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Biomass and wind energy as sources of renewable energy for a more sustainable environment in Indonesia: A review

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Abstract: Pollution continues to experience a rapid increase so cities in the world have required the use of renewable energy. One of the keys that can prevent climate change with a sustainable system is renewable energy. Renewable energy production, especially for hybrid systems from biomass and wind, is the objective of the analysis in this work. The potential of feedstock for different biofuels such as bio-diesel, bio-ethanol, bio-methane, bio-hydrogen, and biomass is also discussed in this paper. The sustainability of the energy system for the long term is the main focus of work in this investigation. The configuration of the hybrid system between biomass energy and wind energy as well as some problems from various design factors are also presented. Based on the findings, this alternative energy utilization through biomass-based hybrids can save costs and improve environmental conditions, especially for the electrification of off-grid rural areas. This paper will provide important information to policymakers, academics, and investors, especially in carrying out the development and factors related to the utilization of wind-biomass-based hybrid energy systems.

Introduction

Interest in the use of various renewable energy-based applications has given attention at the international level. The increase in renewable energy technology, sustainable development, and energy security, due to the depletion of the use of fossil fuels, the application of renewable energy has attracted interest on a global scale. Renewable energy in the 21st century has a very important role because non-renewable energy sources have been excessive and often exploited as emissions continue to increase and the depletion of fossil energy occurs (Deviram et al. 2020; Erdiwansyah et al. 2021; Bodzek 2022). Meanwhile, the current increase in non-renewable energy is at an alarming point as reported in (Erdiwansyah et al. 2019b; Mathimani et al. 2021). The system of climate change, ecology, and environmental stability are strongly influenced by the use of energy sourced from non-renewable sources. Fossil fuels that continue to be used will provide increased prices and climate change through greenhouse gases (Yin et al. 2020; Sheng et al. 2022). More effective use and production of energy, especially from renewable sources, is a very urgent challenge to be carried out in the 21st century (Al-Ghussain et al. 2021; Malik et al. 2022). Researchers around the world report that the use of fossil fuels can affect greenhouse gas emissions, especially from transportation which causes global warming. The higher levels of CO_2, SOx, NOx, CO, and HC can affect ecosystems and their services (Erdiwansyah et al. 2019a, 2022). Production and development of energy from renewable sources is the best way that can be done at this time. Renewable energy can be obtained and produced from various sources because it can be used and recharged on a time scale. Renewable energy sources such as biomass, geothermal, wind, solar, and hydroelectric power have been widely used, especially in several countries in the world (Jurasz and Mikulik 2017; Chmielniak 2019). The status of the availability of renewable energy sources around the world to date is presented in full in Fig. 1. Wind energy sources, biofuels, and hybrid systems are renewable energy sources that have been widely discussed by researchers around the world. Therefore, the investigation of biomass energy sources as fuel for hybrid production with wind energy will provide new insights as a renewable energy source in the future.

The contribution of renewable energy in Indonesia until 2020 is presented in Fig. 2. The requirement for energy and related services to meet the demands of human, social, and economic development, as well as health, has recently come under scrutiny due to evaluations of renewable energy sources, sustainability issues, and climate change mitigation. To maintain the sustainability of renewable energy sources in the long term, it must be able to combat climate change caused by greenhouse gas emissions in particular. Energy sources from biomass, wind power, solar power, hydropower, marine power, and geothermal power that are currently available can be used as alternative energy in the long term. The availability and application of renewable energy systems in more detail are shown in Table 1 (Sharma et al. 2019; Sameeroddin et al. 2021). This is done to ensure and call for a balance, especially for goods and services while protecting future generations. In the future, fossil fuels will still be used due to population growth and global energy demand around the world. Due to rising global energy consumption and a growing global population, the usage of fossil fuels will likely continue for some time. As a result, a number of issues have emerged (coal, oil, gas). These problems will only make the current situation worse, endangering human civilization. On the other side, the only genuine solution to the world's growing problems is renewable energy (Sudhakar et al. 2019; Thanigaivel et al. 2022). Only ten years ago, it seemed unimaginable that renewable energy sources would account for 22% of the world's energy production in 2012. The demand for a consistent energy supply in economies is not limited to that of transportation and industrial machinery (International Energy Agency and Bank 2014; Sellevold et al. 2020). The utilization of renewable energy can reduce greenhouse gas emissions. Since they are formed from ongoing energy flows in our environment, they are anticipated to survive for as long as possible. The supply of renewable energy for environmental services does not have to be limited because it is ecologically acceptable if it is truly sustainable. Renewable energy sources will be largely climate-dependent which requires complex planning and design before it can be put into practice. This is because there are still some challenges to be implemented properly. The cause of the discontinuous seasonal oscillation of renewable energy generation is one of its drawbacks.

The current trend of installed energy in Indonesia is presented in Fig. 3. Renewable energy production capacity in 2022 is expected to grow at a rate that exceeds the long-term trend. The growth of renewable energy that bears a big responsibility is China and the United States. The majority of countries increased their renewable energy capacity at a similar rate to previous years. The increase in global renewable energy capacity will increase in 2022 by 2799 GW (Council 2021; Farina and Anctil 2022). In 2020, renewable energy generating capacity will grow by around 7,465 MW. In this case, the installed new energy capacity will be sourced from geothermal 2,132 MW, hydro 4,621 MW, mini-hydro 411 MW, solar 105 MW, wind energy 154 MW, and bioenergy 42 MW (Outlook 2021). The utilization of energy with a biomass-based hybrid system can save costs and improve environmental conditions, especially for the electrification of rural areas. The specific purpose of this paper is to provide important information,

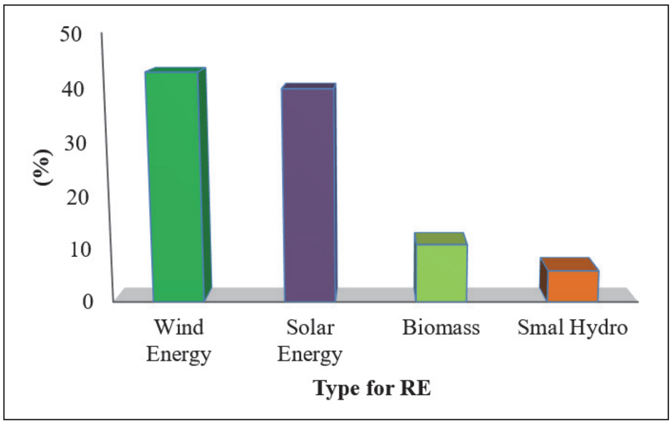


Fig. 1. Status RE of the World in 2020

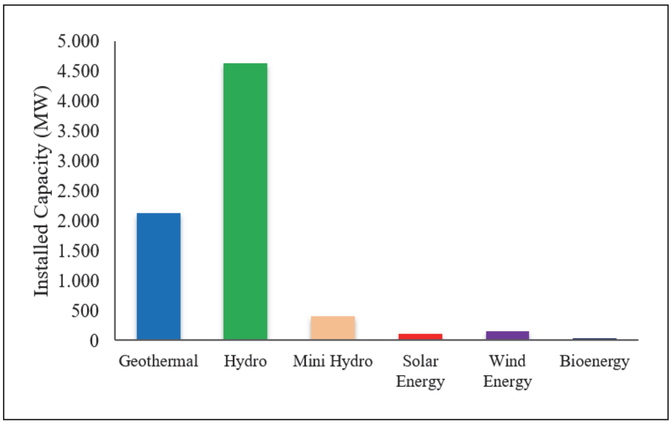


Fig. 2. Installed Capacity RE in Megawatts

Table 1. The utilization of renewable energy sources

Energy Resources	System/Applications for Energy Conversion
Hydroelectricity	Generating Electricity
Wind Energy	Wind turbines, wind generators, and windmills are all terms that can be used to describe the generation of electricity.
Biomass	Transportation fuels, heat and power generating
Energy for Solar	Photovoltaic, solar collectors, and thermal power generation
Geothermal	Hydrothermal system, power generating

especially for policymakers, academics, and investors, in carrying out the development, design, and factors related to the utilization of wind-biomass energy.

