Xylanase from Rice Straw. *Bioresources* **2016**, *11*, 1162–1175. [CrossRef]
58. Rahnama, N.; Mamat, S.; Shah, U.K.M.; Ling, F.H.; Rahman, N.A.; Ariff, A.B. Effect of Alkali Pretreatment of Rice Straw on Cellulase and Xylanase Production by Local Trichoderma Harzianum SNRS3 under Solid State Fermentation. *Bioresources* **2013**, *8*, 2881–2896. [CrossRef]
59. Jung, S.-H.; Kang, B.-S.; Kim, J.-S. Production of Bio-Oil from Rice Straw and Bamboo Sawdust under Various Reaction Conditions in a Fast Pyrolysis Plant Equipped with a Fluidized Bed and a Char Separation System. *J. Anal. Appl. Pyrolysis* **2008**, *82*, 240–247. [CrossRef]

60. Sayre, R.N.; Earl, L.; Kratzer, F.H.; Saunders, R.M. Nutritional Qualities of Stabilized and Raw Rice Bran for Chicks. *Poult. Sci.* **1987**, *66*, 493–499. [CrossRef]
61. Spears, J.K.; Grieshop, C.M.; Fahey, G.C. Evaluation of Stabilized Rice Bran as an Ingredient in Dry Extruded Dog Diets. *J. Anim. Sci.* **2004**, *82*, 1122–1135. [CrossRef]
62. Nagendra Prasad, M.N.; Sanjay, K.R.; Shravya Khatokar, M.; Vismaya, M.N.; Nanjunda Swamy, S. Health Benefits of Rice Bran—A Review. *J. Nutr. Food Sci.* **2011**, *1*, 1–7. [CrossRef]
63. Bhatnagar, A.S.; Prabhakar, D.S.; Prasanth Kumar, P.K.; Raja Rajan, R.G.; Gopala Krishna, A.G. Processing of Commercial Rice Bran for the Production of Fat and Nutraceutical Rich Rice Brokens, Rice Germ and Pure Bran. *LWT Food Sci. Technol.* **2014**, *58*, 306–311. [CrossRef]
64. Rosniyana, A.; Hashifah, M.A.; Shariffah, S.A.N. Nutritional Content and Storage Stability of Stabilised Rice. Bran-MR 220. *J. Trop. Agric. Food Sci.* **2009**, *37*, 163–170.
65. Lavanya, M.N.; Venkatachalapathy, N.; Manickavasagan, A. Physicochemical Characteristics of Rice Bran. In *Brown Rice*; Springer International Publishing: Cham, Switzerland, 2017; pp. 79–90.
66. Ausman, L.M.; Rong, N.; Nicolosi, R.J. Hypocholesterolemic Effect of Physically Refined Rice Bran Oil: Studies of Cholesterol Metabolism and Early Atherosclerosis in Hypercholesterolemic Hamsters. *J. Nutr. Biochem.* **2005**, *16*, 521–529. [CrossRef]
67. Schmidt, J.E.; Ahring, B.K. Treatment of Waste Water from a Multi-Product Food Processing Company in Upflow Anaerobic Sludge Blanket (UASB) Reactors: The Effect of Seasonal Variation. *Pure Appl. Chem.* **1997**, *69*, 2447–2452. [CrossRef]
68. Prakash, J.; Ramaswamy, H.S. Rice Bran Proteins: Properties and Food Uses. *Crit. Rev. Food Sci. Nutr.* **1996**, *36*, 537–552. [CrossRef] [PubMed]
69. Hong, G.-B.; Yu, T.-J.; Lee, H.-C.; Ma, C.-M. Using Rice Bran Hydrogel Beads to Remove Dye from Aqueous Solutions. *Sustainability* **2021**, *13*, 5640. [CrossRef]
70. Qi, J.; Yokoyama, W.; Masamba, K.G.; Majeed, H.; Zhong, F.; Li, Y. Structural and Physico-Chemical Properties of Insoluble Rice Bran Fiber: Effect of Acid–Base Induced Modifications. *RSC Adv.* **2015**, *5*, 79915–79923. [CrossRef]
71. Oliveira, M.D.S.; Feddern, V.; Kupski, L.; Cipolatti, E.P.; Badiale-Furlong, E.; de Souza-Soares, L.A. Physico-Chemical Characterization of Fermented Rice Bran Biomass Caracterización Fisico-Química de La Biomasa Del Salvado de Arroz Fermentado. *CyTA-J. Food* **2010**, *8*, 229–236. [CrossRef]
72. Ameh, M.O.; Gernah, D.I.; Igbabul, B.D. Physico-Chemical and Sensory Evaluation of Wheat Bread Supplemented with Stabilized Undefatted Rice Bran. *Food Nutr. Sci.* **2013**, *4*, 43–48. [CrossRef]
73. Huang, S.C.; Shiau, C.Y.; Liu, T.E.; Chu, C.L.; Hwang, D.F. Effects of Rice Bran on Sensory and Physico-Chemical Properties of Emulsified Pork Meatballs. *Meat Sci.* **2005**, *70*, 613–619. [CrossRef]
74. Sairam, S.; Krishna, A.G.G.; Urooj, A. Physico-Chemical Characteristics of Defatted Rice Bran and Its Utilization in a Bakery Product. *J. Food Sci. Technol.* **2011**, *48*, 478–483. [CrossRef] [PubMed]
75. Li, H.; Wang, C.; Chen, X.; Xiong, L.; Guo, H.; Yao, S.; Wang, M.; Chen, X.; Huang, C. Anaerobic Digestion of Rice Straw Pretreatment Liquor without Detoxification for Continuous Biogas Production Using a 100 L Internal Circulation Reactor. *J. Clean. Prod.* **2022**, *349*, 131450. [CrossRef]
76. Nguyen, H.M.; Duong, M.H. *Rice Husk Gasification for Electricity Generation in Cambodia in December 2014*; Hanoi University of Science And Technology: Hanoi, Vietnam, 2014.
