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Benefit Analysis and Regulatory Actions for Imported Palm Kernel Shell as an Environment-Friendly Energy Source in Taiwan

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Abstract: In response to the lack of locally natural sources and the environmental concerns about greenhouse gas (GHG) emissions, using a wide variety of biomass residues as energy sources has attracted much attention in the past two decades. The purpose of the case study was to examine the energy use of imported palm kernel shell (PKS) in Taiwan, which has generated superheated steam for the end users in the industrial sector. In this work, characterizing the thermochemical properties of imported PKS (including proximate analysis, elemental analysis and calorific value) was first conducted by the standard test methods. Based on the statistics of imported PKS and the method developed by the Intergovernmental Panel on Climate Change (IPCC), the preliminary benefit analysis of PKS-to-energy was further addressed in the paper to verify its equivalent GHG emission mitigation. The results showed the annual benefit of equivalent GHG mitigation of about 78,647 metric tons (using annual imported PKS of 60,000 metric tons on an average). In addition, the economic benefit for purchasing PKS in the industrial boilers can gain the cost-down at approximately NT$60,000,000 (US$2,000,000) in comparison with that of fuel oil. Furthermore, the regulatory measures for upgrading PKS-to-energy and countermeasures for controlling air pollutant emissions from PKS-to-energy facilities were briefly summarized to create another circular economy. Finally, some technological recommendations have been addressed to upgrade the added values of imported PKS in Taiwan.

Keywords: palm kernel shell; biomass-to-energy; boiler; feed-in-tariff; benefit analysis; regulatory measure & countermeasure

1. Introduction

Taiwan is an island country with a high population density (i.e., about 650 people per km^2) and a lack of natural resources. For example, its dependence on imported energy ranged from 97 to 98% in the past two decades. In 2017, the energy supply can be divided into two categories. One belongs to indigenous energy, which contributed 3.0 million kiloliters of oil equivalent (KLOEs) or 2.02% [1]. Another is the imported energy, which occupied 97.98%, or 143.6 million KLOEs. By classifying them with energy forms, their contributions were given as follows [1]: coal 30.17%, oil 48.45% natural gas 15.15%, hydro power 0.36%, solar photovoltaic (PV) and wind power 0.22%, solar thermal heat 0.08%, biomass and waste-to-energy (WTE) 1.15%, and nuclear power 4.43%. According to the definition of biomass energy by the Renewable Energy Development Act (REDA) passed in 2009 [2], it refers to the energy generated from direct use or treatment of vegetation, marsh gas and domestic organic waste. Over the years, the Taiwan government intended to balance the development in energy security (diversification), green economy, and environmental sustainability, thus adopting several regulatory, financial and subsidiary measures to promote the renewable energy use and also mitigate greenhouse gas (GHG) emissions. The renewable energy supply thus increased from 1.03 million KLOEs in 1997 to 2.64 million KLOEs in 2017, showing an average annual growth rate of around 4.8% [1].

Biomass-to-energy has attracted much attention since the Kyoto Protocol of 1997. This transition from fossil resources to renewable resources should be motivated by the environmental issues, such as global warming and air quality deterioration. As compared to coal, the biomass feedstock generally contains relatively low contents of sulfur (S) and toxic metals (e.g., [3]), thus reducing the emissions of air pollutants such as sulfur oxides (SO_x) and mercury. More significantly, biomass is considered as a renewable material with having higher heating values (HHV) from 15 to 21 MJ/kg (dry basis) [4]. Therefore, there is an increasing interest in the use of solid biomass for energy production in the industrial utility boilers and coal-fired power plants [5]. In Taiwan, part of agricultural residues were burned at special waste-to-energy (WTE) plants that produce superheated steam in the boilers, or generate electricity via the combined heat and power (CHP) or cogeneration system [6]. These biomass biofuels are mostly derived from indigenous by-products or residues in the agricultural sector. However, the locally available sources may be not cost-effective due to the feedstock transportation and pretreatment [7], or unable to meet domestic consumption need due to the limited biomass amounts, thus suggesting that these biomass resources need to be supplied by foreign imports.