Capacity and Target Renewable Energy in Indonesia

The use of renewable energy as a source of final energy consumption in Indonesia has increased since 2015. The Central Statistics Agency noted that Indonesia's renewable energy mix increased from 4.4% in 2015 to 11.5% in 2020. In 2016, the renewable energy mix increased to 6.61% from the previous year. But in the following year, the percentage of the renewable energy mix was recorded to have decreased to 6.34%.

It was only in 2018 that the trend for the number of renewable energy mixes continued to increase until 2020. The mix of renewable energy to total final energy consumption was recorded at 8.55% in 2018, 9.15% in 2019, and 11.51% in 2020 as shown in Fig. 4. The Ministry of Energy and Mineral Resources (ESDM) targets the renewable energy mix to reach 15% by 2021. In 2025, Indonesia targets the renewable energy mix to reach 23%. The Ministry itself estimates that Indonesia's renewable energy potential reaches 417.8 GW. This potential of 17.9 GW comes from ocean currents, geothermal 23.9 GW, bioenergy 32.6 GW, wind power 60.6 GW, hydropower 75 GW, and solar 207.8 GW. The Indonesian government has targeted the use of renewable energy by 2025 to reach 23% (Erdiwansyah et al. 2020). However, with the COVID-19 pandemic in the last two years, it will be a very big challenge to achieve this target. But if you look at the achievement in 2021, 23% may be realized in 2025.

The Indonesian Renewable Energy Society (IRES) proposed to the Indonesian government to launch the 50/50 Indonesia Renewable Energy program. The 50/50 Indonesia Renewable Energy program is the initiative for a meeting with the members of the G20 countries that have the largest economies in 2022. The chairman of IRES, Surya Dharma explained that the RE 50/50 program in 2050 is a carbon emission-free target, with a minimum contribution of renewable energy (RE) of 50%. According to him, this target is even lower when compared to other countries which target the contribution of renewable energy at above 70%. We interpret the RE 50/50 as Indonesia's effort to meet the 2050 net-zero (emissions) target with a minimum of 50% renewable energy. By 2050 most areas are already above 70% (renewable energy contribution) (Indonesia 2021). Renewable energy can also be obtained through processed fossil energy, such as liquefied coal, nuclear, hydrogen, and others. However, according to him, for renewable energy to develop in the country, certainty in the regulatory framework is needed, one of which is through the New Renewable Energy Bill which is currently being discussed by the DPR and the government.

Investigation Energy for Biomass

Climate change at the global level such as air pollution and acid rain caused by fossil fuels has raised concerns so that the use of biomass energy sources is considered as a substitute for fossil fuels. Energy sourced from biomass is an alternative, environmentally friendly, and renewable energy. Renewable energy sources like biomass-biofuels could help to meet the world's rising energy needs (Mathimani and Mallick 2019; Zhuang et al. 2022). The world's use of energy from biomass sources has accounted for about 10–14%. The use of fuel from biomass sources in rural areas reaches 90%, while in urban areas biomass energy is used in around 40% (Openshaw 2010; Xu et al. 2019). One-third of the primary energy use is contributed by biomass. Biomass is clean renewable energy that can meet the world's energy demand (Mathimani and Mallick 2019; Olsztyńska 2019; Saravanan et al. 2020). Renewable sources such as biomass are sustainable energy, this is because the production system, growth, and harvest period are quite fast. Oil production from biomass is an alternative energy that can be used as heating, electricity, transportation fuel, etc. In addition, renewable energy from biomass can be applied to small-scale and small-scale industries, as well as household scales such as lighting and cooking (Chudy et al. 2021; Gururani et al. 2022). Liquid and gaseous fuels that are processed from solid waste biomass sources can be used to generate electricity. The researchers' attention to biomass has so far been higher than that to liquid fuels. This is because biomass raw materials have enormous potential as alternative energy in the future. Solid biomass is easy to find in trash

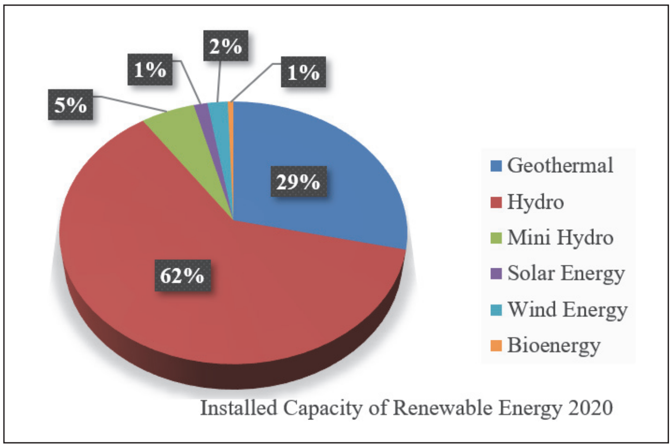


Fig. 3. Installed Capacity RE Indonesia in (%)

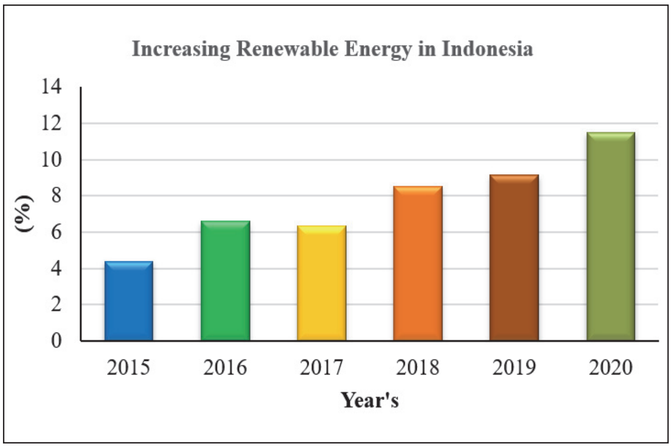
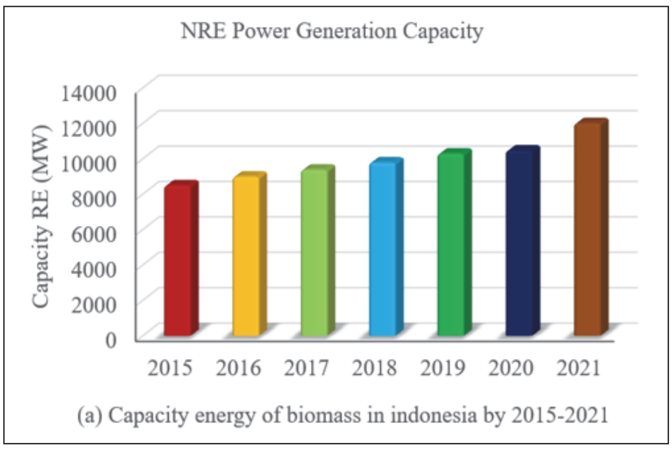


Fig. 4. Increase in Renewable Energy in Indonesia from 2015–2020

bins because it is no longer used. Anaerobic and gasification methods are very feasible options for converting solid biomass into gas. Energy generation with a hybrid model, conversion technique, gasification technology, and anaerobic digestion system is more suitable and often used. This is because it can offer various benefits such as increased electricity efficiency, cost-effectiveness, and reduced use of biomass. In addition, other advantages such as CO, NOx, and non-combustible chemical emissions can be reduced, as well as compactness, flexibility, etc. The anaerobic process that produces biogas is a renewable energy source that can be used in a power plant, heater, and also has the potential to minimize dependence on fossil fuels (Glivin and Sekhar 2020b; Kulyal and Jalal 2022). Sources of biomass can be in the form of straw, paper waste, sawdust, drum fertilizer, forest wood, cyanobacteria, industrial waste, detergents, household waste, microalgae, etc. (Glivin et al. 2021a; Wijayasekera et al. 2022).