77. Waheed, Q.M.K.; Williams, P.T. Hydrogen Production from High Temperature Pyrolysis/Steam Reforming of Waste Biomass: Rice Husk, Sugar Cane Bagasse, and Wheat Straw. *Energy Fuels* **2013**, *27*, 6695–6704. [CrossRef]
78. Dagnino, E.P.; Chamorro, E.R.; Romano, S.D.; Felissia, F.E.; Area, M.C. Optimization of the Acid Pretreatment of Rice Hulls to Obtain Fermentable Sugars for Bioethanol Production. *Ind. Crops Prod.* **2013**, *42*, 363–368. [CrossRef]
79. Abbas, A.; Ansumali, S. Global Potential of Rice Husk as a Renewable Feedstock for Ethanol Biofuel Production. *Bioenergy Res.* **2010**, *3*, 328–334. [CrossRef]
80. Della, V.P.; Kühn, I.; Hotza, D. Rice Husk Ash as an Alternate Source for Active Silica Production. *Mater. Lett.* **2002**, *57*, 818–821. [CrossRef]
81. Jawad, Z.F.; Ghayyib, R.J.; Salman, A.J. Microstructural and Compressive Strength Analysis for Cement Mortar with Industrial Waste Materials. *Civ. Eng. J.* **2020**, *6*, 1007–1016. [CrossRef]
82. Kalapathy, U. A Simple Method for Production of Pure Silica from Rice Hull Ash. *Bioresour. Technol.* **2000**, *73*, 257–262. [CrossRef]
83. Bakar, R.A.; Yahya, R.; Gan, S.N. Production of High Purity Amorphous Silica from Rice Husk. *Procedia Chem.* **2016**, *19*, 189–195. [CrossRef]
84. Cavalcante, D.G.; Marques, M.G.D.S.; Filho, J.D.A.M.; de Vasconcelos, R.P. Influence of the Levels of Replacement of Portland Cement by Metakaolin and Silica Extracted from Rice Husk Ash in the Physical and Mechanical Characteristics of Cement Pastes. *Cem. Concr. Compos.* **2018**, *94*, 296–306. [CrossRef]
85. Korotkova, T.; Ksandopulo, S.; Donenko, A.; Bushumov, S.; Danilchenko, A. Physical Properties and Chemical Composition of the Rice Husk and Dust. *Orient. J. Chem.* **2016**, *32*, 3213–3219. [CrossRef]
86. Nenadis, N.; Kyriakoudi, A.; Tsimidou, M.Z. Impact of Alkaline or Acid Digestion to Antioxidant Activity, Phenolic Content and Composition of Rice Hull Extracts. *LWT Food Sci. Technol.* **2013**, *54*, 207–215. [CrossRef]

87. Das, S.K.; Mishra, J.; Mustakim, S.M.; Adesina, A.; Kaze, C.R.; Das, D. Sustainable Utilization of Ultrafine Rice Husk Ash in Alkali Activated Concrete: Characterization and Performance Evaluation. *J. Sustain. Cem.-Based Mater.* **2022**, *11*, 100–112. [CrossRef]
88. Raheem, A.A.; Kareem, M.A. Chemical Composition and Physical Characteristics of Rice Husk Ash Blended Cement. *Int. J. Eng. Res. Afr.* **2017**, *32*, 25–35. [CrossRef]
89. Rukzon, S.; Chindaprasirt, P.; Mahachai, R. Effect of Grinding on Chemical and Physical Properties of Rice Husk Ash. *Int. J. Miner. Metall. Mater.* **2009**, *16*, 242–247. [CrossRef]
90. Prasad, R.K.; Chatterjee, S.; Mazumder, P.B.; Gupta, S.K.; Sharma, S.; Vairale, M.G.; Datta, S.; Dwivedi, S.K.; Gupta, D.K. Bioethanol Production from Waste Lignocelluloses: A Review on Microbial Degradation Potential. *Chemosphere* **2019**, *231*, 588–606. [CrossRef] [PubMed]
91. Sivagurunathan, P.; Raj, T.; Chauhan, P.S.; Kumari, P.; Satlewal, A.; Gupta, R.P.; Kumar, R. High-Titer Lactic Acid Production from Pilot-Scale Pretreated Non-Detoxified Rice Straw Hydrolysate at High-Solid Loading. *Biochem. Eng. J.* **2022**, *187*, 108668. [CrossRef]
92. Oskoueian, E.; Jahromi, M.F.; Jafari, S.; Shakeri, M.; Le, H.H.; Ebrahimi, M. Manipulation of Rice Straw Silage Fermentation with Different Types of Lactic Acid Bacteria Inoculant Affects Rumen Microbial Fermentation Characteristics and Methane Production. *Vet. Sci.* **2021**, *8*, 100. [CrossRef]
93. Sahu, T.K.; Sahu, V.K.; Mondal, A.; Shukla, P.C.; Gupta, S.; Sarkar, S. Investigation of Sugar Extraction Capability from Rice Paddy Straw for Potential Use of Bioethanol Production towards Energy Security. *Energy Sources Part A Recovery Util. Environ. Eff.* **2022**, *44*, 272–286. [CrossRef]
94. Madzingira, O.; Hepute, V.; Mwenda, E.N.; Kandiwa, E.; Mushonga, B.; Mupangwa, J.F. Nutritional Assessment of Three Baled Rice Straw Varieties Intended for Use as Ruminant Feed in Namibia. *Cogent Food Agric.* **2021**, *7*, 1950402. [CrossRef]
95. Jaspreet, K.; Meenakshi, G.; Singh, L.J.; Kumar, A.R. Sugarcane Tops and Additives Influence Nutritional Quality and Fermentation Characteristics of Mixed Silage Prepared with Rice Straw. *Range Manag. Agrofor.* **2022**, *43*, 309–316.
96. Singh, L.; Brar, B.S. A Review on Rice Straw Management Strategies. *Nat. Environ. Pollut. Technol. Int. Q. Sci. J.* **2021**, *20*, 1485–1493. [CrossRef]
97. Kumar, A.; Nayak, A.K.; Sharma, S.; Senapati, A.; Mitra, D.; Mohanty, B.; Prabhukarthikeyan, S.R.; Sabarinathan, K.G.; Mani, I.; Garhwal, R.S.; et al. Recycling of Rice Straw—A Sustainable Approach for Ensuring Environmental Quality and Economic Security: A Review. *Pedosphere*, 2022; *in press*. [CrossRef]
98. Jerold, M.; Santhiagu, A.; Babu, R.S.; Korapatti, N. *Sustainable Bioprocessing for a Clean and Green Environment*; CRC Press: Boca Raton, FL, USA, 2021; ISBN 9781003035398.
99. Haque, S.; Singh, R.; Pal, D.B.; Harakeh, S.; Alghanmi, M.; Teklemariam, A.D.; Abujamel, T.S.; Srivastava, N.; Gupta, V.K. Recent Update on Anaerobic Digestion of Paddy Straw for Biogas Production: Advancement, Limitation and Recommendations. *Environ. Res.* **2022**, *215*, 114292. [CrossRef]
100. Luo, T.; Ge, Y.; Yang, Y.; Fu, Y.; Kumar Awasthi, M.; Pan, J.; Zhai, L.; Mei, Z.; Liu, H. The Impact of Immersed Liquid Circulation on Anaerobic Digestion of Rice Straw Bale and Methane Generation Improvement. *Bioresour. Technol.* **2021**, *337*, 125368. [CrossRef] [PubMed]
101. Susana, I.G.B.; Alit, I.B. Rice Husk as Sustainable Waste Energy for Small Farmers—A Review. *World J. Adv. Eng. Technol. Sci.* **2021**, *3*, 001–006. [CrossRef]
102. Dafiqurrohman, H.; Safitri, K.A.; Setyawan, M.I.B.; Surjosatyo, A.; Aziz, M. Gasification of Rice Wastes toward Green and Sustainable Energy Production: A Review. *J. Clean. Prod.* **2022**, *366*, 132926. [CrossRef]
103. Umar, H.A.; Sulaiman, S.A.; Said, M.A.; Gungor, A.; Ahmad, R.K. An Overview of Biomass Conversion Technologies in Nigeria. In *Clean Energy Opportunities in Tropical Countries*; Springer: Singapore, 2021; pp. 133–150.