The agro-industrial sector in Southeast Asian countries generates significant amounts of biomass residues or wastes. Among them, palm oil mills significantly produce enormous amounts of empty fruit bunches (EFB), palm kernel shells (PKS), and oil palm fibers (OPF). Herein, PKS is a derived waste produced during the extraction of palm oil by pressing the palm nut. Therefore, it contains residual palm oils, which account for its slightly larger HHV than other lignocellulosic biomass. On the other hand, it is a good quality biomass fuel due to its uniform size distribution, easy handling, easy crushing, and low moisture content. It means that PKS and PKS-derived char (or charcoal) can be directly combusted or readily co-fired with coal in boilers as well as cement kilns for steam generation or reused as an auxiliary fuel [8–14]. Based on its low cost, rich abundance, less carbon emission and high heating value, large amounts of PKS were imported by the Taiwan's end-users to be the most promising and potential renewable feedstock for the energy use in recent years. The primary use of PKS is used as an auxiliary fuel in the industrial boilers.

Based on the abovementioned background, the objectives of this paper were to characterize the thermochemical properties of imported PKS, and analyze the variations of imported PKS in Taiwan. Using the thermochemical and statistical data, its preliminary benefit analysis of PKS-to-energy was addressed in the paper to verify its equivalent CO_2 emission mitigation. Finally, the regulatory measures for upgrading PKS-to-energy and countermeasures for controlling air pollutant emissions from PKS-to-energy facilities were briefly summarized to create another circular economy in Taiwan.

2. Material and Methods

2.1. Thermochemical Characterization Analyses of PKS

In this work, the thermochemical characterization analyses of imported PKS, including proximate analysis, elemental analysis and higher heating value (HHV), were performed in duplicate. According to the standard methods set by the Environmental Analysis Laboratory, the proximate analysis of the received PKS sample was used to determine the contents (wt. %) of moisture, combustibles, and ash. The moisture was determined by heating the sample at about 105 °C for at least 2 h. The ratio of weight loss to its initial sample weight is defined as its moisture content. The determination of ash content was similar to the moisture where the PKS sample was burnt in the muffle furnace at about 750 °C for 3 h. The combustibles content was determined by subtracting the weight percentages of moisture and ash from 100%. Regarding the elemental analysis, it refers to the contents of organic elements except for its moisture and inorganic constituents (ash) [15]. Using a sample mass (1–3 mg), its elemental concentrations, including carbon (C), hydrogen (H), nitrogen (N), sulfur (S) and oxygen (O), were determined in duplicate by an elemental analyzer (vario EL III; Elementar Co., Langenselbold, Germany). On the other hand, the heating value of dried PKS sample was obtained by an adiabatic calorimeter (CALORIMETER ASSY 6200; Parr Instrument Co., Moline, IL, USA).

2.2. Statistical Database and Its Environmental Benefit Analysis Using PKS as Biomass Fuel

In order to analyze the variations of imported PKS and environmental benefits using it as biomass fuel in Taiwan, the statistical data and methods in the case study were briefly summarized below.

2.2.1. Activity (Statistics and Status) of Imported PKS

In Taiwan, there is no production for palm oil because of the climatic factors. Therefore, the amounts of PKS totally depended on imports, especially from Southeast Asian countries. The updated data on the statistical amounts of imported PKS in Taiwan can be obtained from the official website, which was compiled by the Customs Administration of the Ministry of Finance [16].

2.2.2. Environmental Benefit Analysis of PKS-to-ENERGY

In this work, the default emission factors (DEF), developed by the Intergovernmental Panel on climate Change (IPCC) [17], were adopted to analyze the environmental benefit analysis using PKS as biomass fuel based on the GHG emission mitigation.