The capacity of renewable energy sourced from biomass in Indonesia from 2015–2021 which is used to generate electricity is as presented in Fig. 5. Indonesia's energy capacity in 2021 has shown a significant increase. Indonesia's energy capacity is higher than that of India and Germany as shown in Fig. 5 (a) and (b). Biomass power plants in Indonesia have been widely developed in recent years. Biomass-fueled power plants have been built in many countries such as India which are intended for rural areas (Glivin and Sekhar 2020a; Wu et al. 2021). The steam generated from the use of biomass can be used as a turbo-generator (Klaimi et al. 2021; Musharavati et al. 2021). Research through the investigation of trends in biomass as renewable energy has been carried out since 1978–2018 by (Wang et al. 2016; Micallef and Rezaeiha 2021). The research conducted specifically aims to help the research community to understand the trends and situation of biomass resources around the world for the future. According to the volume of scientific output, the results of this bibliometric study specifically demonstrate that the United States is the world leader in biomass research as a renewable energy source. Other developing countries such as China, Germany, India, and Italy are also the largest after the United States. Future energy demand will be utilized from biomass sources because large countries need sufficient energy supply and biomass is an alternative as their energy fulfillment. Research on economic characteristics has been reported mainly on the source of various types of biogas plants, life cycle costs, net costs, energy leveling costs, etc. (Glivin et al. 2018, 2021b).

Biomass, which has been designated as the 4th renewable energy source among coal, other new energy sources, gas and fuel, and oil, has contributed about a quarter of global energy demand (Zhao et al. 2019; Kandasamy et al. 2021; Velusamy et al. 2021). There are many fuels from biomass processes such as bio-butanol, bio-diesel, bio-hydrogen, bio-ethanol, bio-oil, biogas, etc., all of which are produced from solid and liquid waste biomass (Kalinichenko and Havrysh 2019; Shanmugam et al. 2021a). Solid fuels such as biochar, as well as bio-gas, bio-hydrogen, syngas, bio-diesel, bio-ethanol, bio-butanol are all derived from biomass (Das et al. 2021a, b; Kandasamy et al. 2022). Extraction of biomass can produce inedible and edible biofuels. Edible sources of biomass are such as peanuts, sugar cane, soybeans, wheat, rapeseed, and corn, while non-edible sources of biomass are such as cooking oil, agricultural waste, microalgae, and industrial waste (Ge et al. 2021, 2022). The biomasses utilized as feedstocks for the first, second, third, and fourth generations of biofuels are known as these (Chen et al. 2021; Whangchai et al. 2021). Crops such as sorghum, cereals, sugar beet, barley, maize, molasses, and wheat are the first generation of fermentable raw materials for biofuel production. Meanwhile, oil palm, soybean, coconut, rapeseed, and sunflower crops can be used to produce biodiesel (Karpagam et al. 2021; Chen et al. 2022). Biodiesel products can also be obtained from cassava, castor oil, Pongamia Pinnata, Calophyllum inophyllum, Miscanthus, Hevea Brasiliense, as well as sources of lignocellulose such as grass, rice straw, and wood. All types of biomass sources that have been mentioned are biofuels of the second generation (Aguilar-Rivera et al. 2021; Narwane et al. 2021). Sunflower, soybean oil, and castor oil can produce biodiesel through transesterification catalysts at 96%, 96%, and 84.5%, respectively (Kim et al. 2019; Ferreira Mota et al. 2022). Biomass raw materials of the first and second generations have disadvantages including lower productivity, risk of resilience, and having a large area of land (Arias et al. 2021; Moshood et al. 2021). Food versus fuel dispute, high capital costs, uncompetitive retail prices, conflict with the food processing industry for land (Karpagam et al. 2021; Chen et al. 2022). First generation feedstocks in particular have economic, environmental, and political problems because they require significant agricultural acreage for pilot scale biofuel



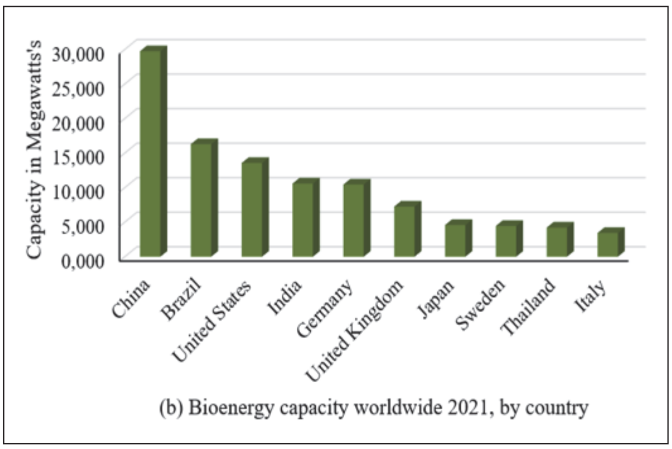


Fig. 5. (a) Capacity Energy of Biomass in Indonesia, (b) Bioenergy Capacity Worldwide in 2021, by Country

production, which in turn reduces the amount of land available for growing food for people (Gambelli et al. 2017; Chowdhury et al. 2019).

Due to third generation biofuels' numerous benefits and the shortcomings of first and second generation biofuels, third generation biofuels received a lot of attention (Alagumalai et al. 2020; Tuan Hoang and Viet Pham 2021). Third-generation raw materials such as microalgae/cyanobacteria have potential because of the higher cultivation and growth system and high lipid production (Sutherland et al. 2021; Wicker et al. 2021). Microalgae produce products that can be gathered all year round and accumulate 20–50% neutral fats. Microalgae use less water than crops and are very CO2 absorbing (1.83 kg of CO_2 absorbed by 1 kg of dry biomass). Certain minerals can be removed from wastewater using microalgae. They don't face competition from edible crops for the cultivation of arable soils (Srivastava et al. 2021; Chen et al. 2022). Biofuels converted from biomass can be carried out by three pathways such as biochemistry, chemical processes, and thermochemistry (Das et al. 2021a). Chemical conversion can be carried out by biochemical methods of anaerobic fermentation, anaerobic digestion, and transesterification. Thermochemical methods of torrefaction, hydrothermal treatment, gasification, and pyrolysis are used for solid, gas, and liquid fuel products made from biomass.

One of the liquid fuels is bioethanol which can be produced through anaerobic fermentation obtained from biomass such as wheat straw, corn, wood chips, microalgae, and lignocellulose. This bio ethanol fuel can reduce emissions because it has about 35% oxygen (Mielcarek-Bocheńska and Rzeźnik 2019; Tarique et al. 2021). Bioethanol can also be mixed with gasoline which can increase thermal efficiency and higher brake power because the octane rating is higher than that of gasoline which reaches 30% (Ghosh et al. 2020; Goh et al. 2020). The first country to produce bioethanol was Brazil (Ge et al. 2022). The status of global ethanol production is shown in Fig. 6. Ethanol production with alcohol has a long history. The liquor is fermented in batches for a number of hours using substances like corn, grape juice, molasses, and other things (minimum 40 h). This is done to avoid unwanted chemicals and water so that the obtained purity is up to 99% more. Given the demand for more ecologically friendly energy sources, scientists are working against the clock to develop the most efficient source of energy. The production of bioethanol is carried out in four main steps, namely, pretreatment for the separation of hemicellulose and lignin has sugar for carbohydrate fermentation by hydrolysis, the distillation of ethanol into bioethanol, and microbial fermentation into bioethanol.