104. Mohiuddin, O.; Mohiuddin, A.; Obaidullah, M.; Ahmed, H.; Asumadu-Sarkodie, S. Electricity Production Potential and Social Benefits from Rice Husk, a Case Study in Pakistan. *Cogent Eng.* **2016**, *3*, 1177156. [CrossRef]
105. Hasan, K.M.F.; Horváth, P.G.; Bak, M.; Le, D.H.A.; Mucsi, Z.M.; Alpár, T. Rice Straw and Energy Reed Fibers Reinforced Phenol Formaldehyde Resin Polymeric Biocomposites. *Cellulose* **2021**, *28*, 7859–7875. [CrossRef]
106. Basta, A.H.; Lotfy, V.F. Impact of Pulping Routes of Rice Straw on Cellulose Nanoarchitectonics and Their Behavior toward Indigo Dye. *Appl. Nanosci.* **2022**, *12*, 1–5. [CrossRef]
107. Zhu, L.; Feng, Z.; Wang, D.; Wu, J.; Qiu, J.; Zhu, P. Highly-Efficient Isolation of Cellulose Microfiber from Rice Straw via Gentle Low-Temperature Phase Transition. *Cellulose* **2021**, *28*, 7021–7031. [CrossRef]
108. Thabah, W.; Kumar Singh, A.; Bedi, R. Tensile Properties of Urea Treated Rice Straw Reinforced Recycled Polyethylene Terephthalate Composite Materials. *Mater. Today Proc.* **2022**, *56*, 2151–2157. [CrossRef]
109. Vinoth, V.; Sathiyamurthy, S.; Ananthi, N.; Elaiyarasan, U. Chemical Treatments and Mechanical Characterisation of Natural Fibre Reinforced Composite Materials—A Review. *Int. J. Mater. Eng. Innov.* **2022**, *13*, 208. [CrossRef]
110. Buzarovska, A.; Bogoeva, G.G.; Grozdanov, A.; Avella, M.; Gentile, G.; Errico, M. Potential Use of Rice Straw as Filler in Eco-Composite Materials. *Aust. J. Crop Sci.* **2008**, *1*, 37–42.

111. Jena, P.K.; Bhoi, P.; Behera, R. Mechanical and Thermal Properties of Rice/Wheat Straw Fiber Reinforced Epoxy Composites: A Comparative Study. In *Recent Advances in Mechanical Engineering. Lecture Notes in Mechanical Engineering*; Springer: Singapore, 2023; pp. 727–735.
112. Quintana-Gallardo, A.; Romero Clausell, J.; Guillén-Guillamón, I.; Mendiguchia, F.A. Waste Valorization of Rice Straw as a Building Material in Valencia and Its Implications for Local and Global Ecosystems. *J. Clean. Prod.* **2021**, *318*, 128507. [CrossRef]
113. Xie, X.; Zhang, W.; Luan, X.; Gao, W.; Geng, X.; Xue, Y. Thermal Performance Enhancement of Hollow Brick by Agricultural Wastes. *Case Stud. Constr. Mater.* **2022**, *16*, e01047. [CrossRef]
114. Tachaudomdach, S.; Hempao, S. Investigation of Compression Strength and Heat Absorption of Native Rice Straw Bricks for Environmentally Friendly Construction. *Sustainability* **2022**, *14*, 12229. [CrossRef]
115. Awoyera, P.O.; Akinrinade, A.D.; de Sousa Galdino, A.G.; Althoey, F.; Kirgiz, M.S.; Tayeh, B.A. Thermal Insulation and Mechanical Characteristics of Cement Mortar Reinforced with Mineral Wool and Rice Straw Fibers. *J. Build. Eng.* **2022**, *53*, 104568. [CrossRef]
116. El-Kassas, A.M.; Elsheikh, A.H. A New Eco-Friendly Mechanical Technique for Production of Rice Straw Fibers for Medium Density Fiberboards Manufacturing. *Int. J. Environ. Sci. Technol.* **2021**, *18*, 979–988. [CrossRef]
117. Zhu, Y.; Tang, W.; Jin, X.; Shan, B. Using Biochar Capping to Reduce Nitrogen Release from Sediments in Eutrophic Lakes. *Sci. Total Environ.* **2019**, *646*, 93–104. [CrossRef]
118. Xu, Y.; Chen, J.; Chen, R.; Yu, P.; Guo, S.; Wang, X. Adsorption and Reduction of Chromium(VI) from Aqueous Solution Using Polypyrrole/Calcium Rectorite Composite Adsorbent. *Water Res.* **2019**, *160*, 148–157. [CrossRef]
119. Okeke, E.S.; Olagbaju, O.A.; Okoye, C.O.; Addey, C.I.; Chukwudozie, K.I.; Okoro, J.O.; Deme, G.G.; Ewusi-Mensah, D.; Igun, E.; Ejeromedoghene, O.; et al. Microplastic Burden in Africa: A Review of Occurrence, Impacts, and Sustainability Potential of Bioplastics. *Chem. Eng. J. Adv.* **2022**, *12*, 100402. [CrossRef]
120. Guo, X.; Zheng, P.; Zou, X.; Chen, X.; Zhang, Q. Influence of Pyroligneous Acid on Fermentation Parameters, CO_2 Production and Bacterial Communities of Rice Straw and Stylo Silage. *Front. Microbiol.* **2021**, *12*, 701434. [CrossRef]
121. Ahmed, M.A.; Rafii, M.Y.; Ain Izzati, M.Z.N.; Khalilah, A.K.; Awad, E.A.; Kaka, U.; Chukwu, S.C.; Liang, J.B.; Sazili, A.Q. Biological Additives Improved Qualities. *Anim. Prod. Sci.* **2022**, *62*, 1414–1429. [CrossRef]
122. Chen, Y.F.; Ouyang, J.L.; Shahzad, K.; Qi, R.X.; Wang, M.Z. Effects of Facultative Heterofermentative Lab, Enzymes and Fermentable Substrates on the Fermentation Quality, Aerobic Stability and In Vitro Ruminal Fermentation of Rice Straw. *Anim. Nutr. Feed Technol.* **2022**, *22*, 67–78. [CrossRef]
123. Wang, Y.; Xu, B.; Ning, S.; Shi, S.; Tan, L. Magnetically Stimulated Azo Dye Biodegradation by a Newly Isolated Osmo-Tolerant Candida Tropicalis A1 and Transcriptomic Responses. *Ecotoxicol. Environ. Saf.* **2021**, *209*, 111791. [CrossRef] [PubMed]
124. Rusdy, M. Chemical Composition and Nutritional Value of Urea Treated Rice Straw for Ruminants. *Livest. Res. Rural. Dev.* **2022**, *34*, 10.
