energies

Review

Overview of Biomass-to-Energy Supply and Promotion Policy in Taiwan

Yu-Ru Lee [1] and Wen-Tien Tsai [2,*]

[1] Graduate Institute of Environmental Management, Tajin University, Pingtung 907, Taiwan
[2] Graduate Institute of Bio Resources, National Pingtung University of Science and Technology, Neap Township, Pingtung 912, Taiwan
* Correspondence: wttsai@mail.npust.edu.tw

Abstract: During the past two decades, Taiwan's average dependence on imported energy was 97.6%, thus pushing the government to promote the indigenous energy supply. In this regard, the energy policy and regulatory incentives for promoting biomass-to-energy or bioenergy have been recently established. In this work, the updated statistics of biomass-derived waste and energy supply from biomass during the period of 2005–2021 were analyzed using national/official reports. It was found that the annual agricultural waste amounts in Taiwan ranged from 4.5 to 5.2 million metric tons, and about 80% of those were generated from rice-derived residues (rice straw and rice husk) and livestock/poultry-derived waste (manure). In addition, a decreasing trend was observed in the indigenous bioenergy supply, mostly from the solid-type biomass resources, including waste wood, rice husk, and sugarcane bagasse. In order to expand bioenergy diversification, the central competent authorities, including the Ministry of Economic Affairs (MOEA), Council of Agriculture (COA), and Environmental Protection Administration (EPA), have announced the relevant policies for bioenergy promotion under the authorization of acts. Among them, the Renewable Energy Development Act is the legal foundation for promoting bioenergy and its industry development through economic incentives like feed-in-tariff (FIT), installation supports (or subsidies), and electrical grid connection.

Keywords: energy supply; biomass-to-energy; bioenergy; promotion policy; regulatory incentive

Citation: Lee, Y.-R.; Tsai, W.-T. Overview of Biomass-to-Energy Supply and Promotion Policy in Taiwan. *Energies* **2022**, *15*, 6576. https://doi.org/10.3390/en15186576

Academic Editors: Charisios Achillas and Christos Vlachokostas

Received: 24 August 2022
Accepted: 4 September 2022
Published: 8 September 2022

1. Introduction

In order to reduce the emissions of carbon dioxide (CO_2) from existing fossil fuel plants, biomass or lignocellulose-based waste was used directly as a solid fuel or as a supplement to fossil fuels. Although the traditional combustion of solid-type biomass in open fires or cook stoves could have an impact on human health and the environment, bioenergy for power generation (or electricity) and transport fuels (i.e., bioethanol and biodiesel) has been growing quickly in recent years, mainly because of the policy support and regulatory compliance. Based on the report by the International Energy Agency (IEA) [1], bioenergy (or biomass energy) accounts for about one-tenth of the total primary energy supply around the world, implying that it is an important source of renewable energy. However, the most significant drawback for the biomass is the small energy density, because of its relatively high moisture content, inorganic constituent (i.e., ash), and non-carbon elements (i.e., sulfur, nitrogen, and chlorine) involved [2]. In addition, biomass is likely to absorb moisture (i.e., hygroscopic) even when it has been dried, thus making extended storage difficult and increasing the pretreatment requirements (e.g., shredding, screening, and compaction) for energy use [3].

In Taiwan, the dependence on imported energy over the past two decades ranged from 97.44 to 97.88% [4], showing a shortage of self-produced energy in this country. With industrial and social development, the total energy supply went from 101.88 million kiloliters of oil equivalent (KLOE) in 2000 to 143.97 million KLOE in 2021 [4]. Of this value in 2021, indigenous energy supply only contributed 2.27%. In contrast, imported energy supply accounted for 97.73%, which mostly included fossil fuels like coal, petroleum oil, and natural gas. However, fossil fuel combustion has resulted in significant emissions of greenhouse gas (GHG) in Taiwan [5]. In order to reduce the dependence on imported energy supply as well as to mitigate GHG emissions, the Taiwanese government has been actively promoting renewable energy development to increase the indigenous energy supply for electricity and heat generation in the energy and industrial sectors [6]. For example, the power generation from municipal solid waste (MSW) incineration plants equipped with combined heat and power (CHP) has increased from 3054 gigawatt-hour (GWh) in 2005 to 3604 GWh in 2021 through revamping projects and operational improvements [7]. Moreover, the overall energy efficiencies of MSW incineration plants were increased by feeding unattended/fewer priorities biomass residues (e.g., drift wood and thinned fruit/street tree twigs) with higher calorific values. The overall energy efficiencies thus indicated an increasing trend from 16.65% in 2011 to 18.44% in 2021. Obviously, the energy supply from local biomass and wood-based waste may be an option for the diversification and low carbon on the supply side.

As mentioned above, diversification of the energy supply with indigenous energy sources is very critical to Taiwan. However, this issue has not been addressed in the literature, but more noticeably, it is also important for many countries to develop biomass energy. Therefore, this paper reports an updated overview of Taiwan's energy supply from biomass (e.g., spent mushroom compost and crop residues) and lignocellulose-based waste (e.g., waste wood and drift wood) and its relevant promotion policies and regulations. First, the status of Taiwan's energy supply and biomass/waste-to-energy supply during the period of 2005–2021 is presented. The updated statistics of energy supply, the reported amounts of agriculture-derived waste, and biomass-to-energy are obtained from national reports and/or official websites [4,7–10], which were compiled by the Council of Agriculture (COA) and the Ministry of Economic Affairs (MOEA). Subsequently, the policies for promoting energy supply from biomass are addressed in response to the international trends and national situations [6]. Finally, the regulatory measures and incentives for promoting energy supply from indigenous biomass in Taiwan are summarized to echo its significant progress in recent years, especially in the modified feed-in-tariff (FIT) scheme.