The use of alternative fuels for biodiesel is believed to be able to reduce dependence on the use of fossil fuels (Oliveira et al. 2021; Whangchai et al. 2021). Liquid fuel from biodiesel produced from animal vegetable fats, mycobacterial lipids, and microalgae can be an alternative energy source that can be applied and used alone or by blending with diesel, especially for compression engines (Chilakamarry et al. 2021; Lin and Lu 2021; Thanigaivel et al. 2022). The process of converting biomass into biodiesel can be done by transesterification. Transesterification is a chemical process that turns biomass (lipids) into biodiesel. In this process, an ester (lipids from biomass) is changed into a mixture of esters of the fatty acids that make up the oil. Biodiesel consumption and production systems have been widely developed as a substitute for mineral diesel for the short term. This is due to the increasing demand for diesel fuel worldwide. The demand for diesel fuel is increasing due to the level of human concern for health and the environment as a result of direct combustion. However, the synthesis of biodiesel used from vegetable and non-vegetable raw materials has sparked various debates, especially concerning its availability and related techno-economic issues. Bioethanol is the most commonly used biofuel in the world, accounting for 62 percent of all global production of biofuels in 2022, followed by biodiesel at 26 percent.

Biogas fuel (biomethane) is a type of fuel obtained from organic waste (biomass) which contains an energy density of about 50–55 MJ/kg. Biomass waste from different sources such as industrial waste, municipal waste, and agricultural waste can be converted into biogas by the anaerobic digestion process (metalorganic bacteria). The amount of CH_4 and CO_2

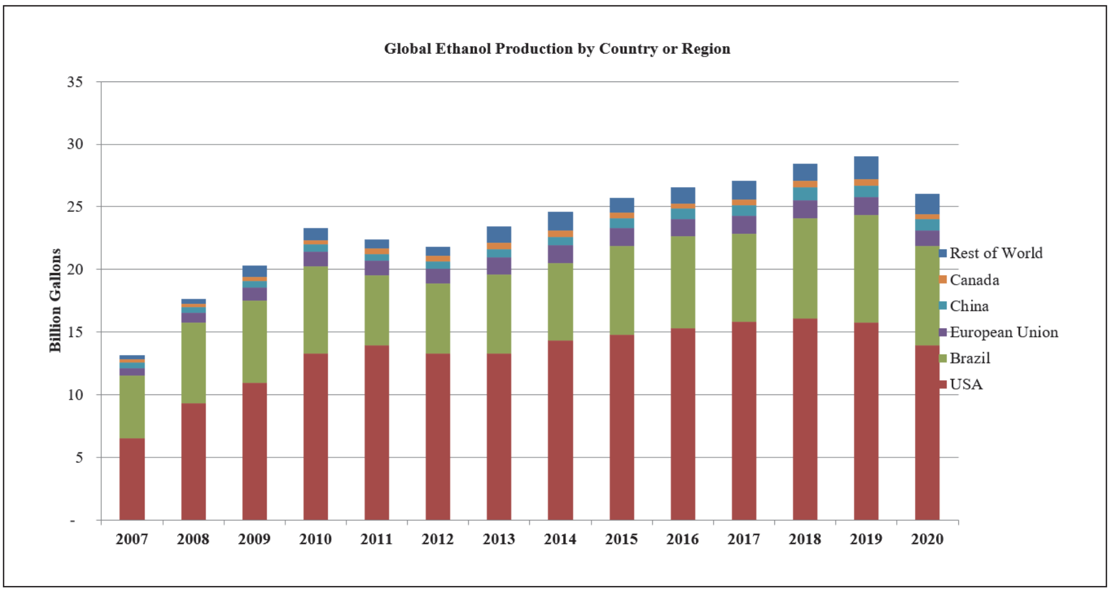


Fig. 6. The status of ethanol of Global

in biogas produced by anaerobic digestion of different wastes ranges from 50% to 75% and 50% to 25%, respectively (Sangeetha et al. 2020; Thanarasu et al. 2022)more emphasis is being laid on the enhancement of microbial electrolysis (ME. Anaerobic digestion by involving bio methanation of decomposed organic waste can produce biogas and most of it is methane and carbon dioxide. Waste reduction and management have considerable advantages because energy costs are lower and the supply is more secure, resulting in new job creation opportunities and better waste management system practices. Biomethane produced from biomass in recent years has become increasingly popular because greenhouse gas emissions can be reduced and the energy supply for the long term is increased.

The right biomass production process can produce bio--hydrogen fuel. Clean fuels such as bio-hydrogen can release water during combustion so they have a high energy density of around 141.9 MJ/kg. In addition, bio-hydrogen can be mixed with gaseous fuel as a catalyst which can improve combustion properties (Shanmugam et al. 2021a). The production of biomass such as wastewater and organic waste through photobiological fermentation can produce bio-hydrogen (Wójcik and Stachowicz 2019; Saha et al. 2022). Three methods can be used for the bio-hydrogen process, i.e., photolysis (cyanobacteria and algae using water), dark fermentation (heterotrophs), and photo-fermentation (photosynthetic bacteria) using organic compounds (Kumar et al. 2020; Kumar Sharma et al. 2021). Biohydrogen production uses biomass such as jatropha, beverage wastewater, rice waste, sugar beet molasses, glycerol, glucose, and various other plants (Ergal et al. 2018; Kumar et al. 2018). However, the most suitable raw material for biohydrogen production is biomass which has a lot of carbohydrates (Sitarz-Palczak et al. 2019; Ong et al. 2021; Zheng et al. 2021). A recently discovered renewable fuel is bio-hythane which has a methane number of about 30% and hydrogen of 10% and which is produced from biomass sources such as food, municipal waste, and agricultural waste processed through anaerobic digestion (Shanmugam et al. 2021b, a). Biomass-based bio-hythane fuels are highly available because they have a high energy density and fewer primary and secondary pollutants (Ta et al. 2020).

Energy from Wind

The demand for energy from renewable sources that have continued to increase significantly in the last few decades will have an impact on environmental protection in the long term. Of all the renewable energy sources being currently developed around the world, the most prominent is wind power (Arumugam et al. 2021; Pichika et al. 2022). The utilization of very strong wind sources can produce electrical energy through the application of wind turbine technology. In 2000, global wind energy capacity was 17 GW and increased to 59 GW in 2005. The increase in wind energy capacity continued to increase to 198 GW in 2010 and to 433 GW in 2015. Wind energy continued to increase by around 540 GW in 2017, and in 2018, it reached 591 GW. Meanwhile, in 2019 the increase in wind energy reached 651 GW, and in 2020 it reached 743 GW (Update 2017). Meanwhile, global wind energy capacity in 2021 reached 817 GW and is predicted to continue to increase in the following years (GWEC 2021). The global state of wind energy was provided in Fig. 7. The use of energy from renewable sources of wind power is increasingly popular in many developing countries. The design, production, and manufacturing of bladed wind turbines, which are separated into two groups, are all done to maximize power output and efficiency. The achievement of efficiency and power generated is likely to be higher if the manufacturing system, design, and fabrication of wind turbines can be divided into two categories, namely, Vertical Axis Wind Turbine and Horizontal Axis Wind Turbine. This is based on an in-depth inspection of each unit including hub height and rotor diameter. In addition, the material composition and mass of the blade, as well as the shape of the tip angle and nacelle unit must also be considered (Pourrajabian et al. 2021; Gaonkar and Hegde 2022). Analysis by using a computer at the proposed horizontal HAWT turbine angle will increase turbine efficiency because it can create large amounts of energy. This illustrates that the analysis system with the use of Blade Element Momentum (BEM) can extract more turbine rotor power so that the turbine rotor calculation is more ideal (Arteaga-López and Angeles-Camacho 2021; Guo et al. 2021).