125. Buasri, A.; Chaiyut, N.; Tapang, K.; Jaroensin, S.; Panphrom, S. Removal of Cu^{2+} from Aqueous Solution by Biosorption on Rice Straw—An Agricultural Waste Biomass. *Int. J. Environ. Sci. Dev.* **2012**, *3*, 10. [CrossRef]
126. Rocha, C.G.; Zaia, D.A.M.; Alfaya, R.V.D.S.; Alfaya, A.A.D.S. Use of Rice Straw as Biosorbent for Removal of Cu(II), Zn(II), Cd(II) and Hg(II) Ions in Industrial Effluents. *J. Hazard. Mater.* **2009**, *166*, 383–388. [CrossRef]
127. Nawar, N.; Ebrahim, M.; Sami, E. Removal of Heavy Metals Fe^{3+}, Mn^{2+}, Zn^{2+}, Pb^{2+} and Cd^{2+} from Wastewater by Using Rice Straw as Low Cost Adsorbent. *Acad. J. Interdiscip. Stud.* **2013**, *2*, 85. [CrossRef]
128. Cao, L.; Zhang, C.; Hao, S.; Luo, G.; Zhang, S.; Chen, J. Effect of Glycerol as Co-Solvent on Yields of Bio-Oil from Rice Straw through Hydrothermal Liquefaction. *Bioresour. Technol.* **2016**, *220*, 471–478. [CrossRef] [PubMed]
129. Bishnoi, N.R.; Bajaj, M.; Sharma, N.; Gupta, A. Adsorption of Cr(VI) on Activated Rice Husk Carbon and Activated Alumina. *Bioresour. Technol.* **2004**, *91*, 305–307. [CrossRef]
130. Gao, H.; Liu, Y.; Zeng, G.; Xu, W.; Li, T.; Xia, W. Characterization of Cr(VI) Removal from Aqueous Solutions by a Surplus Agricultural Waste—Rice Straw. *J. Hazard. Mater.* **2008**, *150*, 446–452. [CrossRef]
131. Rungrodnimitchai, S. Modification of Rice Straw for Heavy Metal Ion Adsorbents by Microwave Heating. *Macromol. Symp.* **2010**, *295*, 100–106. [CrossRef]
132. Cao, W.; Dang, Z.; Zhou, X.-Q.; Yi, X.-Y.; Wu, P.-X.; Zhu, N.-W.; Lu, G.-N. Removal of Sulphate from Aqueous Solution Using Modified Rice Straw: Preparation, Characterization and Adsorption Performance. *Carbohydr. Polym.* **2011**, *85*, 571–577. [CrossRef]
133. Amin, M.N.; Mustafa, A.I.; Khalil, M.I.; Rahman, M.; Nahid, I. Adsorption of Phenol onto Rice Straw Biowaste for Water Purification. *Clean. Technol. Environ. Policy* **2012**, *14*, 837–844. [CrossRef]
134. Fathy, N.A.; El-Shafey, O.I.; Khalil, L.B. Effectiveness of Alkali-Acid Treatment in Enhancement the Adsorption Capacity for Rice Straw: The Removal of Methylene Blue Dye. *ISRN Phys. Chem.* **2013**, *2013*, 208087. [CrossRef]
135. Goodman, B.A. Utilization of Waste Straw and Husks from Rice Production: A Review. *J. Bioresour. Bioprod.* **2020**, *5*, 143–162. [CrossRef]
136. Eladel, H.; Abd-Elhay, R.; Anees, D. Effect of Rice Straw Application on Water Quality and Microalgal Flora in Fish Ponds. *Egypt. J. Bot.* **2018**, *59*, 171–184. [CrossRef]
137. Yang, W.; Guo, F.; Wan, Z. Yield and Size of Oyster Mushroom Grown on Rice/Wheat Straw Basal Substrate Supplemented with Cotton Seed Hull. *Saudi J. Biol. Sci.* **2013**, *20*, 333–338. [CrossRef] [PubMed]

138. Li, T.; Gao, J.; Bai, L.; Wang, Y.; Huang, J.; Kumar, M.; Zeng, X. Influence of Green Manure and Rice Straw Management on Soil Organic Carbon, Enzyme Activities, and Rice Yield in Red Paddy Soil. *Soil Tillage Res.* **2019**, *195*, 104428. [CrossRef]
139. Lu, K.; Yang, X.; Shen, J.; Robinson, B.; Huang, H.; Liu, D.; Bolan, N.; Pei, J.; Wang, H. Effect of Bamboo and Rice Straw Biochars on the Bioavailability of Cd, Cu, Pb and Zn to Sedum Plumbizincicola. *Agric. Ecosyst. Environ.* **2014**, *191*, 124–132. [CrossRef]
140. Cui, H.-J.; Wang, M.K.; Fu, M.-L.; Ci, E. Enhancing Phosphorus Availability in Phosphorus-Fertilized Zones by Reducing Phosphate Adsorbed on Ferrihydrite Using Rice Straw-Derived Biochar. *J. Soils Sediments* **2011**, *11*, 1135–1141. [CrossRef]
141. Wannapeera, J.; Worasuwannarak, N.; Pipatmanomai, S. Product Yields and Characteristics of Rice Husk, Rice Straw and Corncob during Fast Pyrolysis in a Drop-Tube/Fixed-Bed Reactor. *Songklanakarin J. Sci. Technol.* **2008**, *30*, 393–404.