2.2.3. Regulatory Measures for Governing PKS-to-Energy

The information about the regulatory measures for governing PKS-to-energy was accessed on the official websites, which include the imported tariff issues by the Ministry of Finance, the FIT rates by the Ministry of Economic Affairs, and the air pollutant emission standards by the Environmental Protection Administration.

3. Results and Discussion

3.1. Thermochemical Characterization of Imported PKS

Table 1 listed the measurement results of proximate analysis, elemental analysis and HHV for the imported PKS. It showed that the thermochemical characterization was similar to those of other biomass fuels [4,18]. Based on the data in Table 1, this biomass fuel had a relatively high calorific value (20.8 MJ/kg, dry basis), which was in accordance with its high carbon content (50.8 wt. %) and low content in ash (3.5 wt. %). More importantly, the low contents of nitrogen and sulfur (i.e., 0.6 and 0.0 wt. %, respectively) indicated a low potential for the emissions of air pollutants from the combustion of PKS. In addition to being neutral in carbon dioxide (CO_2) emission, PKS and its resulting biochar will reduce the emissions of sulfur oxides (SO_x) and nitrogen oxides (NO_x) if it is directly used as a solid fuel. On the other hand, the ash content of PKS was less than other agricultural husks like almond, cocoa, peanut and rice [18]. In order to obtain the contents of inorganic element in the PKS sample, the dried sample was observed using the scanning electron microscopy—energy dispersive X-ray spectroscopy (SEM-EDS) (S-3000N; Hitachi Co., Tokyo, Japan). It was found that the dominant elements in the PKS sample were calcium (Ca), potassium (K) and aluminum (Al). This result was very reasonable because these elements are the dominant sources of alkali metal and alkaline earth metals present in most biomass fuels [3].

Table 1. Thermochemical properties of palm kernel shell (PKS).

Property	Value	
	Test 1	Test 2
Proximate analysis [a]		
Moisture (wt. %)	11.89	12.20
Ash (wt. %)	3.87	2.98
Combustibles [b] (wt. %)	85.76	84.82
Ultimate analysis [c]		
Carbon (wt. %)	50.83	50.81
Hydrogen (wt. %)	5.81	5.71
Oxygen (wt. %)	41.54	41.28
Nitrogen (wt. %)	0.65	0.53
Sulfur (wt. %)	0.00	0.00
Calorific value (MJ/kg) [c]	20.89	20.43

[a] As received sample; [b] By difference; [c] On a dry basis.

3.2. Statistics of Imported PKS in Taiwan

The energy use of PKS has received much attention in the past two decades. This trend was mainly motivated by the advances in combustion technologies, soaring oil price, low-cost PKS, energy supply diversification and global warming issue. Currently, the source of PKS in Taiwan was totally imported from oversea countries, including Indonesia, Malaysia, Thailand, Vietnam, India, and Ghana. Table 2 listed the statistical amounts of imported PKS in Taiwan since 2010 [16], giving the following notable features:

- Indonesia and Malaysia were the two main countries of imported PKS in Taiwan. It is well known that they ranked the world palm oil production as No. 1 and No. 2, respectively. Based on the cost consideration, the imported PKS was shifted from Malaysia to Indonesia. For example, the percentages of PKS imported from Malaysia changed from 96.8% in 2011 to 3.5% in 2017.
- The yearly imported amounts of PKS indicated an upward trend, up to the maximal amount at 92,591 metric tons in 2014. As explained later, it should be attributed to the regulatory measures for promoting PKS-to-energy in the industrial steam boilers and cogeneration turbines during this period. However, this trend began to decline since 2015, mainly due to the increasing PKS cost and the newly regulatory pressure for controlling air pollutant emissions from PKS-to-energy facilities in Taiwan. As seen in Table 2, the imported PKS amounts decreased from 92,591 metric tons in 2014 to 30,637 metric tons in 2017.

Table 2. Statistics of imported PKS in Taiwan since 2010 [a].