2. Data Mining

In order to describe the data mining in this work, Figure 1 depicts a conceptual diagram to show the important steps and significance of the article. The main procedures are briefly stated below.

- Baseline data of the generated amounts of agricultural waste and its energy use

The updated data on the statistics of agricultural waste generation and biomass-to-energy in Taiwan were extracted from the official handbook/yearbook [4,7–10], established by the COA and MOEA.

- Environmental and energy policies for promoting biomass-to-energy

Concerning biomass-to-energy or energy recovery from waste in Taiwan [6], information about the environmental and energy policies for these issues was accessed on the websites of EPA [11] and MOEA [12], respectively.

- Regulatory measures and incentives for promoting biomass-to-energy

In order to echo the environmental and energy policies for promoting biomass-to-energy, regulatory measures and incentives have been established by the official laws (or acts) and their relevant regulations, which were compiled by the Ministry of Justice (MOJ) [13].

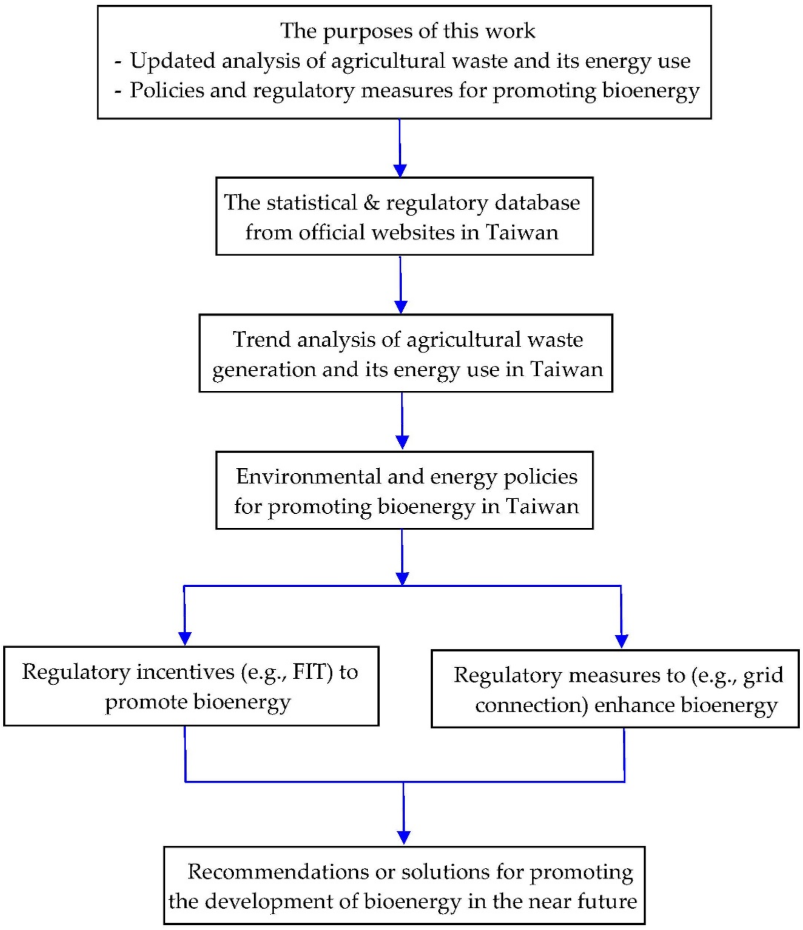


Figure 1. A conceptual flowchart for the major steps of this work.

3. Status of Biomass-to-Energy in Taiwan

3.1. Status of Agricultural Waste Generation

In general, the agricultural sector comprises establishments primarily engaged in growing crops/fruits/vegetables/flowers, raising animals, logging wood, and harvesting fish and other animals from a farm, ranch, or their natural habitats. Agricultural waste can be defined as unwanted waste or residue produced from agricultural activities. Table 1 summarizes the statistics of biological waste generation from the agricultural sector since 2010 [8], grouped into five categories. The significant notes are summarized below:

- In brief, the agricultural waste generation in Taiwan ranged from 4.5 to 5.2 million metric tons. About 80% of that was from rice-derived residues (rice straw and rice husk) and livestock/poultry-derived waste (manure mainly produced from swine- and cattle-raising). Other significant agriculture-derived residues included spent mushroom compost, oyster shell, and fruit/vegetable residues.
- In order to expand the supply of indigenous biological waste, thinned fruit twigs and bamboo residue were grouped into the statistical items of agriculture-derived waste since 2020. As listed in Table 1, the amounts of thinned fruit twigs accounted for about 250 thousand metric tons, which were derived from a variety of subtropical/tropical fruits like banana, pineapple, citrus, longan, mango, guava, grape, and lichee [9]. In addition, bamboo residues may include bamboo branches, leaves, shoot apex, joint, skin, sawdust, and shoot shell [14]. According to the Forestry Statistics Yearbook [10], the area of bamboo forest amounted to about 191.6 thousand hectares, representing Taiwan's rich bamboo resources.
- Regarding the fishery-derived waste, it should include various scraps (e.g., head, tail, shell, internal organs, scale, leather, fin, and bone) after processing or eating fishes,

shellfishes, and other aquaculture animals. In Taiwan, the COA only provided the statistics of oyster shell in the fishery-derived waste, indicating a declining trend from 226 thousand metric tons in 2005 to 99 thousand metric tons in 2021. Because of its chemical composition (i.e., $CaCO_3$), this biological waste is not relevant to energy use.