142. Ye, S.; Zeng, G.; Wu, H.; Liang, J.; Zhang, C.; Dai, J.; Xiong, W.; Song, B.; Wu, S.; Yu, J. The Effects of Activated Biochar Addition on Remediation Efficiency of Co-Composting with Contaminated Wetland Soil. *Resour. Conserv. Recycl.* **2019**, *140*, 278–285. [CrossRef]
143. Liu, W.-J.; Jiang, H.; Yu, H.-Q. Emerging Applications of Biochar-Based Materials for Energy Storage and Conversion. *Energy Environ. Sci.* **2019**, *12*, 1751–1779. [CrossRef]
144. Jing, X.-R.; Wang, Y.-Y.; Liu, W.-J.; Wang, Y.-K.; Jiang, H. Enhanced Adsorption Performance of Tetracycline in Aqueous Solutions by Methanol-Modified Biochar. *Chem. Eng. J.* **2014**, *248*, 168–174. [CrossRef]
145. Zaccheria, F.; Mariani, M.; Ravasio, N. The Use of Rice Bran Oil within a Biorefinery Concept. *Chem. Biol. Technol. Agric.* **2015**, *2*, 23. [CrossRef]
146. Roth-Maier, D.A.; Kettler, S.I.; Kirchgessner, M. Availability of Vitamin B 6 from Different Food Sources. *Int. J. Food Sci. Nutr.* **2002**, *53*, 171–179. [CrossRef]
147. Nyström, L.; Mäkinen, M.; Lampi, A.-M.; Piironen, V. Antioxidant Activity of Steryl Ferulate Extracts from Rye and Wheat Bran. *J. Agric. Food Chem.* **2005**, *53*, 2503–2510. [CrossRef]
148. Nyström, L.; Achrenius, T.; Lampi, A.-M.; Moreau, R.A.; Piironen, V. A Comparison of the Antioxidant Properties of Steryl Ferulates with Tocopherol at High Temperatures. *Food Chem.* **2007**, *101*, 947–954. [CrossRef]
149. Bhunia, R.K.; Sinha, K.; Kaur, R.; Kaur, S.; Chawla, K. A Holistic View of the Genetic Factors Involved in Triggering Hydrolytic and Oxidative Rancidity of Rice Bran Lipids. *Food Rev. Int.* **2021**, *37*, 1–26. [CrossRef]
150. Ranjan, A.; Kumar, S.; Sahu, N.P.; Jain, K.K.; Deo, A.D. Strategies for Maximizing Utilization of De-Oiled Rice Bran (DORB) in the Fish Feed. *Aquac. Int.* **2022**, *30*, 99–114. [CrossRef]
151. Jha, B.; Chandra, R.; Vijay, V.K.; Subbarao, P.M.V.; Isha, A. Utilization of De-Oiled Rice Bran as a Feedstock for Renewable Biomethane Production. *Biomass Bioenergy* **2020**, *140*, 105674. [CrossRef]
152. Zaidel, D.N.A.; Muhamad, I.I.; Daud, N.S.M.; Muttalib, N.A.A.; Khairuddin, N.; Lazim, N.A.M. Production of Biodiesel from Rice Bran Oil. In *Biomass, Biopolymer-Based Materials, and Bioenergy*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 409–447.
153. Hoang, A.T.; Tabatabaei, M.; Aghbashlo, M.; Carlucci, A.P.; Ölçer, A.I.; Le, A.T.; Ghassemi, A. Rice Bran Oil-Based Biodiesel as a Promising Renewable Fuel Alternative to Petrodiesel: A Review. *Renew. Sustain. Energy Rev.* **2021**, *135*, 110204. [CrossRef]
154. Marchetti, J.M. A Summary of the Available Technologies for Biodiesel Production Based on a Comparison of Different Feedstock's Properties. *Process Saf. Environ. Prot.* **2012**, *90*, 157–163. [CrossRef]
155. Abbaszadeh, A.; Ghobadian, B.; Najafi, G.; Yusaf, T. An Experimental Investigation of the Effective Parameters on Wet Washing of Biodiesel Purification. *Int. J. Automot. Mech. Eng.* **2014**, *9*, 1525–1537. [CrossRef]
156. Zhang, Y.; Wong, W.-T.; Yung, K.-F. One-Step Production of Biodiesel from Rice Bran Oil Catalyzed by Chlorosulfonic Acid Modified Zirconia via Simultaneous Esterification and Transesterification. *Bioresour. Technol.* **2013**, *147*, 59–64. [CrossRef] [PubMed]
157. Sutanto, S.; Go, A.W.; Chen, K.-H.; Ismadji, S.; Ju, Y.-H. Maximized Utilization of Raw Rice Bran in Microbial Oils Production and Recovery of Active Compounds: A Proof of Concept. *Waste Biomass Valorization* **2017**, *8*, 1067–1080. [CrossRef]
158. Gupte, A.P.; Basaglia, M.; Casella, S.; Favaro, L. Rice Waste Streams as a Promising Source of Biofuels: Feedstocks, Biotechnologies and Future Perspectives. *Renew. Sustain. Energy Rev.* **2022**, *167*, 112673. [CrossRef]
159. Alexandri, M.; López-Gómez, J.P.; Olszewska-Widdrat, A.; Venus, J. Valorising Agro-Industrial Wastes within the Circular Bioeconomy Concept: The Case of Defatted Rice Bran with Emphasis on Bioconversion Strategies. *Fermentation* **2020**, *6*, 42. [CrossRef]
160. Friedman, M. Rice Brans, Rice Bran Oils, and Rice Hulls: Composition, Food and Industrial Uses, and Bioactivities in Humans, Animals, and Cells. *J. Agric. Food Chem.* **2013**, *61*, 10626–10641. [CrossRef]
161. Chandel, A.K.; Narasu, M.L.; Rudravaram, R.; Pogaku, R.; Rao, L.V. Bioconversion of De-Oiled Rice Bran (DORB) Hemicellulosic Hydrolysate into Ethanol by Pichia Stipitis NCM3499 under Optimized Conditions. *Int. J. Food Eng.* **2009**, *5*. [CrossRef]
162. Beliya, E.; Tiwari, S.; Jadhav, S.K.; Tiwari, K.L. De-Oiled Rice Bran as a Source of Bioethanol. *Energy Explor. Exploit.* **2013**, *31*, 771–782. [CrossRef]
163. Alexandri, M.; Neu, A.; Schneider, R.; López-Gómez, J.P.; Venus, J. Evaluation of Various *Bacillus coagulans* Isolates for the Production of High Purity L-lactic Acid Using Defatted Rice Bran Hydrolysates. *Int. J. Food Sci. Technol.* **2019**, *54*, 1321–1329. [CrossRef]

164. Kurniasih, N.; Dinna, F.; Amalia, V.; Widiastuti, D. The effect of fortification of brands and chitosan on tempeh on fiber levels and probiotic bacteria growth. *Helium J. Sci. Appl. Chem.* **2021**, *1*, 37–41. [CrossRef]
165. Nontasan, S.; Moongngarm, A.; Deeseenthum, S. Application of Functional Colorant Prepared from Black Rice Bran in Yogurt. *APCBEE Procedia* **2012**, *2*, 62–67. [CrossRef]