Year	Total Imported Amount (MT)	Imported Country (%)		
		Indonesia	Malaysia	Other Countries [b]
2010	2651.7	1579.9 (59.6%)	0 (0.0%)	1071.8 (40.4%)
2011	21,870.4	55.6 (0.3%)	21,167.3 (96.8)	647.5 (3.0%)
2012	18,070.1	8281.1 (45.8%)	9611.0 (53.2%)	178.0 (1.0%)
2013	66,357.7	27,122.0 (40.9%)	38,956.4 (58.7%)	279.3 (0.4%)
2014	92,591.4	75,697.3 (81.7%)	16,081.0 (17.4%)	813.1 (0.9%)
2015	82,958.9	71,581.2 (86.3%)	10,544.1 (12.7%)	833.6 (1.0%)
2016	49,049.5	35,920.9 (73.2%)	13,037.1 (26.6%)	91.5 (0.2%)
2017	30,637.0	29,490.0 (96.3%)	1082.5 (3.5%)	64.5 (0.2%)

[a] Source [16]; unit: metric ton (MT); [b] Including Thailand, Vietnam, India, and Ghana.

3.3. Environmental and Economic Benefit Analyses of PKS-to-Energy in Taiwan

In Taiwan, the imported PKS has been considered as a biomass fuel, which was almost used in the industrial boilers for the production of superheated steam. In this work, the author assumed that the biomass substituted for fuel oil in the steam boilers for energy use. In addition, a simple method (Tier 1 method), developed by the IPCC [17], was used to estimate equivalent CO_2 emissions mitigation based on the utilization of imported PKS as an energy source in Taiwan. According to the IPCC method, its calculation was based on the consumed amounts of PKS and the average DEF (CO_2 kg/TJ). Therefore, the former must be converted into the energy content (TJ) using the data on the moisture and HHV of PKS, which have been described in the Section 3.2. Adopting the following data, the equivalent mitigation of CO_2 emissions resulting from the energy use of PKS can be thus estimated in comparison with that of fuel oil.

- Annual imported amount on an average (the data in 2014–2018, seen in Table 2): 60,000 metric tons.
- Moisture content: 12 wt. %.
- Calorific value: 20.8 MJ/kg (dry basis).
- DEF values for PKS: 0 CO_2 kg/TJ, 30 CH_4 kg/TJ, and 4 N_2O kg/TJ.
- DEF values for fuel oil: 73,300 CO_2 kg/TJ, 3 CH_4 kg/TJ, and 0.6 N_2O kg/TJ [17].
- Global warming potential (GWP) values for 100-year time horizon: 25 for CH_4 and 298 for N_2O [19].

Equivalent CO_2 emission mitigation has been estimated as follows:

$$6.0 \times 10^7 \text{ kg/year} \times (1 - 0.12) \times 20.8 \text{ MJ/kg} \times 10^{-6} \text{ TJ/MJ} \times [(73{,}300 - 0) \times 1 + (3 - 30) \times 25 + (0.6 - 4) \times 298] \text{ kg/TJ} = 78{,}646{,}943 \text{ kg} = 78{,}647 \text{ metric tons}$$

Regarding the cost-down of purchasing fuel for the industrial boilers, its economic benefit analysis can be further estimated in comparison with that of fuel oil based on the following assumptions:

- Annual imported amount on an average: 60,000 metric tons.
- Annual fuel oil consumption: 20,000 KL (3.0 ton PKS/KL fuel oil, based on the calorific value and energy efficiency).
- Purchase cost of fuel oil (low sulfur-0.5%): NT$18,000/KL.
- Purchase cost of PKS (including marine transportation fee): NT$5000/ton

$$20{,}000 \text{ KL} \times \text{NT\$}18{,}000/\text{KL} - 60{,}000 \text{ ton} \times \text{NT\$}5000/\text{ton} = \text{NT\$}60{,}000{,}000$$