Table 1. Statistics of biological waste generation from the agricultural sector in Taiwan [a].

Item	2010	2015	2016	2017	2018	2019	2020	2021
Agriculture-derived waste	1,931,212	2,123,990	2,083,533	2,229,001	2,495,628	2,292,389	2,676,130	2,460,717
Rice husk	290,201	316,346	317,555	350,810	389,959	358,242	350,146	312,174
Rice straw	1,451,011	1,581,732	1,587,776	1,754,049	1,949,796	1,791,211	1,750,729	1,560,870
Spent mushroom compost	190,000	225,912	178,202	124,142	155,873	142,935	156,487	175,975
Thinned fruit twigs	- [b]	-	-	-	-	-	247,396	248,282
Bamboo residue	-	-	-	-	-	-	171,372	163,416
Fishery-derived waste	226,272	131,196	123,966	139,068	128,574	116,352	118,734	99,312
Oyster shell	226,272	131,196	123,966	139,068	128,574	116,352	118,734	99,312
Livestock/poultry-derived waste	2,388,860	2,208,519	2,244,007	2,275,410	2,362,121	2,337,559	2,397,497	2,369,246
Manure	2,319,348	2,135,193	2,151,795	2,178,005	2,255,423	2,227,532	2,272,454	2,265,234
Post-slaughter waste	18,722	31,518	48,308	52,647	61,271	64,410	78,274	56,437
Dead livestock/poultry	50,790	41,809	43,904	44,759	45,427	45,617	46,769	47,575
Wholesale-market waste	131,011	29,436	28,673	29,285	31,703	25,099	23,512	21,189
Fruit/vegetable residue	127,596	26,382	25,599	26,554	28,848	22,593	21,331	18,433
Flower residue	1196	819	620	596	806	585	655	1076
Fishery residue	2219	2235	2454	2135	2049	1921	1526	1680
Food-processing waste	28,000	31,200	31,300	31,952	32,515	14,610	17,535	16,560
Total	4,705,355	4,524,341	4,511,479	4,704,716	5,050,541	4,786,009	5,233,408	4,967,023

[a] Source [8], unit: metric ton. [b] Not available in the current year.

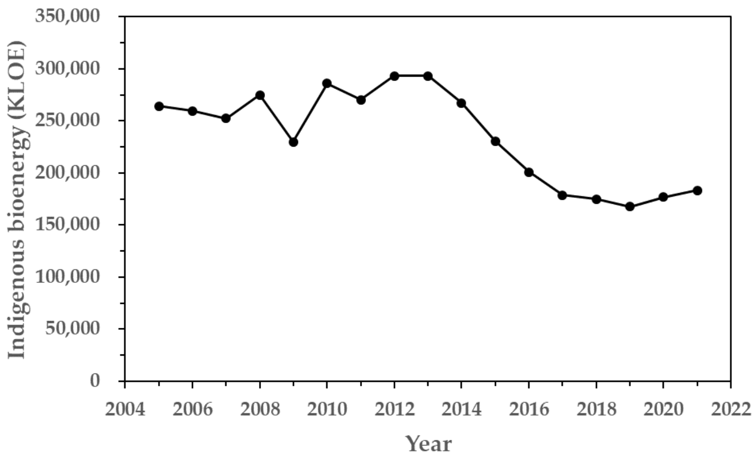
3.2. Status of Biomass-to-Energy

According to the definition by the Renewable Energy Development Act (REDA) in Taiwan [13], biomass energy or bioenergy refers to energy generated from the direct use or treatment of vegetation, biogas, and domestic organic waste. Lignocellulosic biomass like wood may be the largest biomass energy source. Other sources included crop residues, grassy and woody plants, residues from agricultural production (products derived from forestry, aquaculture, and livestock/poultry), oil-rich algae, spent cooking oil, kitchen waste, and the organic components of non-hazardous industrial waste such as sugarcane bagasse and pulp black liquor [15]. These resources can be used to produce a variety of energy forms, including biofuels (e.g., biodiesel and bioethanol), heat (or stream), and electricity. Table 2 lists the statistics of imported biomass-based fuels in Taiwan since 2005 [7]. Figure 1 depicts the variations in the energy supply from indigenous bioenergy, indigenous solid-type bioenergy, indigenous liquid-type bioenergy, and indigenous gas-type bioenergy, respectively [7]. Based on the statistical data on biomass-to-energy in Table 2 and Figure 2, some noticeable points are further summarized as follows:

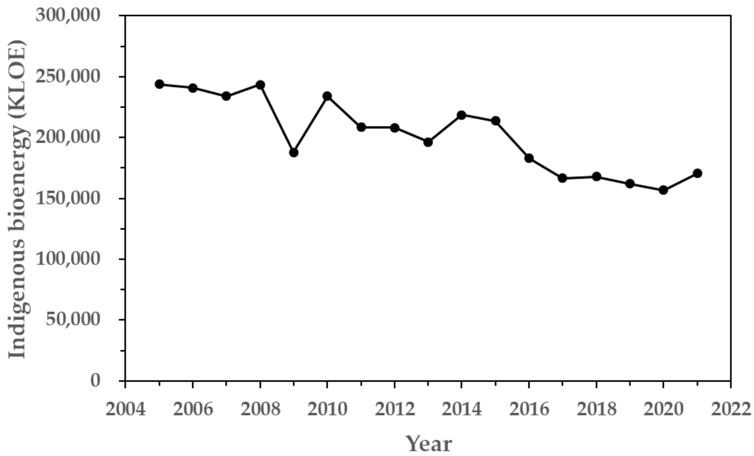
- As seen in Figure 2a, although the energy supply from indigenous biomass or bioenergy indicated a slight increase since 2019, the reduction from the highest value (293,275 KLOE) in 2013 has exceeded 37.4% in comparison with the value in 2021 (i.e., 183,508 KLOE). Obviously, indigenous bioenergy was mostly from indigenous solid biomass resources (Figure 2b), including waste wood and sugarcane bagasse. These solid-type biofuels were generally reused as auxiliary fuels in industrial boilers and heaters.
- As listed in Table 2, the imported energy from biomass has been supplied since the late 2010s, which mainly referred to the imported palm kernel shell for stream generation in the industrial use [16]. Because of the high price of palm kernel shell imported from Southeastern Asian countries in recent years, the imported energy supply has significantly decreased from about 9000 KLOE in 2018 (the highest) to close to zero in 2021.
- In Taiwan, waste cooking oil (WCO) has been reused as a feedstock for biodiesel production since 2006. Under the policy promotion, the supply amounts of biodiesel indicated a soaring growth from 1029 kiloliters in 2006 to 96,373 kiloliters in 2013 [7]. However, the users have complained about some issues, including fuel tank and filter clogging/plugging, ignition delay, and exhaust emissions at higher levels. The

Taiwanese government thus temporarily terminated the biodiesel blends (B2) promotion policy in May 2014. Since then, the B2 supply and consumption showed a rapid decline, as shown in Figure 2c. In order to continuously support WCO recycling in Taiwan, the vast majority of biodiesel by domestic production was exported to European (e.g., Spain) and Asian countries (e.g., South Korea).

- The policy for promoting the use of bioethanol and its domestic production plan started from 2007 [17]. Since then, limited gas stations in the metropolitan cities (i.e., 8 gas stations in Taiwan city and 6 gas stations in Kaohsiung city) provided E3 gasohol for all vehicles by subsidizing a discount rate at NT $1.0–2.0 per liter. However, the bioethanol in the E3 gasohol was completely imported because the commercial establishment of a new bioethanol plant in Taiwan was not profitable from the feasibility study. As listed in Table 2, the supply amounts of bioethanol indicated a decreasing trend, which could be attributed to the inconvenient refueling and insufficient incentives [17]. In the future, the bioethanol must be domestically produced from non-food lignocellulosic resources like crop residues (e.g., rice straw), kitchen waste (food waste), and wood chips.
- The variation in energy supply from indigenous gas-type bioenergy indicated a fluctuating pattern (Figure 2d). During the period of 2005–2014, it can be seen that the energy supply from biogas-to-power decreased mainly as a result of the depletion of landfill gas from sanitary landfill plants in Taiwan. However, the EPA and COA have jointly managed the applications of livestock (pig and cattle) farms for producing digestate and biogas-to-power from the anaerobic digestion (AD) process since 2015. Since then, it showed an upward trend in bioenergy by biogas-to-power.

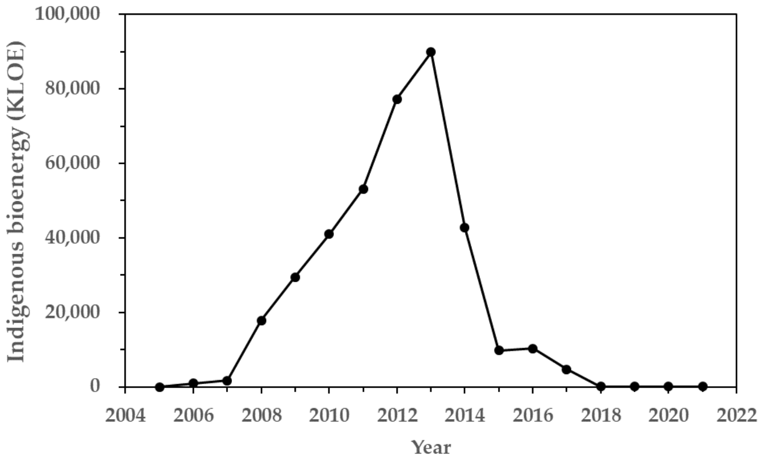


(**a**)

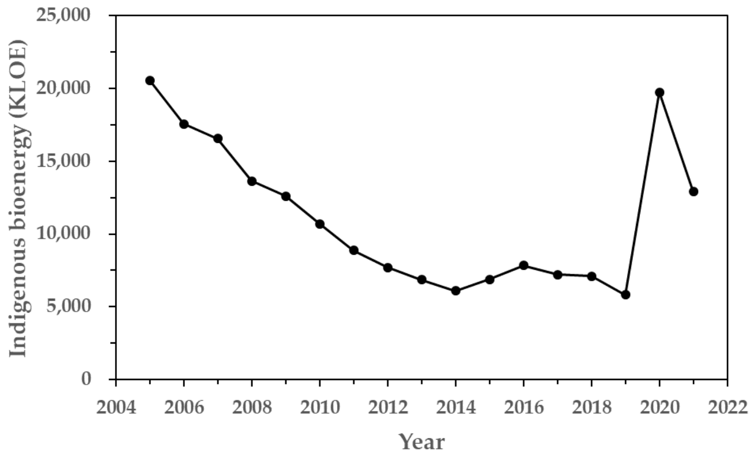


(**b**)

Figure 2. *Cont.*



(**c**)



(**d**)

Figure 2. Variations in energy supply from (**a**) indigenous bioenergy, (**b**) indigenous solid-type bioenergy, (**c**) indigenous liquid-type bioenergy, and (**d**) indigenous gas-type bioenergy [7].