166. Caplice, E. Food Fermentations: Role of Microorganisms in Food Production and Preservation. *Int. J. Food Microbiol.* **1999**, *50*, 131–149. [CrossRef] [PubMed]
167. Al-Shorgani, N.K.N.; Al-Tabib, A.I.; Kadier, A.; Zanil, M.F.; Lee, K.M.; Kalil, M.S. Continuous Butanol Fermentation of Dilute Acid-Pretreated De-Oiled Rice Bran by Clostridium Acetobutylicum YM1. *Sci. Rep.* **2019**, *9*, 4622. [CrossRef] [PubMed]
168. Ranjan, D.; Talat, M.; Hasan, S.H. Rice Polish: An Alternative to Conventional Adsorbents for Treating Arsenic Bearing Water by Up-Flow Column Method. *Ind. Eng. Chem. Res.* **2009**, *48*, 10180–10185. [CrossRef]
169. Lai, Q.D.; Doan, N.T.T.; Nguyen, H.D.; Nguyen, T.X.N. Influence of Enzyme Treatment of Rice Bran on Gamma-aminobutyric Acid Synthesis by *Lacto bacillus*. *Int. J. Food Sci. Technol.* **2021**, *56*, 4722–4729. [CrossRef]
170. Chugh, P.; Soni, R.; Soni, S.K. Deoiled Rice Bran: A Substrate for Co-Production of a Consortium of Hydrolytic Enzymes by Aspergillus Niger P-19. *Waste Biomass Valorization* **2016**, *7*, 513–525. [CrossRef]
171. Tang, S.; Hettiarachchy, N.S.; Shellhammer, T.H. Protein Extraction from Heat-Stabilized Defatted Rice Bran. 1. Physical Processing and Enzyme Treatments. *J. Agric. Food Chem.* **2002**, *50*, 7444–7448. [CrossRef]
172. Tandon, M.; Thakur, V.; Tiwari, K.L.; Jadhav, S.K. Enterobacter Ludwigii Strain IF2SW-B4 Isolated for Bio-Hydrogen Production from Rice Bran and de-Oiled Rice Bran. *Environ. Technol. Innov.* **2018**, *10*, 345–354. [CrossRef]
173. Soares, J.F.; Confortin, T.C.; Todero, I.; Mayer, F.D.; Mazutti, M.A. Dark Fermentative Biohydrogen Production from Lignocellulosic Biomass: Technological Challenges and Future Prospects. *Renew. Sustain. Energy Rev.* **2020**, *117*, 109484. [CrossRef]
174. Azman, N.F.; Abdeshahian, P.; Al-Shorgani, N.K.N.; Hamid, A.A.; Kalil, M.S. Production of Hydrogen Energy from Dilute Acid-Hydrolyzed Palm Oil Mill Effluent in Dark Fermentation Using an Empirical Model. *Int. J. Hydrog. Energy* **2016**, *41*, 16373–16384. [CrossRef]
175. Soltani, N.; Bahrami, A.; Pech-Canul, M.I.; González, L.A. Review on the Physicochemical Treatments of Rice Husk for Production of Advanced Materials. *Chem. Eng. J.* **2015**, *264*, 899–935. [CrossRef]
176. Pode, R. Potential Applications of Rice Husk Ash Waste from Rice Husk Biomass Power Plant. *Renew. Sustain. Energy Rev.* **2016**, *53*, 1468–1485. [CrossRef]
177. Ho, Y.-S.; Chiang, C.-C.; Hsu, Y.-C. Sorption kinetics for dye removal from aqueous solution using activated clay. *Sep. Sci. Technol.* **2001**, *36*, 2473–2488. [CrossRef]
178. Zhang, Y.; Zheng, R.; Zhao, J.; Ma, F.; Zhang, Y.; Meng, Q. Characterization of -Treated Rice Husk Adsorbent and Adsorption of Copper(II) from Aqueous Solution. *Biomed. Res. Int.* **2014**, *2014*, 496878. [CrossRef] [PubMed]
179. Da Rosa, M.P.; Igansi, A.V.; Lütke, S.F.; Sant'Anna Cadaval, T.R.; do Santos, A.C.R.; de Oliveira Lopes Inacio, A.P.; de Almeida Pinto, L.A.; Beck, P.H. A New Approach to Convert Rice Husk Waste in a Quick and Efficient Adsorbent to Remove Cationic Dye from Water. *J. Environ. Chem. Eng.* **2019**, *7*, 103504. [CrossRef]
180. Chandrasekhar, S.; Pramada, P.N. Rice Husk Ash as an Adsorbent for Methylene Blue—Effect of Ashing Temperature. *Adsorption* **2006**, *12*, 27–43. [CrossRef]
181. Chowdhury, S.; Mishra, R.; Saha, P.; Kushwaha, P. Adsorption Thermodynamics, Kinetics and Isosteric Heat of Adsorption of Malachite Green onto Chemically Modified Rice Husk. *Desalination* **2011**, *265*, 159–168. [CrossRef]
182. Deshmukh, W.S.; Attar, S.J.; Waghmare, M.D. Investigation on Sorption of Fluoride in Water Using Rice Husk as an Adsorbent. *Nat. Environ. Pollut. Technol. Int. Q. Sci. J.* **2009**, *8*, 217–223.
183. Ahmaruzzaman, M.; Gupta, V.K. Rice Husk and Its Ash as Low-Cost Adsorbents in Water and Wastewater Treatment. *Ind. Eng. Chem. Res.* **2011**, *50*, 13589–13613. [CrossRef]
184. Masoumi, A.; Hemmati, K.; Ghaemy, M. Low-Cost Nanoparticles Sorbent from Modified Rice Husk and a Copolymer for Efficient Removal of Pb(II) and Crystal Violet from Water. *Chemosphere* **2016**, *146*, 253–262. [CrossRef] [PubMed]
185. Hubadillah, S.K.; Othman, M.H.D.; Harun, Z.; Ismail, A.F.; Rahman, M.A.; Jaafar, J. A Novel Green Ceramic Hollow Fiber Membrane (CHFM) Derived from Rice Husk Ash as Combined Adsorbent-Separator for Efficient Heavy Metals Removal. *Ceram. Int.* **2017**, *43*, 4716–4720. [CrossRef]
186. Al-Sultani Kadhim, F.; Al-Seroury, F.A. Characterization the Removal of Phenol from Aqueous Solution in Fluidized Bed Column by Rice Husk Adsorbent. *Res. J. Recent Sci.* **2012**, *1*, 145–151.
187. Shen, Y.; Fu, Y. KOH-Activated Rice Husk Char via CO_2 Pyrolysis for Phenol Adsorption. *Mater. Today Energy* **2018**, *9*, 397–405. [CrossRef]
188. Nakbanpote, W.; Thiravetyan, P.; Kalambaheti, C. Preconcentration of Gold by Rice Husk Ash. *Miner. Eng.* **2000**, *13*, 391–400. [CrossRef]
189. Sarker, N.; Fakhruddin, A.N.M. Removal of Phenol from Aqueous Solution Using Rice Straw as Adsorbent. *Appl. Water Sci.* **2017**, *7*, 1459–1465. [CrossRef]
190. Anshar, A.M.; Taba, P.; Raya, I. Kinetic and Thermodynamics Studies on the Adsorption of Phenol on Activated Carbon from Rice Husk Activated by $ZnCl_2$. *Indones. J. Sci. Technol.* **2016**, *1*, 47–60. [CrossRef]

191. Singh, D.K.; Bhavana, S. *Basic Dyes Removal from Wastewater by Adsorption on Rice Husk Carbon*; NISCAIR-CSIR: New Delhi, India, 2001; Volume 8, pp. 133–139.
