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Utilization and development of biomass energy

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Abstract: ***As the depletion of fossil fuels becomes increasingly severe, it is crucial to find alternative and sustainable sources of energy. Biomass, which is the largest renewable energy source in the world, is considered an effective solution to the problem of fossil fuel scarcity due to its sustainability, eco-friendly nature, and the wide range of raw materials available. This paper analyzes the current energy situation, energy policies, opportunities, and challenges of biomass energy development in several countries across Europe, Asia, and America. Based on the research results, most countries are proactively seeking to transform their energy systems to ensure sustainable economic development, particularly by utilizing solid biomass, which includes the recycling of industrial and agricultural residues and the cultivation of energy crops. However, biomass energy also faces challenges such as the impact on biodiversity, complex production processes, and high costs.***

Keywords: biomass; development; energy status; challenges**.**

1. Introduction

The world needs a lot of energy to sustain its economy in the future. In 2016, the global primary energy supply was 13.8 billion tons of oil equivalent, or 576 joules. Fossil fuels (coal, fossil oil and natural gas) accounted for 81% of the total primary energy supply, nuclear energy for 5% and renewable energy for 14%. Biomass is the world's largest renewable energy source at 10% (70% of all renewables), followed by hydropower at 2.5% and other renewables (solar, wind, geothermal, tidal, etc.) at 1.5%[1]. Global primary energy demand grows by a record 5.8% in 2021, natural gas demand grows by 5.3%, surpassing pre-2020 epidemic levels, and coal consumption grows by more than 6%, reaching its highest level since 2014[2]. Faced with the severe depletion of fossil energy sources and serious environmental problems, finding alternative sustainable energy sources is a top priority. Considering the three aspects of energy supply, energy security and environmental pollution [3], biomass resources are considered a promising solution to the problems associated with coal-fired and other thermal power resources [4] for the following reasons [5-7]:

(1) The sustainability of biomass makes it an inexhaustible global resource.

(2) Biomass has a carbon content derived only from CO_2 in the air, resulting in a carbon-free system.

(3) The diversity of biomass supply makes it possible to obtain different products by converting bio-oil (gasoline, kerosene and diesel) into various platform chemicals.

(4) Compared to conventional fossil fuels, there are virtually no emissions of sulphur dioxide, nitrogen oxides and soot.

The sources of biomass are diverse and can be divided into three main categories: lignin, cellulose and vegetable oils (or animal fats) [8-9]. Lignocellulosic biomass is the most abundant and cheapest source of carbon and is found in wood, grass and agricultural waste. The main compounds of lignocellulosic biomass are complex and diverse in terms of both compounds and chemical groups [8,10]. Cellulose and hemicellulose account for 60-80% of biomass and are polysaccharide carbohydrates that can be distributed as carbonyl-containing fractions such as aldehydes, ketones, aldehydes, and acids [11]. Lignin is an aromatic phenolic or guaiacol skeleton linked by functional groups ether, carbonyl or carboxylate, while for vegetable oils and animal fats, C14-C22 saturated/unsaturated acids (palmitic, oleic, linoleic, fatty acids, etc.) and triglycerides associated with fatty acids are the main components [12].

In this study, we aim to analyze the current energy situation and energy policies of some representative countries in different regions in recent years, as well as what opportunities and challenges exist in their transition from fossil fuel dependence to biomass energy, in order to provide some reference for the future development of biomass energy.

2. National energy status and biomass energy development in the European region

As Europe's largest political and economic complex, the EU's total energy consumption decreased from 1,226 Mtoe in 2005 to 1,162 Mtoe in 2017. The share of agricultural biomass, forest biomass and renewable waste (collectively referred to as "bioenergy") in the EU's total final energy consumption increased from 5.9% in 2005 to 10.3% in 2017. 5.9% in 2005 to 10.3% in 2017. In comparison, bioenergy consumption in the EU was about 120 million barrels of oil equivalent (58%) in 2017, while other renewable energy sources such as solar PV, wind and hydroelectricity were about 86 million barrels of oil equivalent (42%). In 2017, Germany, France, Sweden, Italy and Finland were the leading countries, accounting for nearly 55% of the EU's final bioenergy consumption. By 2017, installed biomass capacity in the EU tripled to 32 GW compared to 2005, which represents a 7.7% share of total renewable electricity stagnation capacity. Around 2011, bioenergy deployment declined, driven mainly by a reduction in solid biomass consumption in the heating/cooling sector and a reduction in biofuels in the transport sector. Another distinction is made between solid biomass, gaseous biomass and liquid biomass. Bioenergy in the EU is expected to increase to 139.5 million tonnes of oil equivalent in 2020, although its share in final renewable energy will decline to 57% due to the rapid growth of other renewables [13-14]. The way biomass is supported in the EU energy sector is not similar across EU countries, with feed-in tariffs and feed-in fees remaining the main support schemes for bioelectricity deployment, while subsidies remain the main support for bioheat, in addition to mandatory blending quotas for biofuels for transport in many EU countries [15], while the main support schemes for promoting renewables are shown in Fig. 1.