Table 2. Statistics of imported biomass-based fuels in Taiwan [a].

Fuel Type	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Solid	0	0	0	0	0	0	0	0	0	0	0	0	0	8817	7443	4317	0
Liquid	0	0	70	14	55	125	69	139	113	99	84	94	83	70	70	56	42

[a] Source [7]; unit: kiloliters of oil equivalent (KLOE).

4. Policies for Promoting Biomass-to-Energy in Taiwan

4.1. Ministry of Economic Affairs (MOEA)

In April 2017, the Taiwanese government announced the “Guidelines for Energy Development” [6], which was under the authorization of the Energy Management Act. This Guideline focused on the four core values, including energy security, green economy, environmental sustainability, and social equity, for achieving the goals of nuclear-free homeland and 20% renewable energy power by 2025. Among these guiding principles, the most important issue is to expand the renewable energy (RE) installation, strengthen the incentives for green (or low-carbon) energy development, establish the friendly environment for RE development, and take the environmental and ecological protection into account. The Guideline also encouraged the installation of distributed power plants that will contribute to the regional balance on the supply and demand sites so as to accelerate the RE development, including biomass energy like biogas-to-power and biomass-to-power.

In addition, the central competent authority (MOEA) further announced the "Energy Transition White Paper" in November 2020 [12] and "Key Indicators for Energy Transition" in July 2021. Among these eleven key indicators, the No. 4 indicator is to promote RE development, which was based on the installed capacity. In this regard, the MOEA set 813 megawatts (MW) as the target of bioenergy (including biogas-to-power, biomass-to-power, and waste-to-power) by 2025, which increased by 13.6% in comparison with the installed capacity of 716 MW in 2020.

4.2. Council of Agriculture (COA)

Although the value of agricultural production is comparatively smaller than other industries, it is vital to socio-economic development and food security, and is also extremely critical to coping with environmental sustainability. In addition, the agricultural sector is a significant contributor to global warming and the reduction in GHG emissions, especially in methane and nitrous gas. In this regard, it could play an important role in climate change mitigation. In Taiwan, the COA is the competent authority on agricultural (crops, fruits, vegetables, and flowers), forestry, fishery, animal husbandry, and food affairs in Taiwan. In recent years, the COA's policies relevant to environmental and energy issues aimed at the promotion of green energy (solar PV system built on the covers of agricultural facilities) and the circular economy for developing RE (e.g., biogas-to-power) and organic farming.

Regarding the energy supply from indigenous biomass and agricultural waste, the COA recently focused on the policies for promoting biogas-to-power and waste-to-fuel. The former referred to the AD process of swine manure for the production of biogas, which will be further reused as an energy source to generate electricity [18]. In order to enhance the biogas generation as well as to treat food waste (kitchen waste), the joint-venture project under the support by the COA and EPA has been performed in the co-fermentation system, showing an increase of about 50% for methane generation. On the other hand, the carbon-negative policies for reusing waste wood as material and energy resources are beneficial to the mitigation of GHG emissions [19]. Therefore, the COA also encouraged the reuse of wood-based residues (e.g., wood chips, drift wood, fruit tree trimmings, and spent mushroom compost) as feedstocks for producing solid fuels or densified biomass fuels (DBFs). According to the legal definition, waste wood may be grouped into industrial waste because it could be generated from industrial/commercial activities like wood dust from wood-processing facilities and wooden pallet from imported commodities. Moreover, it should be noted that the industrial wood-based waste reused as a biomass fuel must be non-hazardous.

4.3. Environmental Protection Administration (EPA)

Over the past two decades, waste-to-energy or energy recovery from waste has been listed as one of the circular economy policies in many countries. This approach not only reduces the environmental burden from waste management, but also generates green energy (electricity and/or heat) and mitigates the emissions of GHG from disposal sites. In Taiwan, the central competent authority (EPA) started the "Multiple Waste Treatment Plan" from 207 [11], which focused on the policies for promoting waste-to-energy, including biomass-based solid recovered fuel (SRF), waste cooking oil for producing biodiesel or other products, and biological treatment of food waste (or kitchen waste) for biogas-to-power. For example, SRF features its high calorific value and small contents of ash and sulfur, leading to its widespread applications in co-incineration plants such as industrial boilers [20–22]. In March 2020, the EPA further promulgated the regulation ("Co-firing Ratios and Component Standards for Fuel Used in Stationary Pollution Sources") under the authorization of the Air Pollution Control Act, which aims at promoting the use of primary solid biomass and other fuels as energy sources. Herein, primary solid biomass refers to forestry or wood residue without chemical treatment, gluing, or surface coating procedures. Table 3 summarizes the quality standards of primary solid biomass fuel. Table 4 further listed the reported amounts of industrial biomass-derived waste generation in Taiwan [23], which was under the authorization of the Waste Management Act. It indicated a significant increase in kitchen waste, animal-derived residue, plant-derived residue, waste wood, and textile sludge. Moreover, the reported amounts of kitchen waste from industrial enterprises showed a soaring increase during the period 2015–2018, which could be attributed to the regulatory requirements (e.g., mandatory reporting) owing to the food safety (or tainted oil) scandal in 2014 [24].