192. El-Maghraby, A.; El-Deeb, H.A. Removal of a basic dye from aqueous solution by adsorption using rice hulls. *Glob. NEST J.* **2011**, *13*, 90–98.
193. Mohamed, M.M. Acid Dye Removal: Comparison of Surfactant-Modified Mesoporous FSM-16 with Activated Carbon Derived from Rice Husk. *J. Colloid Interface Sci.* **2004**, *272*, 28–34. [CrossRef]
194. Malik, P.K. Use of Activated Carbons Prepared from Sawdust and Rice-Husk for Adsorption of Acid Dyes: A Case Study of Acid Yellow 36. *Dye. Pigment.* **2003**, *56*, 239–249. [CrossRef]
195. Bansal, M.; Garg, U.; Singh, D.; Garg, V.K. Removal of Cr(VI) from Aqueous Solutions Using Pre-Consumer Processing Agricultural Waste: A Case Study of Rice Husk. *J. Hazard. Mater.* **2009**, *162*, 312–320. [CrossRef] [PubMed]
196. Sugashini, S.; Begum, K.M.M.S. Preparation of Activated Carbon from Carbonized Rice Husk by Ozone Activation for Cr(VI) Removal. *New Carbon Mater.* **2015**, *30*, 252–261. [CrossRef]
197. Ma, J.; Li, T.; Liu, Y.; Cai, T.; Wei, Y.; Dong, W.; Chen, H. Rice Husk Derived Double Network Hydrogel as Efficient Adsorbent for Pb(II), Cu(II) and Cd(II) Removal in Individual and Multicomponent Systems. *Bioresour. Technol.* **2019**, *290*, 121793. [CrossRef] [PubMed]
198. Hagemann, N.; Spokas, K.; Schmidt, H.-P.; Kägi, R.; Böhler, M.; Bucheli, T. Activated Carbon, Biochar and Charcoal: Linkages and Synergies across Pyrogenic Carbon's ABCs. *Water* **2018**, *10*, 182. [CrossRef]
199. Jeyasubramanian, K.; Thangagiri, B.; Sakthivel, A.; Dhaveethu Raja, J.; Seenivasan, S.; Vallinayagam, P.; Madhavan, D.; Malathi Devi, S.; Rathika, B. A Complete Review on Biochar: Production, Property, Multifaceted Applications, Interaction Mechanism and Computational Approach. *Fuel* **2021**, *292*, 120243. [CrossRef]
200. Alkurdi, S.S.A.; Herath, I.; Bundschuh, J.; Al-Juboori, R.A.; Vithanage, M.; Mohan, D. Biochar versus Bone Char for a Sustainable Inorganic Arsenic Mitigation in Water: What Needs to Be Done in Future Research? *Environ. Int.* **2019**, *127*, 52–69. [CrossRef]
201. Sakhiya, A.K.; Anand, A.; Kaushal, P. Production, Activation, and Applications of Biochar in Recent Times. *Biochar* **2020**, *2*, 253–285. [CrossRef]
202. Quispe, I.; Navia, R.; Kahhat, R. Energy Potential from Rice Husk through Direct Combustion and Fast Pyrolysis: A Review. *Waste Manag.* **2017**, *59*, 200–210. [CrossRef]
203. Decker, S.R.; Brunecky, R.; Tucker, M.P.; Himmel, M.E.; Selig, M.J. High-Throughput Screening Techniques for Biomass Conversion. *Bioenergy Res.* **2009**, *2*, 179–192. [CrossRef]
204. Faaij, A. Modern Biomass Conversion Technologies. *Mitig. Adapt. Strateg. Glob. Chang.* **2006**, *11*, 343–375. [CrossRef]
205. Yahaya, D.B.; Ibrahim, T.G. Development of rice husk briquettes for use as fuel. *Res. J. Eng. Appl. Sci.* **2012**, *1*, 130–133.
206. Wu, H.-C.; Ku, Y.; Tsai, H.-H.; Kuo, Y.-L.; Tseng, Y.-H. Rice Husk as Solid Fuel for Chemical Looping Combustion in an Annular Dual-Tube Moving Bed Reactor. *Chem. Eng. J.* **2015**, *280*, 82–89. [CrossRef]
207. Islam, M.N.; Ani, F.N. Techno-Economics of Rice Husk Pyrolysis, Conversion with Catalytic Treatment to Produce Liquid Fuel. *Bioresour. Technol.* **2000**, *73*, 67–75. [CrossRef]
208. Salam, M.A.; Ahmed, K.; Hossain, T.; Habib, M.S.; Uddin, M.S.; Papri, N. Prospect of Molecular Sieves Production Using Rice Husk in Bangladesh: A Review. *Int. J. Chem. Math. Phys.* **2019**, *3*, 105–134. [CrossRef]
209. Sun, L.; Gong, K. Silicon-Based Materials from Rice Husks and Their Applications. *Ind. Eng. Chem. Res.* **2001**, *40*, 5861–5877. [CrossRef]
210. Li, D.; Ma, T.; Zhang, R.; Tian, Y.; Qiao, Y. Preparation of Porous Carbons with High Low-Pressure CO_2 Uptake by KOH Activation of Rice Husk Char. *Fuel* **2015**, *139*, 68–70. [CrossRef]
211. Illankoon, W.A.M.A.N.; Milanese, C.; Girella, A.; Medina-Llamas, M.; Magnani, G.; Pontiroli, D.; Ricco, M.; Collivignarelli, M.C.; Sorlini, S. Biochar derived from the rice industry by-products as sustainable energy storage material. In Proceedings of the 30th European Biomass Conference and Exhibition (EUBCE), Online, 9–12 May 2022; Chevet, P.-F., Scarlat, N., Grassi, A., Eds.; ETA-Florence Renewable Energies: Florence, Italy, 2022.