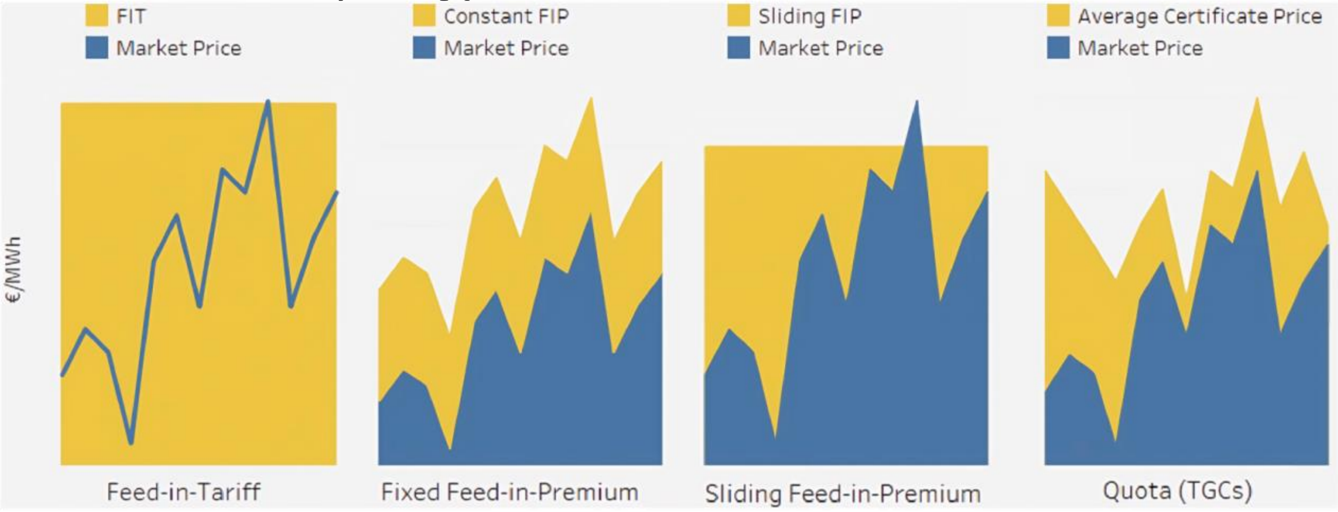

Fig. 1. Main types of support schemes to promote the deployment of renewable energy technologies[15].

The latest legal requirements in the Netherlands aim to prevent unwanted land use changes, take into account carbon debt, ensure nutrient balance in vulnerable soils and other sustainability criteria. Subsidy recipients in the energy sector are required to demonstrate that their biomass supply is sustainable using either (i) a certification scheme approved by the Minister of Economic Affairs and Climate Policy or a combination of certification and validation, or (ii) Third-party validation [16].

In Germany, biomass power generation has become an important source of income in rural areas of the northern federal states of Germany, in addition to large-scale energy production from wind turbines [17]. In Belgium, perennial energy crops such as manzanita, short-rotation woody crops, and forest and agricultural residues (e.g., corn straw, wheat straw) are potential biomass feedstocks for bioenergy production in Belgium. By 2015, these feedstocks could provide about 782 ktoe of total energy per year, of which about 47% comes from agricultural residues, 31% from forest residues and 22% from perennial energy crops [18].

In Croatia, according to the CLC database [19], the total amount of abandoned agricultural land in Croatia is 541,930 ha, which represents great potential for the introduction of energy crops without affecting existing agricultural production. The possibility of introducing energy crops into agricultural production without creating competition between food and energy is open. In the cultivation of lignocellulosic energy crops, emphasis should be placed on the use of abandoned agricultural land. Croatia produces a large amount of energy waste every year. The largest energy potential is corn stover, wheat straw and soybean straw, as well as grape pruning residues, as detailed in Table 1. The inclusion of agricultural biomass in Croatian green energy production would ensure a significant increase in total energy production, increase the share of renewable energy in total energy and reduce energy imports [20].