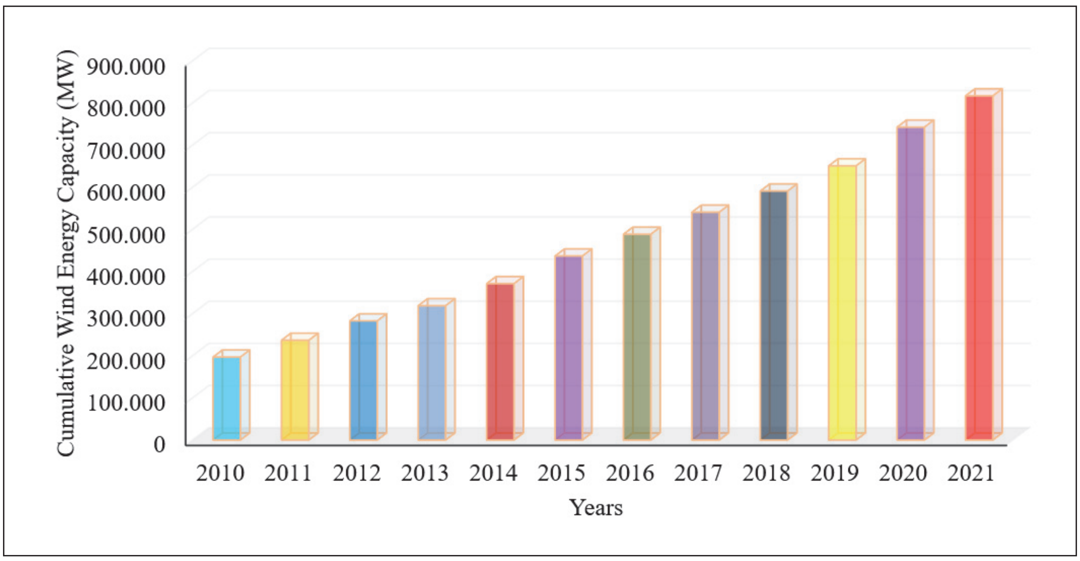


Fig. 7. Status of wind energy in Global 2010–2021

The installed wind energy capacity shown globally in 2021 worldwide will reach 817 GW. Wind turbines that are utilized through wind kinetic energy can be converted into mechanical energy and can be used as energy. Wind energy sources have provided researchers with a very attractive business for generating energy (Liu et al. 2020; Zhang et al. 2021). Blade aerodynamic design is the first step that can be taken to deliver powerful performance. Performance study for wind turbine blade design must take into account the air foil shape, attack angle, tip speed ratio, and rated wind speed. The use of computational fluid dynamics (CFD) and temperature element momentum theory can solve the Navier-Stokes equation to analyze numerical aerodynamics. Determination of the highest power coefficient can use the work system in BEM theory. The best turbine rotor rotation speed using the BEM theory has been carried out by (Ortolani et al. 2020). The development of the BEM theory with the mathematical model used for forecasting the HAWT design has been carried out. CFD is the best way to analyze aerodynamics because the results of the analysis can save costs. Indonesia has a very good source of wind energy among other Asian countries. However, until now, the installed capacity of wind energy in Indonesia is still very small compared to developing countries and even far from India. A huge influence on wind turbine efficiency is mechanical failure, electrical failure, and grid failure. Wind turbine efficiency levels may decrease with low wind speed (Amjith and Bavanish 2021a; Solomin et al. 2022). Increasing the efficiency of wind turbines can be affected by large wind losses so it is a very important step to overcome them. In this case, we assert that the decrease in performance in wind turbines is caused by very low wind speeds so that the problem in wind power plants can be reduced (Amjith and Bavanish 2021b; Pitchia Krishnan et al. 2021). Low wind speed has become a concern in all wind power plants around the world. However, the level of global wind energy capacity continues to increase as shown in Fig. 7. The shortage of wind speed, especially in India, has given a level of concern and problem. This implies that the implementation of the engineering concept developed on the wind farm does not provide a good solution (Neupane et al. 2022).

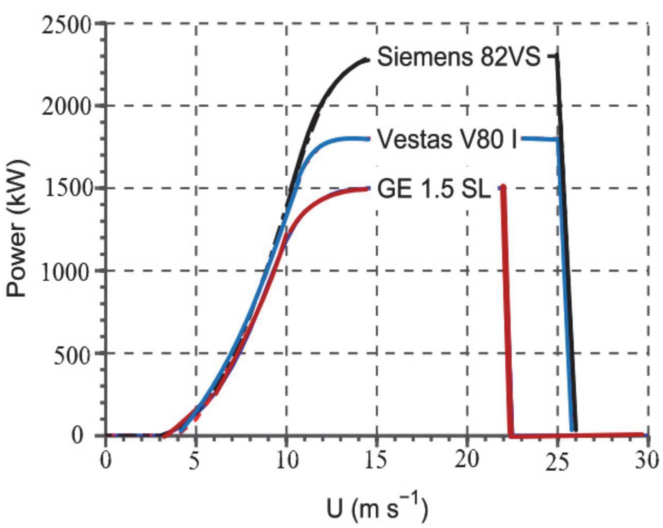


Fig. 9. Schematic diagram of representation energy hybrid biomass-wind

Great energy can be generated using windmills, wind turbines positioned to the tower. In this way, faster winds can be obtained over an altitude of about 100 feet or those with the highest landmasses. The blades such as the blades found in the turbine are used to capture wind energy with a rotor consisting of two to three blades positioned on the shaft. When the wind blows it will form an air pocket with low pressure with the blade position against the wind (Reilly 2020). Furthermore, the low--pressure air pocket will pull the blades so that the rotor will rotate which is called lift. Thus, the drag force is lower due to a stronger lifting force to form a wind force against the front side of the blade. The output power generated from the turbine more than 100 kW is a utility-scale turbine. Utility-scale turbines are often found in multi-turbine areas that have large scale and are connected to the national transmission network. The utility-scale level of a wind turbine based on engine performance is presented in Fig. 8. The turquoise angle of 5 MW which was built through a computer analysis based on performance in a research study has been carried out. The drag, lift, and momentum are used as a function of the blade angle ranging from 0–90. Maximum momentum was recorded from three different wind input speeds of 3 m/s, 12.5 m/s, and 25 m/s at the angle of 82 (Lagdani et al. 2021). The optimal blade angle of attack on the turbine will be around 81, resulting in a rotation angle at maximum speed when the wind speed is moderate. Thus, HAWT power production at low wind speeds is highly dependent on blade orientation (Shakya 2020). The presented model to evaluate comparative economy through different configurations especially for gas engine, steam turbine, the gas turbine is carried out. Based on the results, it can be found that, among others, capital expenditure and factory size are the determinants of economic improvement and the ideal system size in producing energy is obtained at low costs. The most important factors for determining energy costs with any system must be in terms of operating costs, maintenance costs, investment costs, and interest rates.