212. Feng, Q.; Lin, Q.; Gong, F.; Sugita, S.; Shoya, M. Adsorption of Lead and Mercury by Rice Husk Ash. *J. Colloid Interface Sci.* **2004**, *278*, 1–8. [CrossRef]
213. Naiya, T.K.; Bhattacharya, A.K.; Mandal, S.; Das, S.K. The Sorption of Lead(II) Ions on Rice Husk Ash. *J. Hazard. Mater.* **2009**, *163*, 1254–1264. [CrossRef]
214. Ganvir, V.; Das, K. Removal of Fluoride from Drinking Water Using Aluminum Hydroxide Coated Rice Husk Ash. *J. Hazard. Mater.* **2011**, *185*, 1287–1294. [CrossRef]
215. Chakraborty, S.; Chowdhury, S.; das Saha, P. Adsorption of Crystal Violet from Aqueous Solution onto NaOH-Modified Rice Husk. *Carbohydr. Polym.* **2011**, *86*, 1533–1541. [CrossRef]
216. Lawagon, C.P.; Amon, R.E.C. Magnetic Rice Husk Ash "cleanser" as Efficient Methylene Blue Adsorbent. *Environ. Eng. Res.* **2019**, *25*, 685–692. [CrossRef]
217. Sarkar, D.; Bandyopadhyay, A. Adsorptive Mass Transport of Dye on Rice Husk Ash. *J. Water Resour. Prot.* **2010**, *2*, 424–431. [CrossRef]

218. Lakshmi, U.R.; Srivastava, V.C.; Mall, I.D.; Lataye, D.H. Rice Husk Ash as an Effective Adsorbent: Evaluation of Adsorptive Characteristics for Indigo Carmine Dye. *J. Environ. Manag.* **2009**, *90*, 710–720. [CrossRef] [PubMed]
219. Manique, M.C.; Faccini, C.S.; Onorevoli, B.; Benvenutti, E.V.; Caramão, E.B. Rice Husk Ash as an Adsorbent for Purifying Biodiesel from Waste Frying Oil. *Fuel* **2012**, *92*, 56–61. [CrossRef]
220. Zou, Y.; Yang, T. Rice Husk, Rice Husk Ash and Their Applications. In *Rice Bran and Rice Bran Oil*; Elsevier: Amsterdam, The Netherlands, 2019; pp. 207–246.
221. Azadi, M.; Bahrololoom, M.E.; Heidari, F. Enhancing the Mechanical Properties of an Epoxy Coating with Rice Husk Ash, a Green Product. *J. Coat. Technol. Res.* **2011**, *8*, 117–123. [CrossRef]
222. Tipsotnaiyana, N.; Jarupan, L.; Pechyen, C. Synthesized Silica Powder from Rice Husk for Printing Raw Materials Application. *Adv. Mater. Res.* **2012**, *506*, 218–221. [CrossRef]
223. Nair, D.G.; Fraaij, A.; Klaassen, A.A.K.; Kentgens, A.P.M. A Structural Investigation Relating to the Pozzolanic Activity of Rice Husk Ashes. *Cem. Concr. Res.* **2008**, *38*, 861–869. [CrossRef]
224. Zahedi, M.; Ramezanianpour, A.A.; Ramezanianpour, A.M. Evaluation of the Mechanical Properties and Durability of Cement Mortars Containing Nanosilica and Rice Husk Ash under Chloride Ion Penetration. *Constr. Build Mater.* **2015**, *78*, 354–361. [CrossRef]
225. Ramezanianpour, A.A.; Pourbeik, P.; Moodi, F.; Sabzi, M.Z. Sulfate Resistance of Concretes Containing Rice Husk Ash. In Proceedings of the 9th International Congress on Advances in Civil Engineering, Karadeniz Technical University, Trabzon, Turkey, 30 September 2010.
226. Zareei, S.A.; Ameri, F.; Dorostkar, F.; Ahmadi, M. Rice Husk Ash as a Partial Replacement of Cement in High Strength Concrete Containing Micro Silica: Evaluating Durability and Mechanical Properties. *Case Stud. Constr. Mater.* **2017**, *7*, 73–81. [CrossRef]
227. Haxo, H.E.; Mehta, P.K. Ground Rice-Hull Ash as a Filler for Rubber. *Rubber Chem. Technol.* **1975**, *48*, 271–288. [CrossRef]
228. Nzila, C.; Oluoch, N.; Kiprop, A.; Ramkat, R.; Kosgey, I. *Advances in Phytochemistry, Textile and Renewable Energy Research for Industrial Growth*; CRC Press: London, UK, 2022; ISBN 9781003221968.
229. Wang, L.; Guo, Y.; Zhu, Y.; Li, Y.; Qu, Y.; Rong, C.; Ma, X.; Wang, Z. A New Route for Preparation of Hydrochars from Rice Husk. *Bioresour. Technol.* **2010**, *101*, 9807–9810. [CrossRef]
230. Kirchherr, J.; Piscicelli, L. Towards an Education for the Circular Economy (ECE): Five Teaching Principles and a Case Study. *Resour. Conserv. Recycl.* **2019**, *150*, 104406. [CrossRef]
231. Nassereddine, H.; Seo, K.W.; Rybkowski, Z.K.; Schranz, C.; Urban, H. Propositions for a Resilient, Post-COVID-19 Future for the AEC Industry. *Front. Built. Environ.* **2021**, *7*, 117–123. [CrossRef]
232. Okorie, O.; Salonitis, K.; Charnley, F.; Moreno, M.; Turner, C.; Tiwari, A. Digitisation and the Circular Economy: A Review of Current Research and Future Trends. *Energies* **2018**, *11*, 3009. [CrossRef]
233. Kevin van Langen, S.; Vassillo, C.; Ghisellini, P.; Restaino, D.; Passaro, R.; Ulgiati, S. Promoting Circular Economy Transition: A Study about Perceptions and Awareness by Different Stakeholders Groups. *J. Clean. Prod.* **2021**, *316*, 128166. [CrossRef]
234. Let's Build a Circular Economy. Available online: https://ellenmacarthurfoundation.org/ (accessed on 8 December 2022).
235. Cecchin, A.; Salomone, R.; Deutz, P.; Raggi, A.; Cutaia, L. What Is in a Name? The Rising Star of the Circular Economy as a Resource-Related Concept for Sustainable Development. *Circ. Econ. Sustain.* **2021**, *1*, 83–97. [CrossRef]
236. EU. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on Waste and Repealing Certain Directives. Official Journal of EU L 2008, 312. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02008L0098-20180705&from=SV (accessed on 9 November 2022).
237. Pinjing, H.; Fan, L.; Hua, Z.; Liming, S. Recent Developments in the Area of Waste as a Resource, with Particular Reference to the Circular Economy as a Guiding Principle. *Issues Environ. Sci. Technol.* **2013**, *37*, 144–161.
238. Nikolaou, I.E.; Jones, N.; Stefanakis, A. Circular Economy and Sustainability: The Past, the Present and the Future Directions. *Circ. Econ. Sustain.* **2021**, *1*, 1–20. [CrossRef]
239. Traditional Rice. Available online: https://it.lakpura.com/pages/traditional-rice?shpxid=7f0e5626-b366-4d60-9fd0-312089d431ff (accessed on 29 November 2022).
240. Jayaneththi.Blogspot.Com. Available online: http://jayaneththi.blogspot.com/2011/03/trunk-of-rubber-tree.html (accessed on 3 January 2023).
241. Fu, F.; Wang, Q. Removal of Heavy Metal Ions from Wastewaters: A Review. *J. Environ. Manag.* **2011**, *92*, 407–418. [CrossRef]
242. Wang, L.; Templer, R.; Murphy, R.J. High-Solids Loading Enzymatic Hydrolysis of Waste Papers for Biofuel Production. *Appl. Energy* **2012**, *99*, 23–31. [CrossRef]