Tab. 1. Total annual biomass residues and its energy potential in Croatia[22]

Biomass source	Svenario	Demand of biomass (000 t $year^{-1}$)	Potential of energy production		
			PJ $year^{-1}$	GWh $year^{-1}$	Mtoe $year^{-1}$
Crop residues	S1	1686.1	27.83	7731.56	0.665
	S2	927.4	15.31	4252.36	0.366
	S3	505.8	8.36	2322.22	0.199
Pruned residues	S1	220.6	3.76	1044.39	0.090
	S2	121.3	2.07	574.41	0.049
	S3	66.18	1.1	305.56	0.026
Agro-industrial residues	S1	55.0	0.77	213.60	0.018
	S2	30.3	0.42	117.48	0.010
	S3	16.5	0.22	61.11	0.005
Miscanthus x giganteus	S1	1088.6	18.78	5216.67	0.449
	S2	362.8	6.26	1738.89	0.150
	S3	145.2	2.50	694.44	0.060
TOTAL	S1	3050.3	51.14	14,206.22	1.222
	S2	1441.8	24.06	6683.14	0.575
	S3	733.68	12.18	3383.33	0.290

S1: progressive scenario S2: optimistic scenario S3: conservative scenario

3. National energy status and biomass energy development in the Asian region

In Pakistan, a serious energy crisis needs to be addressed urgently. In summer, power outages last 6-8 hours in urban areas and 12-16 hours in rural areas [21]. From 2012 to 2018, the country's per capita electricity consumption increased from 500 kWh to 960 kWh. Due to the increase in per capita electricity consumption, the country suffers from severe electricity shortages.

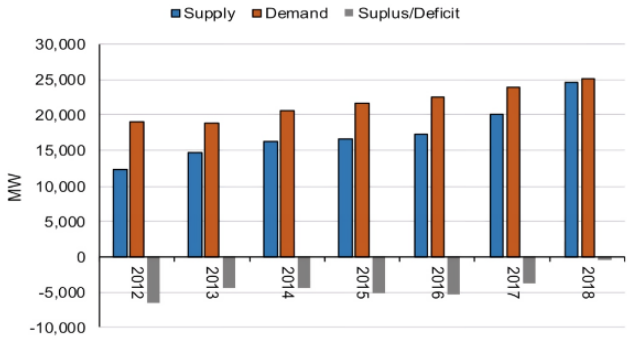

Fig. 2. Trend of power demand–supply in Pakistan from 2012–2018[22].

Fig. 2. shows electricity supply and demand in Pakistan for the period 2012-2018[22]. The electricity demand and supply projections for the period 2010-2030 are shown in Fig. 3. It is clear from Figure 3 that energy demand continues to grow at an annual rate of 5-7%.

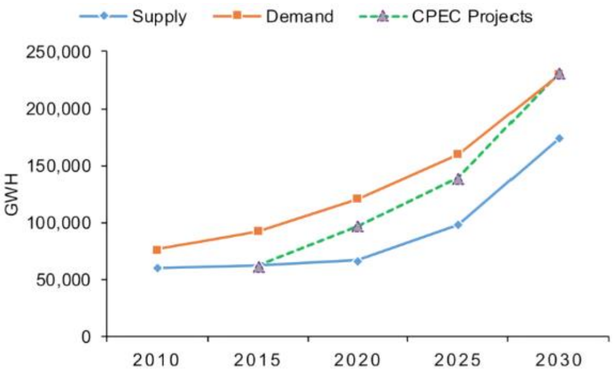

Fig. 3. Projected demand–supply situation in Pakistan from 2010-2030[22]

Pakistan's energy mix is heavily dependent on fossil fuels, which will continue to be the dominant source of energy [23]. Pakistan gets 61% of its electricity from oil and gas. These traditional sources are costly and also pose a threat to the environment. On the other hand, the share of renewable energy in total electricity generation is only 1.1% [24]. Pakistan relies mainly on fossil fuels for electricity generation, which causes environmental degradation. The use of renewable energy sources is the only permanent solution to sustainable development. The country is rich in biomass resources including wood, municipal solid waste, agricultural residues and animal manure. Forty-eight percent of domestic energy needs are met by fuelwood, while crops and animal residues together provide the other 32 percent. Pakistan's forest growth rate has fallen to 8.76% as only 5% of the country's land is covered by forests, indicating a negligible supply of fuelwood. The country has 85 sugar mills that can produce 40-12 million tons of bagasse. With this amount of bagasse, 5800 GWh of electricity can be generated. If bagasse is used for cogeneration, the national grid can supply 800 MW. Corn stover, sugar cane bagasse, rice straw, wheat straw and cotton straw are the main crop residues, producing 6.43, 8.94, 17.86, 35.6 and 50.6 million tons respectively. The annual processing residue of all these crops is 2638 Mt with an annual power generation potential of 790.36 TWh/year. Animal manure is also an important source of energy. There are 202 million animals in this country. In addition, animal manure produces 58.6 million kg of nitrogen-rich biofertilizer per day. Similarly, the MSW potential for electricity generation through thermochemical and biochemical conversion is 560 kWh/t and 220 kWh/t, respectively. The country has the potential to successfully operate 15 million biogas power plants [25]. In an agricultural country like Pakistan, biomass has enormous potential for generating energy to bridge the widening gap between demand and supply of electricity [26]. Most importantly, electrify remote areas that are far from the national grid and have no access to electricity [27].