Table 3. Quality standards of primary solid biomass fuel in Taiwan.

Quality Item	Limit	Unit	Sample Basis
Lower calorific value	≥3000	kcal/kg	Wet basis
Clorine content	≤0.1	wt%	Dry basis
Sulfur content	≤0.05	wt%	Dry basis
Mercury content	≤0.1	mg/kg	Dry basis
Lead content	≤20	mg/kg	Dry basis
Cadmiun content	≤1	mg/kg	Dry basis

Table 4. Reported amounts of industrial biomass-derived waste generation potential for bioenergy production or fuel reuse in Taiwan [23].

Industrial Biomass-Derived Waste (Waste Reuse Code)	2015	2016	2017	2018	2019	2020	2021
Sugarcane bagasse (R-0102)	24,575	13,836	23,183	14,870	15,993	19,718	23,554
Wine-manufacturing residues (R-0105)	149,207	152,061	139,973	142,029	127,453	103,198	128,616
Kitchen waste (R-0106)	155	1850	42,040	64,792	70,211	73,549	66,169
Animal-derived residue (R-0119)	19,399	26,306	30,362	36,264	46,400	48,508	54,684
Plant-derived residue (R-0120)	37,018	38,162	42,525	42,607	51,039	59,699	67,178
Waste bleaching earth (R-0404)	13,931	6276	6397	6188	6670	6145	5626
Waste diatomaceous earth (R-0405)	6280	6505	5677	5395	6039	5938	6755
Waste wood (R-0701)	57,099	51,705	60,476	65,932	64,329	71,922	96,919
Sugar-manufacturing mud (R-0901)	24,367	17,400	20,586	17,138	21,308	23,074	23,156
Food-processing sludge (R-0902)	49,739	54,205	64,215	62,423	65,370	49,996	63,499
Brewing sludge (R-0903)	12,461	12,676	12,751	13,598	12,546	10,577	9443
Pulp sludge (R-0904)	3,883,231	377,654	430,424	413,723	398,836	402,126	462,711
Textile sludge (R-0906)	26,123	42,509	47,358	45,264	53,837	53,734	61,243
Waste edible oil (R-1702)	11,278	15,523	16,085	3772	4119	15,558	14,502

5. Regulatory Incentives and Measures for Biomass-to-Energy in Taiwan

Although the use of biomass residues for energy purposes possesses many benefits such as being carbon-neutral (renewable), waste reduction, and reduced dependence on fossil fuels, the major weakness and threats are often encountered from a practical viewpoint. First, the construction and operating cost of a biomass-to-energy plant could be expensive in comparison with traditional forms of power generation. Moreover, the transportation and pretreatment costs of biomass materials may be an expensive task owing to their high water content and low energy density. Depending on the seasonal production in the agricultural sector, the variations in biomass supply will present a potential challenge for the stable operation of biomass energy plants. Like fossil fuels, burning biomass fuels also releases various air pollutants such as carbon monoxide (CO), nitrogen oxides (NOx), particulates, and volatile organic compounds (VOCs), which should comply with local air pollution control regulations.

In Taiwan, the legal foundation for promoting RE and its industry development is the REDA, which was first passed on 8 July 2009 and revised on 1 May 2019. Although the data on the energy supply by indigenous biomass-to-energy in the past fifteen indicated a declining trend (Figure 2a), the production of indigenous bioenergy slightly increased from 167,760 KLOE in 2019 to 183,508 KLOE in 2021 [7]. This progressive bioenergy development can be attributed to the promotional incentives and measures, including feed-in-tariff (FIT), installation supports (or subsidies), and electrical grid connection [13]. Regarding the FIT mechanism and trend variation in Taiwan, there were some articles that discussed and/or reviewed this scheme [25–27]. Basically, the FIT scheme will provide long-term (20 years) financial stability for compensating the RE investors at a guaranteed rate. In Taiwan, the FIT rates for solar PV power and wind power showed a slight decline because of the market expansion and cost reduction in a PV panel/wind turbine. In order to promote other RE types in the limited domestic market, their FIT rates, however, indicated an increasing trend. Figure 3 depicts the variations in the FIT rates for biomass-to-power and waste-to-power since 2010 [28]. Herein, the waste-to-power referred to the power generation from general waste and non-hazardous industrial waste. As shown in Figure 3, the FIT rates of biomass-to-power with the AD process have shown a rising trend, especially in the period from 2016 to 2017. The FIT rates significantly increased from 3.9211 NTD$/kW-h (≈0.131 US$/kW-h) in 2016 to 5.0087 NTD$/kW-h (≈0.167 US$/kW-h) in 2017. In order to expand the biomass energy diversification, the central competent authority (i.e., MOEA) further announced the FIT rate (i.e., 5.1407 NTD$/kW-h) for the waste-to-power from agricultural residues since 2022.