3.4. Regulatory Measures for Upgrading PKS-to-Energy in Taiwan

3.4.1. Renewable Energy Development Act

The main purposes of the Act, passed on 8 July 2009, aimed at encouraging renewable energy use, promoting energy diversification, improving environmental quality, assisting relevant industries and enhancing sustainable development in Taiwan. According to the definition of biomass energy in the Act, it refers to energy generated from direct use or treatment of vegetation (plant) residue, marsh gas (biogas) and domestic organic waste. To encourage and promote non-pollution green energy, and increase the willingness of renewable energy installers to invest, the so-called feed-in tariffs (FIT) shall not be lower than the average cost of domestic power generation by fossil fuel [2]. Since 2010, the FIT rates in Taiwan have been announced by the Ministry of Economic Affairs (MOEA) to promote power generation from a variety of renewable resources under the authorization of the REDA. As shown in Figure 1, the FIT rates of biomass-to-power indicated an increasing trend from 2010 to 2016. For instance, the FIT rates of biomass-to-power in 2010 and 2016 were 2.0615 and 2.7174

NTD$/kW-h (1 US$ ≈ 30 NTD$), respectively. However, it should be noted that the rates slightly declined in recent years because of the integrated considerations for the average installation cost, service life, operation and maintenance fees, annual electricity generation capacity and related factors for biomass-to-power facilities in Taiwan.

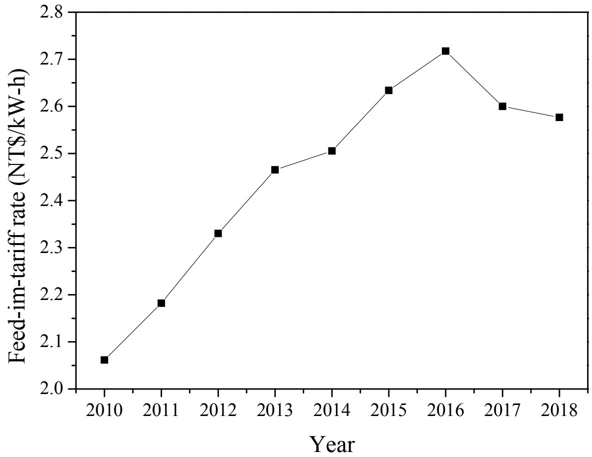

Figure 1. Feed-in-tariff rates of biomass-to-power in Taiwan since 2010.

3.4.2. Customs Import Tariff

As described above, Taiwan is a developed island country with high population density and high dependence on imported fossil energy. As a result, the Taiwan's total GHG emissions increased from 136,178 kilotons of CO_2 (excluding CO_2 removal) in 1990 up to 284,514 kilotons of CO_2 equivalent (excluding CO_2 removal) in 2013 [20], with emission increased by 108.93% at an average annual growth rate of 2.94%. In this regard, some industrial manufacturers generated the superheated steam by co-firing fuel oils with biomass resources in the boilers. However, they mostly used imported biomass resources (i.e., wood dust, PKS) in replacement of domestic ones due to the cost and availability. Since 2011, a new business model was subsequently developed for supplying the steam from the combustion of imported biomass (i.e., PKS) to the related manufacturing plants in the industrial park. The benefits of adopting centralized steam-making system included as follows: cost-down for purchasing (making) steam, avoidance of punishment because of violating air pollutant emission standards, getting a rid of boiler explosion hazards, and mitigation of GHG emissions. However, the biomass importers were requested to pay the imported tariffs at 20% by the customs authority during the period of 2015–2017. On the other hand, biomass-to-power plants have also been built or are still under construction in Japan, South Korea, Singapore and elsewhere in Asia. These situations have caused the significant increase in purchasing PKS cost, thus resulting in the reduced imports of PKS listed in Table 1. In order to boost industrial competitiveness, mitigate the GHG emissions and also promote the innovative green energy industry through this 8-year "pillar industries" plan (2017–2025), the Ministry of Finance announced the exemption from customs duty for imported PKS under the authorization of the Customs Import Tariff (CIT) on 22 November 2017. However, this duty free for imported PKS must be proved by the MOEA for its energy use only.