Based on this, in terms of policy, the government of Pakistan should establish appropriate financial mechanisms to provide subsidies and monetary benefits to local developers for rapid penetration of biomass and initiate training programs to make local people aware of the benefits of developing biomass energy and join the biomass energy industry [25].

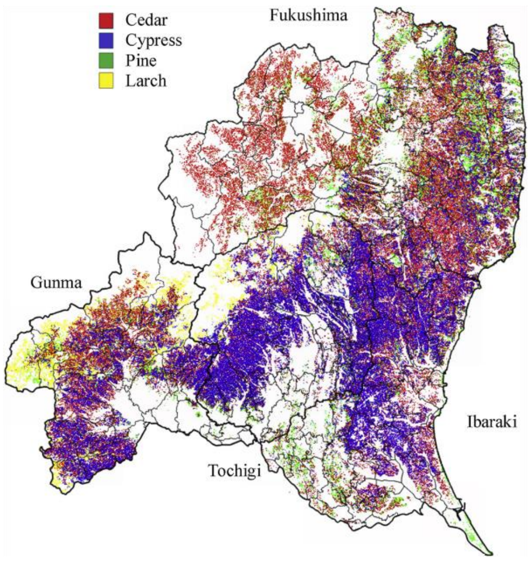

Fig. 4. Tree species in each prefecture of Japan[33]

Japan is one of the world's largest importers of fossil fuels. As the third largest economy in the world and the second largest electricity market in the OECD [28], as well as a country with virtually no energy resources such as oil and gas, Japan is at a policy impasse in terms of energy and economic development [29]. Therefore, there is an urgent need to find alternative energy sources and improve energy efficiency.

A previous study estimated the availability of woody biomass in Japan to be about 400 PJ, or 40% of the total biomass available. An approximate calculation suggests that about 10% of Japan's primary energy supply could be provided by forests if all the tree growth in 240,000 km^2 of Japanese forests were used to provide energy [30]. Japan is close to 70% of its land is forested [31] and has a diverse range of crops, as shown in Figure 4, and has the sixth largest potential biomass market in the world [28], but forestry productivity in Japan is low, despite high forest potential and abundant reserves [32]. This indicates a serious imbalance between potential supply and demand for wood biomass in Japan.

In order to maximize the introduction of renewable energy while minimizing the burden on the state, Japan has introduced feed-in tariff programs for renewable energy sources, such as solar power and biomass power using wood materials in general. The FIT program is a system in which electric utilities purchase renewable energy for a certain price to generate electricity. These fees are levied on electricity users. Due to the introduction of FIT, the installed capacity of renewable energy is growing rapidly [33]. In addition, it has been shown that in Japan, heat production is feasible for small-scale biomass energy use of 2660 t/yr or higher, and electricity generation is feasible for large-scale biomass energy use of 13100 t/yr or larger [30].

4. National energy status and biomass energy development in the American region

As the world's largest economy, the United States is also second to none when it comes to energy consumption. In 2017, the United States was one of the world's largest producers of oil and natural gas and the world's second largest emitter of energy-related carbon dioxide, with a global share of 14.58%, behind China's 27.21%. In 2019, U.S. energy production exceeded energy consumption, with fossil fuels accounting for the highest share of energy production, with U.S. coal 's share of energy production declining by 16% (from 30% in 1957 to 14% in 2019); however, the share of crude oil production declined by only 7% (from 38% to 31%) [34-35]. In 2021, the U.S. per capita fossil fuel consumption is 63,130 (kWh), which is ten times higher [36]. In contrast, renewable energy sources contribute about 11% of total U.S. energy consumption in 2018 (more than 11 QBtu out of 100) [37]. In the long run, renewable energy consumption is non-positively correlated with U.S. CO_2 emissions. In other words, a 1% increase in renewable energy consumption reduces environmental degradation by 0.01%, while the short-term impact is negligible and can contribute significantly to the country's green growth [38].