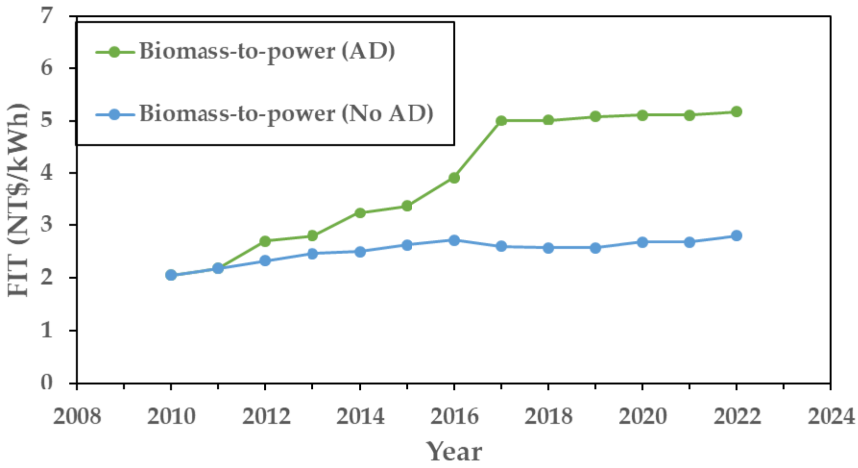


Figure 3. Variations in feed-in-tariff (FIT) rates for biomass-to-power and waste-to-power since 2010 [28].

According to the revised REDA in 2019, the important features in connection with biomass-to-power have been addressed in a previous study [29]. Under the authorization of the REDA (Article 11), the MOEA shall provide relevant reward encouragement within a certain period for the purpose of demonstration in the preliminary stage of RE power generation facilities and energy storage facilities with development potential. In this regard, the "Directions for Promotion Plan Subsidizing Biogas Power Generation System" were announced by the MOEA in 2013. This promotion regulation focused on the biogas-to-power system, including the biogas purification unit, power generator set, and related power distribution facility. The biogas was generated from the treatment of general waste (MSW), general industrial waste, sewage, or sludge in the AD process. The new biogas-to-power system with a total installation capacity between 30 kilowatts (kW) and 500 kW can apply a maximum of NT$ 45,000/kW subsidies from the MOEA, but the total amount of the grant must be below 50% of the total installation fee. In order to plant energy crops for producing biomass fuels, the reward expenses for the exploitation of fallow land or idle land will be financed by the Agricultural Development Fund. The regulation governing such reward eligibility, conditions and subsidy methods, and schedule shall be prescribed by the MOEA in conjunction with the COA under Article 13 of this Act. When we consider reducing the environmental effects and costs caused by the consolidation (collection and transportation) of agricultural residues in the origin, the restriction on the establishment of the biomass-to-power plants with combustion type in an industrial park by Article 15 seemed to be not beneficial to biomass energy development. The MOEA is forewarning the revision of the REDA in July 2022.

6. Conclusions and Recommendations

Biomass, as a clean and renewable energy source, has the potential for bioenergy production in Taiwan ranging from different bioresource origins and agricultural sectors. This energy supply is playing an important role in the climate change mitigation and biocircular economy development. This paper summarized the potential and possibilities of agricultural residues (approximately 5.0 million metric tons per year) for bioenergy production through thermochemical (e.g., cogeneration and combustion) and biochemical (e.g., anaerobic digestion) processes. In order to expand the energy supply diversification using indigenous biomass, the Taiwanese government also provided the regulatory incentives and measures for promoting biomass-to-energy or bioenergy under the REDA. The central competent authority (i.e., MOEA) further announced the FIT rate (i.e., 5.1407 NTD$/kW-h or 0.175 US$/kW-h) for waste-to-power from agricultural waste (or residues) in 2022.

In 2020, the total installed capacity of biomass energy (including biogas-to-power, biomass-to-power, and waste-to-power) in Taiwan was 716 megawatts (MW). In order to reach the goal of 813 MW by 2025, some recommendations or solutions are addressed below:

- Expanding the indigenous bioenergy sources, including bamboo residues, spent mushroom compost, biological sludge, thinned fruit twigs, and cattle manure.
- Deregulating the restriction on the establishment of biomass-to-power plants in industrial parks. Furthermore, agricultural lands, especially in livestock/poultry farms, can be permitted to establish biogas-to-power systems.
- Promoting the use of biomass-based solid recovered fuel (SRF) in industrial boilers and heaters. In addition, co-firing with the addition of biomass as a partial substitute fuel in high-efficiency coal-fired power plants may be performed to mitigate the emissions of GHGs.
- Increasing the FIT rates of biomass-to-power because of the increased capital and operating costs in recent years.
- Promulgating the specific agricultural waste (rice-derived residues) management regulations to conduct a sustainable material management priority through recycling and biomass-to-energy technologies like gasification.

Author Contributions: Conceptualization, W.-T.T. and Y.-R.L.; data collection, W.-T.T.; data analysis, W.-T.T.; writing—original draft preparation, W.-T.T.; writing—review and editing, W.-T.T. and Y.-R.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Bioenergy. International Energy Agency, IEA. Available online: https://www.iea.org/fuels-and-technologies/bioenergy (accessed on 2 August 2022).
2. Basu, P. *Biomass Gasification, Pyrolysis and Torrefaction*, 2nd ed.; Academic Press: London, UK, 2013; pp. 47–86.
3. De Jong, W. Physical pretreatment of biomass. In *Biomass as a Sustainable Energy Source for the Future: Fundamentals of Conversion Processes*; de Jong, W., van Ommen, J.R., Eds.; John Wiley & Sons: Hoboken, NJ, USA, 2015; pp. 233–267.
4. Ministry of Economic Affairs (MOEA, Taiwan). *Energy Statistics Handbook-2021*; MOEA: Taipei, Taiwan, 2022.
5. Environmental Protection Administration (EPA). *Taiwan Greenhouse Gases Inventory*; EPA: Taipei, Taiwan, 2021.
6. Guidelines on Energy Development. Bureau of Energy, Ministry of Economic Affairs, Taiwan. Available online: https://www.moeaboe.gov.tw/ECW/english/content/ContentDesc.aspx?menu_id=2042 (accessed on 2 August 2022).
7. Energy Statistics. Bureau of Energy, Ministry of Economic Affairs, Taiwan. Available online: https://www.moeaboe.gov.tw/ECW/english/content/SubMenu.aspx?menu_id=8706 (accessed on 2 August 2022).
8. Green National Income Account—Agricultural Solid Waste. Council of Agriculture, Taiwan. Available online: https://agrstat.coa.gov.tw/sdweb/public/common/Download.aspx (accessed on 16 August 2022).