Wind-biomass hybrid system

Hybrid-based renewable energy technology has given particular interest to power systems in supplying electricity to rural areas. Interest in hybrid energy technology is due to better technological advances and rising oil prices. The hybrid power system is based on the combination of several renewable energy sources so that the efficiency and balance of energy supply are further improved. Implementation through a hybrid energy system has provided enormous benefits in reducing carbon emissions, reliability, guaranteed supply, increasing power quality, and providing new jobs for local communities. Renewable energy sources are inherently disjointed so the use and incorporation of several renewable energy sources will provide more assurance of supply. The hybrid energy technology in this review is limited in the form of gas sourced from biomass energy. Therefore, a process with two methods of anaerobic digestion and gasification is discussed in this work. The hybrid energy technology system designed between PV-Biomass-Wind is the best and is cost--effective. The concurrent charge cycle approach with PSO is a cost-effective option for further consideration. An innovative approach was created and proposed to analyze the feasibility of a system to combine biomass power generation through a gasification storage system, and generators can stabilize wind energy up to 40 MW (Hien 2019; Mori 2021; Heffron et al. 2022). Renewable energy will play a very important role in the future, this can be seen from primary energy consumption which reaches 30% as predicted by experts. Technology modeling through hybrid power generation systems among biomass, solar, and wind has been studied recently. Simulation through the MATLAB application contains all the realistic components required in hybrid biomass, solar, and wind power generation system. The electricity generated from the modeling of the Biomass-PV-Wind hybrid system can save costs, which is lower than the amount of electricity obtained from fossil fuels and is more environmentally friendly. This system cannot detect hazardous compounds and gases at the time of waste products because the energy that is owned is fully sourced from renewable energy. The use of renewable energy such as biomass, sun, and wind aims to power urban infrastructure. The optimal size of a wind-biomass hybrid system with and without energy storage can be determined by increasing supply and demand. According to, increasing the demand-supply fraction (DSF) and the percentage of renewable energy (FR) while keeping a net present value larger than zero will yield the ideal size for a wind/biomass hybrid system with and without energy storage. Mechanisms for pricing and green energy are being developed. This development is carried out to increase accommodation and energy demand at various scales. The use of software carried out by several researchers is a strategy optimization I developing a hybrid wind-biomass energy system with lower costs and higher efficiency. Renewable energy sources are estimated to be able to guarantee large-scale energy needs which are used for cooling and other electrical equipment. A more complete schematic representation of a hybrid power plant from wind biomass sources is presented in Fig. 9.

The process for designing a hybrid system is highly dependent on the reliability of the available power. To meet the costs and costs effectively and efficiently, energy technology can be utilized through a hybrid system. While schematic diagrams for different wind power plants are shown in Fig. 10.

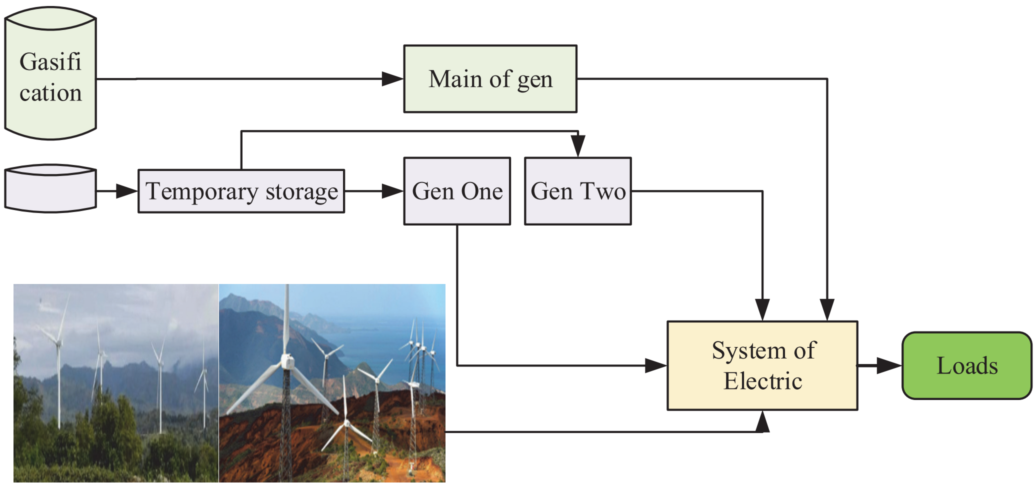


Fig. 9. Schematic diagram of representation energy hybrid biomass-wind

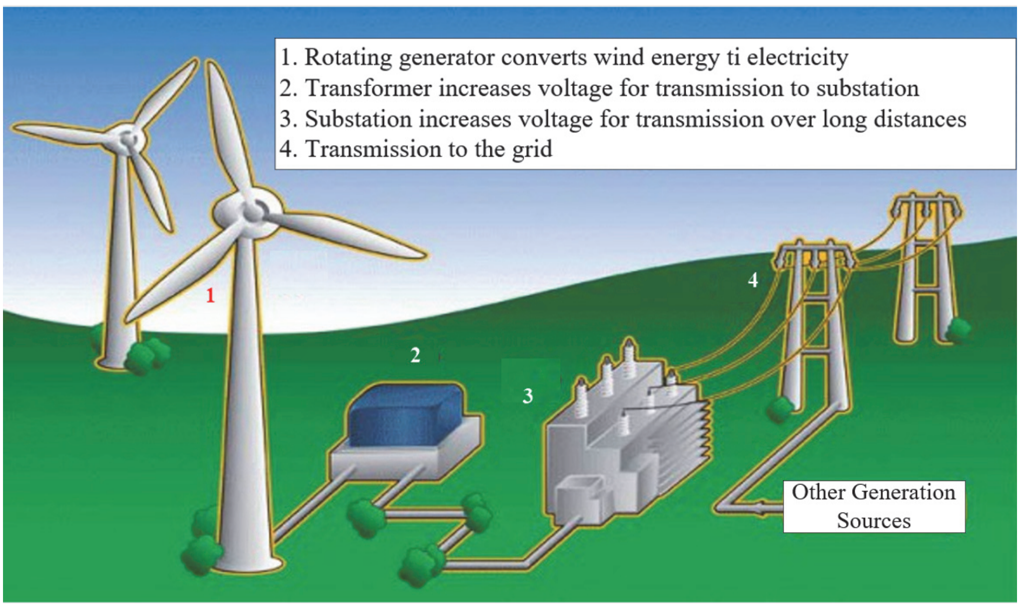


Fig. 10. Schematic diagram for different type of wind energy

The study of cost systems covers several economic characteristics in addition to energy distribution costs, life cycle costs, and current net costs. Determination of Net Present Cost through the sum of the current value of system components and component maintenance costs will apply for the duration of the project. The longevity and robustness of the power generation industry is the most important part. The energy throughout the year must have a cost ratio for its maintenance system so that it can be used for the cost of energy equipment each year. A 50-kW biomass gasifier system requires an initial investment of ±4.3 IDR. While the cost of maintenance from scratch for each year requires about 3%. Fuel supply from biomass energy requires more maintenance than wind energy. Technology with the biomass gasifier system is expected to last more than 20 years. In 20 years can provide a discount of 0.456. Biomass gasifier system maintenance costs are estimated at 28 lakhs and wind energy costs ±5.5 IDR.

Based on Government Regulation No. 79 of 2014 concerning National Energy Policy, the target for a new and renewable energy mix in 2025 are at least 23% and 31% in 2050. The target capacity of Wind Power Plant WPP) in 2025 is 255 MW. Meanwhile, until 2020, WPP has only installed around 135 MW with details of 75 MW in the Sidrap area and 60 MW in the Janeponto area). Thus, the development of wind energy in Indonesia is still a national challenge. The availability of an accurate wind energy potential map throughout Indonesia is essential as the first step in identifying and selecting wind energy project locations. The map provides information on wind characteristics in various areas such as average wind speed, and maximum and minimum speed which can be converted into power density maps and annual energy maps (in kWh/ or W/m^2).

Conclusion

Energy has become a very important need in everyday human life. Availability of sufficient energy can improve infrastructure and human development to increase productivity and the economy. Substitution of fossil energy into renewable energy sources is one of the most appropriate strategies in combating climate change, especially greenhouse gas emissions. However, its application must be carried out sustainably in supplying and providing energy so that future energy needs will continue to be met. Improved wind energy technology is a renewable energy that has experienced a sharp increase globally. Several main parameters can affect the performance of a wind turbine, such as blade angle, pitch angle, and angle of attack. The discussion of parametric conditions optimally is the best working system for wind turbines even with the lowest wind speeds. Biomass fuel will offer several advantages especially at home and at work. The advantages offered are environmentally friendly, sustainable, and an alternative to fossil fuels. The hybrid wind-biomass system has a comprehensive life cycle because it can take into account operating costs, maintenance costs, and initial costs. The biomass-wind hybrid system technology is one of the most cost-effective and competent technologies now and in the future.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Aguilar-Rivera, N., Michel-Cuello, C., Cervantes-Niño, J.J, Gómez--Merino, F.C. Olvera, & Vargas, L.A. (2021). 12 – Effects of public policies on the sustainability of the biofuels value chain. In: Ray RCBT-SB (ed) Applied Biotechnology Reviews. Academic Press, pp. 345–379.