As an important component of renewable energy, biomass use in the United States increased by 60% from 2002 to 2013. This increase is entirely due to the increased consumption of biomass for the production of biofuels, mainly ethanol, but also to a lesser extent biodiesel and other biomass-based diesel fuels. In 2017, the U.S. consumed an average of 1.2 million barrels per day of biodiesel and other renewable fuels (excluding ethanol) [39]. In 2013, biomass accounted for approximately half of all renewable energy consumption and 5% of total energy consumption in the United States [40]. Biomass energy accounts for 4.5% of total U.S. energy consumption by 2018, as shown in Figure 5. In addition, studies have found that biomass consumption also has a positive impact on U.S. economic growth [41].

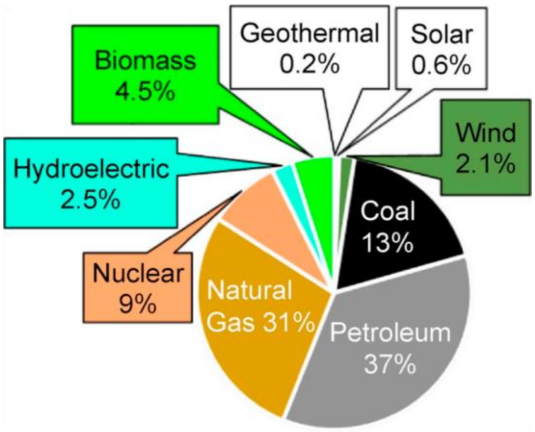

Fig. 5. U.S. total energy consumption by source in 2018[41]

At the same time, wood harvested from U.S. forests provides rural employment and value-added processing for a variety of solid wood, paper, and fiber products, as well as wood waste for heating, power generation, mulch, animal bedding, and other products. After meeting other projected demand for wood products, up to 105 million tons per year of additional woody biomass is expected to be available in the United States for bioenergy on existing forest lands [43]. Much of this potential occurs in the southeastern United States, which currently accounts for 74% of the total U.S. industrial pellet plant capacity of 10.7 million metric tons per year [44].

5. Opportunities and challenges of biomass energy development

As far as the past literature shows, biomass energy, as a renewable energy source, will be an effective supplement to traditional fossil energy sources for a considerable period of time in the future. However, we cannot ignore some opportunities and challenges of biomass energy itself.

Biomass energy can be produced on a large scale in rural or peri-urban areas, is more sustainable than fossil energy, and can provide employment opportunities for the local population. In this context, the use of woody biomass energy has been growing worldwide [45]. Similarly, Lauri et al. conducted an economic analysis of woody biomass energy potential on a global scale up to 2050 and showed that woody biomass could meet 18% of the world's primary energy consumption by 2050 [46]. In particular, agricultural and forest residues are considered to be one of the most energy-efficient and climate-friendly feedstocks for heating and/or power generation [47-48]. This is due to their lower managed energy consumption compared to perennial energy crops and the fact that they do not compete with food production [49].

On the other hand, the cultivation of energy crops and even the use of biomass for energy is being increasingly debated. The reason is that land-intensive strategies such as the expansion of bioenergy monoculture plantations may hinder the goals of biodiversity conservation and sustainable development [50] and may have negative impacts on humans and the environment. This includes global land use changes, driven mainly by the expansion of bioenergy use in industrialized countries, but also by increased demand for animal products and correspondingly high feed demand in emerging markets. In addition, the increased demand for biomass has triggered an expansion of agricultural production areas, which may lead to the loss of valuable ecosystems such as forests and species-rich grasslands. The intensification of agricultural production through the increased use of synthetic fertilizers and pesticides may also be associated with ecological deficiencies, such as the loss of weeds and landscape elements valuable for biodiversity. Given these challenges and risks, it cannot be ruled out that society may reduce or even not grow energy crops, affecting the success of the energy transition [51]. Also, considering that the production process of biomass energy is more complex, the production costs are higher and the energy density of biomass energy is lower compared to fossil energy sources, which means that a larger production volume is required to achieve the same energy output [52-53].

6. Conclusion

With the increasing depletion of fossil fuels, the search for new renewable energy sources has become an urgent issue. Biomass is the world's largest share of renewable energy, and with its advantages of abundant resources and environmental friendliness, it is expected to become an important means to alleviate the world's oil scarcity. Through the analysis of the current energy situation, energy policies and the opportunities and challenges facing the development of biomass energy in many countries in Europe, Asia and America, it can be seen that in order to guarantee the sustainable development of the economy, many countries are undergoing energy transformation. a part. At the same time, the use of biomass energy and other uses also has problems affecting biodiversity, complex production processes, and high costs.

Acknowledgements

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