3.4.3. Waste Management Act

Based on the green energy supply diversification and GHG emission mitigation, the Environmental Protection Administration (EPA) once approved the imported PKS as one of industrial raw materials after consultation with the MOEA starting from 22 May 2007 to 30 March 2018 under the authorization of the Waste Management Act (WMA). In this regard, the import of PKS was not subject to this legal provision regarding the receipt of permission granted by the local government authorities. That was why the amounts of imported PKS indicated an increasing trend during the period of 2010–2015, as shown in Figure 1. However, the public is increasingly worried about particulate air pollutants from the combustion facilities (including industrial boilers and power plants) in recent years because it has an adverse effect on the respiratory health. On 31 March 2018, the EPA thus deleted the imported PKS in the list officially categorized as one of industrial raw materials.

3.5. Regulatory Measures for Controlling Air Pollutant Emissions from PKS-to-Energy Facilities in Taiwan

In Taiwan, the basic law for governing air pollution control and prevention is the Air Pollution Control Act (APCA), which was recently amended in August 2018. The Act was enacted to control air pollution, maintain the air quality in the living environment, and safeguard public health. Under the authorization of the APCA, some relevant regulations for controlling air pollutant emissions from PKS-to-energy facilities have been promulgated to protect against air quality deterioration, especially for the reduction in visibility.

3.5.1. Air Pollutant Emission Standards for Electricity Generation Facilities

In 1994, the implementation of the Air Pollutant Emission Standards for Electricity Generation Facilities came into effect. Thereafter, this regulation has been revised four times in response to the public concern about ambient air quality and in comparison with the emission standards of air pollutants (i.e., carbon dioxide-CO_2, sulfur oxides-SO_x, nitrogen oxides-NO_x, and particulate matters) for power plants promulgated by other countries [21,22]. In the recent regulation revised on 1 December 2014, its significant features were described below:

- In order to raise the heat efficiency, the concept of overall heat efficiency was adopted to relax the emission standards for cogeneration turbines. As listed in Table 3, the emission standards of air pollutants (i.e., SOx, NO_x, and particulate matter) for existing facilities (came into force on 1 December 2016) are multiplied by 1.4 and 2.0 when the overall heat efficiency achieved over 52% and 72%, respectively. Herein, the overall heat efficiency (Hs) is an average value based on continuous 12-h operation and is defined below:

  $$\text{Hs} = (\text{effective heat output} + \text{effective power output})/(\text{lower heating value of fuel})$$

- In order to cut the emissions of SO_x, NO_x and particulate matter, their standards for both newly installed and existing facilities were tightened after taking composite considerations of domestic emission circumstances, overseas emission standards, feasible control technologies, and cos-benefit analyses.

Table 3. Emission standards of air pollutants for cogeneration turbines [a].

Air Pollutant	Overall Heat Efficiency (Hs)	Emission Standard [b]	
		New Facility	Existing Facility
Particulate	Hs < 50%	10 mg/Nm^3	20 mg/Nm^3
	50% ≤ Hs < 52%		28 mg/Nm^3
	52% ≤ Hs < 72%	14 mg/Nm^3	28 mg/Nm^3
	72% ≤ Hs < 90%		40 mg/Nm^3
	Hs ≥ 90%		50 mg/Nm^3
Sulfur oxides (SO_x)	Hs < 50%	30 ppm	60 ppm
	50% ≤ Hs < 52%		83 ppm
	52% ≤ Hs < 72%	43 ppm	86 ppm
	72% ≤ Hs < 90%		120 ppm
	Hs ≥ 90%		150 ppm
Nitrogen oxides (NO_x)	Hs < 50%	30 ppm	70 ppm
	50% ≤ Hs < 52%		97 ppm
	52% ≤ Hs < 72%	43 ppm	101 ppm
	72% ≤ Hs < 90%		140 ppm
	Hs ≥ 90%		175 ppm

[a] The implementation date came into force were 19 September 2018 for newly installed facilities, and 19 September 2020 for existing facilities; [b] Reference conditions for the standards are 0 °C, 101.3 kPa and on a dry flue gas basis.