Al-Ghussain, L., Darwish, Ahmad, A., Abubaker, A.M. & Mohamed, M.A. (2021). An integrated photovoltaic/wind/biomass and hybrid energy storage systems towards 100% renewable energy microgrids in university campuses. *Sustain Energy Technol Assessments*, 46:101273, DOI: 10.1016/j.seta.2021.101273

Alagumalai, A., Mathimani, T., Pugazhendhi, A., Atabani, A.E., Brindhadevi, K. & Canh, N.D. (2020). Experimental insight into co-combustion characteristics of oxygenated biofuels in modified DICI engine. *Fuel*, 278:118303, DOI: 10.1016/j.fuel.2020.118303

Amjith, L.R. & Bavanish, B. (2021a). Design and analysis of 5 MW horizontal axis wind turbine. *Mater Today Proc*. 37, pp. 3338–3342.

Amjith, L.R. & Bavanish, B. (2021b). Optimization of horizontal axis wind turbine blade using FEA. *Mater Today Proc*. 37, pp. 3367–3371, DOI: 10.1016/j.matpr.2020.09.215

Arias, D.M., Ortíz-Sánchez, E., Okoye, P.U., Rodríguez-Rangel, H., Ortega, A.B., Longoria, A., Domínguez-Espíndola, R. & Sebastian, P.J. (2021). A review on cyanobacteria cultivation for carbohydrate-based biofuels: Cultivation aspects, polysaccharides accumulation strategies, and biofuels production scenarios. *Sci Total Environ.* 794:148636, DOI: 10.1016/j.scitotenv.2021.148636

Arteaga-López, E. & Angeles-Camacho, C. (2021). Innovative virtual computational domain based on wind rose diagrams for micrositing small wind turbines. *Energy*, 220:119701, DOI: 10.1016/j.energy.2020.119701

Arumugam, P., Ramalingam, V. & Bhaganagar, K. (2021). A pathway towards sustainable development of small capacity horizontal axis wind turbines – Identification of influencing design parameters & their role on performance analysis. *Sustain Energy Technol Assessments*, 44:101019, DOI: 10.1016/j.seta.2021.101019

Bodzek, M. (2022). Nanoparticles for water disinfection by photocatalysis: A review. *Arch Environ Prot.* 48, pp. 3–17, DOI: 10.24425/aep.2022.140541

Chen, H., Xia, A., Zhu, X., Huang, Y., Zhu, X. & Liao, Q. (2022). Hydrothermal hydrolysis of algal biomass for biofuels production: A review. *Bioresour Technol.* 344:126213, DOI: 10.1016/j.biortech.2021.126213

Chen, J., Li, X., Jia, W., Shen, S., Deng, S., Ji, B. & Chang, J. (2021). Promotion of bioremediation performance in constructed wetland microcosms for acid mine drainage treatment by using organic substrates and supplementing domestic wastewater and plant litter broth. *J Hazard Mater*, 404:124125, DOI: 10.1016/j.jhazmat.2020.124125

Chilakamarry, C.R., Mimi Sakinah, A.M., Zularisam, A.W., Pandey, A. & Dai-Viet, N. Vo. (2021). Technological perspectives for utilisation of waste glycerol for the production of biofuels: A review. *Environ Technol Innov.* 24:101902, DOI: 10.1016/j.eti.2021.101902

Chmielniak, T. (2019). Wind and solar energy technologies of hydrogen production – a review of issues. *Polityka Energ – Energy Policy J.* 22, pp. 5–20.

Chowdhury, H., Loganathan, B., Mustary, I., Alam, F. & Mobil, S.M.A. (2019). Chapter 12 – Algae for biofuels: The third generation of feedstock. [In:] Basile, A., Dalena, F.B.T-S. and TG, F. (eds). Elsevier, pp 323–344.

Chudy, R., Szulecki, K., Siry, J. & Grala, R. (2021). Woody Biomass for Energy Production. *Acad – Mag Polish Acad Sci.* 62–65, DOI: 10.24425/academiaPAS.2021.138414

Council GWE (2021) GWEC global wind report 2021. Glob Wind Energy Counc Brussels, Belgium.

Das, P.V.P.C., Mathimani, T. & Pugazhendhi, A. (2021a). A comprehensive review on the factors affecting thermochemical conversion efficiency of algal biomass to energy. *Sci Total Environ.* 766:144213, DOI: 10.1016/j.scitotenv.2020.144213

Das, P.V.P.C., Mathimani, T. & Pugazhendhi, A. (2021b). Recent advances in thermochemical methods for the conversion of algal biomass to energy. *Sci Total Environ.* 766:144608, DOI: 10.1016/j.scitotenv.2020.144608

Deviram, G., Mathimani, T., Anto, S., Ahamed, T.S., Ananth, D.A. & Pugazhendhi, A. (2020). Applications of microalgal and cyanobacterial biomass on a way to safe, cleaner and a sustainable environment. *J Clean Prod.* 253:119770, DOI: 10.1016/j.jclepro.2019.119770

Erdiwansyah, E., Mahidin, M., Husin, H., Nasaruddin, N., Khairil, K., Zaki, M. & Jamaluddin, J. (2020). Investigation of availability, demand, targets, economic growth and development of RE 2017–2050: Case study in Indonesia. *International Journal of Coal Science & Technology*, 8, pp. 483–499, DOI: 10.1007/s40789-020-00391-4

Erdiwansyah, E., Gani, A. M.H.N., Mamat, R. & Sarjono, R.E. (2022). Policies and laws in the application of renewable energy Indonesia: A reviews. *AIMS Energy*, 10, pp. 23–44, DOI: 10.3934/energy.2022002

Erdiwansyah, E., Mahidin, H. H., Nasaruddin, S., Zaki, M. & Muhibbddin. (2021). A critical review of the integration of renewable energy sources with various technologies. *Prot Control Mod Power Syst.* 6:3, DOI: 10.1186/s41601-021-00181-3

Erdiwansyah, E., Mamat, R., Sani, M.S.M., Sudhakar, K., Kadarohman, A. & Sardjono, R.E. (2019a). An overview of Higher alcohol and biodiesel as alternative fuels in engines. *Energy Reports*, 5, pp.467–479, DOI: 10.1016/j.egyr.2019.04.009

Erdiwansyah,E., Mamat, R., Sani, M.S.M. & Sudhakar, K. (2019b). Renewable energy in Southeast Asia: Policies and recommendations. *Sci Total Environ*., DOI: 10.1016/j.scitotenv.2019.03.273

Ergal, İ., Fuchs, W., Hasibar, B., Thallinger, B., Bochmann, G. & Rittmann, S.K-M.R. (2018). The physiology and biotechnology of dark fermentative biohydrogen production. *Biotechnol Adv.* 36, pp. 2165–2186, DOI: 10.1016/j.biotechadv.2018.10.005

Farina, A. & Anctil, A. (2022). Material consumption and environmental impact of wind turbines in the USA and globally. *Resour Conserv Recycl.* 176:105938, DOI: 10.1016/j.resconrec.2021.105938

Ferreira Mota, G., Germano de Sousa, I., Luiz Barros de Oliveira, A., Cavalcante, A.L.G., Moreira, K.S., Cavalcante, F.T.T., Erick da Silva Souza, J., Rafael de Aguiar Falcão, I., Rocha, T.G., Valério, R.B.R., Cristina Freitas de Carvalho, S., Neto, F.S., Serpa, J.F., Karolinny Chaves de Lima, R., Cristiane Martins de Souza, M. & José C.S. dos Santos. (2022). Biodiesel production from microalgae using lipase-based catalysts: Current challenges and prospects. *Algal Res.* 62:102616, DOI: 10.1016/j.algal.2021.102616

Gambelli, D., Alberti, F., Solfanelli, F., Vairo, D. & Zanoli, R. (2017). Third generation algae biofuels in Italy by 2030: A scenario analysis using Bayesian networks. *Energy Policy*, 103, pp. 165–178, DOI: 10.1016/j.enpol.2017.01.013

Gaonkar, R.U. & Hegde, R.N. (2022). An investigation on the performance and viability of a hybrid twisted blade profile for a horizontal axis micro wind turbine. *Mater Today Proc.* 49, pp. 1200–1209, DOI: 10.1016/j.matpr.2021.06.288

Ge, S., Manigandan, S., Mathimani, T., Basha, S., Xia, C., Brindhadevi, K., Unpaprom, Y., Whangchai, K. & Pugazhendhi, A. (2022). An assessment of agricultural waste cellulosic biofuel for improved combustion and emission characteristics. *Sci Total Environ.* 813:152418.