9. Agriculture Statistics Yearbook. Council of Agriculture, Taiwan. Available online: https://agrstat.coa.gov.tw/sdweb/public/book/Book.aspx (accessed on 16 August 2022).
10. Forestry Statistics Yearbook. Forestry Bureau, Council of Agriculture, Taiwan. Available online: https://www.forest.gov.tw/0000110 (accessed on 16 August 2022).
11. Multiple Waste Treatment Plan. Environmental Protection Administration, Taiwan. Available online: https://www.ey.gov.tw/Page/448DE008087A1971/8f06d8fb-0864-41b3-911e-a8e31ed16b60 (accessed on 25 July 2022). (In Chinese)
12. Energy Transition White Paper. Ministry of Economic Affairs, Taiwan. Available online: https://www.moeaboe.gov.tw/ECW/populace/content/ContentLink2.aspx?menu_id=48 (accessed on 25 July 2022). (In Chinese)
13. Renewable Energy Development Act. Ministry of Economic Affairs, Taiwan. Available online: https://law.moj.gov.tw/ENG/LawClass/LawAll.aspx?pcode=J0130032 (accessed on 25 July 2022).
14. Gu, X.; Deng, X.; Liu, Y.; Zeng, Q.; Wu, X.; Ni, Y.; Liu, X.; Wu, T.; Fang, P.; Wang, B.; et al. Review on comprehensive utilization of bamboo residues. *Trans. Chin. Soc. Agri. Eng.* **2016**, *32*, 236–242.
15. Tsai, W.T.; Hsien, K.J. An analysis of cogeneration system utilized as sustainable energy in the industrial sector in Taiwan. *Renew. Sustain. Energy Rev.* **2007**, *11*, 2104–2120. [CrossRef]
16. Tsai, W.T. Benefit analysis and regulatory actions for imported palm kernel shell as an environment-friendly energy source in Taiwan. *Resources* **2019**, *8*, 8. [CrossRef]
17. Lee, Y.R.; Tsai, W.T. Bottlenecks in the development of bioethanol from lignocellulosic resources for the circular economy in Taiwan. *Fermentation* **2021**, *7*, 131. [CrossRef]
18. Lee, Y.R.; Tsai, W.T. Valorization of value-added resources from the anaerobic digestion of swine-raising manure for circular economy in Taiwan. *Fermentation* **2020**, *6*, 81. [CrossRef]
19. Tsai, W.T. Carbon-negative policies by reusing waste wood as material and energy resources for mitigating greenhouse gas emissions in Taiwan. *Atmosphere* **2021**, *12*, 1220. [CrossRef]
20. Garg, A.; Smith, R.; Hill, D.; Simms, N.; Pollard, S. Wastes as co-fuels: The policy framework for solid recovered fuel (SRF) in Europe, with UK Implications. *Environ. Sci. Technol.* **2007**, *41*, 4868–4874. [CrossRef] [PubMed]
21. Yi, S.; Jang, Y.C. Life cycle assessment of solid refuse fuel production from MSW in Korea. *J. Mater. Cycles Waste Manag.* **2018**, *20*, 19–42. [CrossRef]
22. Yang, W.S.; Lee, Y.J.; Kang, J.G.; Shin, S.K.; Jeon, T.W. Assessment of quality test methods for solid recovered fuel in South Korea. *Waste Manag.* **2020**, *103*, 240–250. [CrossRef] [PubMed]
23. Industrial Waste Reporting and Management Information System. Environmental Protection Administration, Taiwan. Available online: https://waste.epa.gov.tw/RWD/Statistics/?page=Month1 (accessed on 12 August 2022). (In Chinese)
24. Tsai, W.T. Mandatory recycling of waste cooking oil from residential and commercial sectors in Taiwan. *Resources* **2019**, *8*, 38. [CrossRef]
25. Wang, K.M.; Cheng, Y.J. The Evolution of feed-in tariff policy in Taiwan. *Energy Strategy Rev.* **2012**, *1*, 130–133. [CrossRef]
26. Chen, C.C. An examination on the feed-in tariff policy for renewable electricity: Taiwan's case example. *Int. J. Environ. Sci. Technol.* **2014**, *11*, 1223–1236. [CrossRef]
27. Tsai, WT Feed-in tariff promotion and innovative measures for renewable electricity: Taiwan case analysis. *Renew. Sustain. Energy Rev.* **2014**, *40*, 1126–1132. [CrossRef]
28. Energy Regulations—Renewable Energy. Bureau of Energy, Ministry of Economic Affairs, Taiwan. Available online: https://www.moeaboe.gov.tw/ECW/populace/Law/LawsList.aspx?kind=6&menu_id=3302 (accessed on 25 July 2022).
29. Tsai, W.T. Overview of wind power development over the two past decades (2000–2019) and its role in the Taiwan's energy transition and sustainable development goals. *AIMS Energy* **2021**, *9*, 342–354. [CrossRef]