3.5.2. Air Pollutant Emission Standards for Boilers

In response to the growing public concern about air quality deterioration (especially in fine particulate in the ambient air) in in the last two years (2017–2018), the EPA specially promulgated the Air Pollutant Emission Standards for Boilers on 19 September 2018. Table 4 listed the emission standards of air pollutants for boilers. This regulation was based on the fact that steam boilers accounted for over 70% of stationary sources in Taiwan. These steam boilers were mostly used in the manufacturing plants. More seriously, they are also installed in hospitals, universities, hotels, laundries, restaurants and SPA (sauna) shops, where are often located in densely populated urban areas. As a consequence, the emissions of air pollutants from steam boilers using fuel oils and/or biomass fuels will affect regional air quality, becoming public nuisances. If the boiler users adopt the best available technologies (e.g., using natural gas as fuel, or electricity for heating source), it was estimated by the EPA that yearly of emissions of SO_x, NO_x, and particulate matters can be reduced by 6930, 3190 and 1.120 metric tons, respectively. However, this regulation will induce the impact of industrial steam boiler users on the willingness of using PKS as biomass fuel in the near future even though the regulatory promulgation on the duty-exemption for imported PKS has been effective on 22 November 2017.

Table 4. Emission standards of air pollutants from boilers.

Air Pollutant	Emission Standards [a]	Came into Force
Particulate	30 mg/Nm^3	New units: 19 September 2018 Existing units: 19 September 2020
Sulfur oxides (SO_x)	50 ppm	
Nitrogen oxides (NO_x)	100 ppm	

[a] Reference conditions for the standards are 0 °C, 101.3 kPa and on a dry flue gas basis.

4. Conclusions and Recommendations

In Taiwan, a new business model for PKS-to-energy has been developed in the past decade for the purposes of increasing biomass utilization, reducing environmental impact on air quality and mitigating GHG emissions. Based on the reasonable assumptions, it showed that the annual benefit of equivalent GHG mitigation was about 78,647 metric tons (using annual imported PKS of 60,000 metric tons). In addition, the economic benefit for purchasing PKS in the industrial boilers can gain the cost-down at approximately NT$60,000,000 (US$2,000,000) in comparison with that of fuel oil. Under the frameworks of the Renewable Energy Development Act and the Customs Import Tariff, some regulatory measures for promoting the energy use of PKS are in progress. They included the FIT policy and the exemption from customs duty. It should be noted that there are some regulatory countermeasures for the environmental concerns about the emissions of particulate matters from the combustion of PKS under the Air Pollution Control Act. Nevertheless, the PKS-to-energy system will be a win-win option for the industrial sector to gain the benefits of environment, energy and economy, gradually achieving the goals of total resource recycling and zero waste disposed of.

In order to upgrade the imported PKS for energy use in Taiwan, the technological recommendations are given below:

- Verifying the emissions from PKS-to-energy systems in compliance with the Air Pollutant Emission Standards for Boilers.
- Increasing the FIT rates for biomass to-power systems regardless of its local or imported resources by reference to the Japan's values.
- Concerting PKS into biochar. This carbon-rich solid can be used as a biomass fuel due to its higher calorific value, low hygroscopicity and porous structure.
- Concerting PKS into biochar. This carbon-rich solid can be used as a biomass fuel due to its higher calorific value, low hygroscopicity and porous structure.

- Adopting gasification process for transforming PKS into syngas. This methane/carbon monoxide-rich product can be used as a gas fuel, or further converted it into C1 chemicals via catalytic synthesis.
- Building PKS-to-power plants, or co-firing PKS in the coal-fired power plants, because this energy form can gain the FIT at higher rates.
- Reusing bottom ash as a soil amendment, because the residue after the combustion of PKS possesses alkaline, mineral-rich and nontoxic characters.

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