Ge, S., Yek, P.N.Y., Cheng, Y.W., Xia, C., Mahari, W.A.W., Liew, R.K., Peng, W., Yuan, T.Q., Tabatabaei, M., Aghbashlo, M., Sonne, C. & Lam S.S. (2021). Progress in microwave pyrolysis conversion of agricultural waste to value-added biofuels: A batch to continuous approach. *Renew Sustain Energy Rev. 1*35:110148, DOI: 10.1016/j.rser.2020.110148

Ghosh, M., Ghosh, A. & Roy, A. (2020). Renewable and Sustainable Materials in Automotive Industry. [In:] Hashmi, S., Choudhury IABT-E of R and SM (eds). Elsevier, Oxford, pp. 162–179.

Glivin, G., Edwin, M. & Sekhar, S.J. (2018). Techno-economic studies on the influences of nonuniform feeding in the biogas plants of educational institutions*. Environ Prog Sustain Energy*, 37, pp. 2156–2164.

Glivin, G., Kalaiselvan, N., Mariappan, V., Premalatha, M., Murugan, P.C. & Sekhar, J. (2021a). Conversion of biowaste to biogas: A review of current status on techno-economic challenges, policies, technologies and mitigation to environmental impacts. *Fuel*, 302:121153, DOI: 10.1016/j.fuel.2021.121153

Glivin, G. & Sekhar, J. (2020a). Simulation of anaerobic digesters for the non-uniform loading of biowaste generated from an educational institution. *Lat Am Appl Res Int J*. 50, pp. 33–40.

Glivin, G. & Sekhar, S.J. (2020b). Waste potential, barriers and economic benefits of implementing different models of biogas plants in a few Indian educational institutions. *BioEnergy Res.* 13, pp. 668–682.

Glivin, G., Vairavan, M., Manickam, P. & Santhappan, J.S. (2021b). Techno Economic Studies on the Effective Utilization of Non--Uniform Biowaste Generation for Biogas Production. *Anaerob Dig Built Environ.* 81.

Goh, Y., Yap, S.P. & Tong, T.Y. (2020). Bamboo: The Emerging Renewable Material for Sustainable Construction. [In:] Hashmi S, Choudhury IABT-E of R and SM (eds). Elsevier, Oxford, pp. 365–376.

Guo, T., Guo, X., Gao, Z., Li, S., Zheng, X., Gao, X., Li, R., Wang, T., Li, Y. & Li, D. (2021). Nacelle and tower effect on a stand--alone wind turbine energy output – A discussion on field measurements of a small wind turbine. *Appl Energy*, 303:117590, DOI: 10.1016/j.apenergy.2021.117590

Gururani, P., Bhatnagar, P., Bisht, B., Jaiswal, K.K., Kumar, V., Kumar, S., Vlaskin, M.S., Grigorenko, A.V. & Rindin, K.G. (2022). Recent advances and viability in sustainable thermochemical conversion of sludge to bio-fuel production. *Fuel*, 316:123351, DOI: 10.1016/j.fuel.2022.123351

GWEC (2021). GWEC forecasts 817 GW of wind power in 2021. https://gwec.net/gwec-forecasts-817-gw-of-wind-power-in-2021/#:~:text=The global cumulative installed wind,153.5 GW in 2017–2021.

Heffron, R.J., Körner, M.-F., Sumarno, T., Wagner, J., Weibelzahl, M. & Fridgen, G. (2022). How different electricity pricing systems affect the energy trilemma: Assessing Indonesia's electricity market transition. *Energy Econ*, 107:105663, DOI: 10.1016/j.eneco.2021.105663

Hien, P.D. (2019) Excessive electricity intensity of Vietnam: Evidence from a comparative study of Asia-Pacific countries. *Energy Policy*, 130, pp. 409–417, DOI: 10.1016/j.enpol.2019.04.025

Indonesia C (2021) RI Targets Renewable Energy to Reach 50% by 2050.

International Energy Agency IEA, Bank W (2014) Sustainable Energy for All 2013–2014: Global Tracking Framework Report. The World Bank.

Jurasz, J. & Mikulik, J. (2017) Economic and environmental analysis of a hybrid solar, wind and pumped storage hydroelectric energy source: a Polish perspective. *Bull. Polish Acad. Sci. Tech. Sci*. 65, pp. 859–869.

Kalinichenko, A. & Havrysh, V. (2019). Feasibility study of biogas project development: technology maturity, feedstock, and utilization pathway. *Arch Environ Prot.* 45, pp. 68–83, DOI: 10.24425/aep.2019.126423

Kandasamy, S., Bhuvanendran, N., Narayanan, M. & He, Z. (2022). Chapter 13 – Thermochemical conversion of algal biomass. [In:] El-Sheekh, M., Abomohra AE-FBT-H of AB (eds). Elsevier, pp. 281–302

Kandasamy, S., Devarayan, K., Bhuvanendran, N., Zhang, B., He, Z., Narayanan, M., Mathimani, T., Ravichandran, S. & Pugazhendhi, A. (2021). Accelerating the production of bio-oil from hydrothermal liquefaction of microalgae via recycled biochar-supported catalysts. *J Environ Chem Eng.* 9:105321, DOI: 10.1016/j.jece.2021.105321

Karpagam, R., Jawaharraj, K. & Gnanam, R. (2021). Review on integrated biofuel production from microalgal biomass through the outset of transesterification route: a cascade approach for sustainable bioenergy. *Sci Total Environ.* 766:144236, DOI: 10.1016/j.scitotenv.2020.144236

Kim, B., Heo, H.Y., Son, J., Yang, J., Chang, Y.K., Lee, J.H. & Lee, J.W. (2019). Simplifying biodiesel production from microalgae via wet in situ transesterification: A review in current research and future prospects. *Algal Res.* 41:101557, DOI: 10.1016/j.algal.2019.101557

Klaimi, R., Alnouri, S.Y. & Stijepović, M. (2021). Design and thermo-economic evaluation of an integrated concentrated solar power – Desalination tri-generation system. *Energy Convers Manag.* 249:114865, DOI: 10.1016/j.enconman.2021.114865

Kulyal, L. & Jalal, P. (2022). Bioenergy, a finer alternative for India: Scope, barriers, socio-economic benefits and identified solution. *Bioresour Technol Reports*, 17:100947, DOI: 10.1016/j.biteb.2022.100947

Kumar, G., Cho, S-K., Sivagurunathan, P., Anburajan, P., Mahapatra, D.M., Park, J.H., Pugazhendhi, A. (2018) Insights into evolutionary trends in molecular biology tools in microbial screening for biohydrogen production through dark fermentation. *Int J Hydrogen Energy*, 43: pp. 19885–19901, DOI: 10.1016/j.ijhydene.2018.09.040

Kumar, G., Mathimani, T., Sivaramakrishnan, R., Shanmugam, S., Bhatia, S.K., Pugazhendhi, A. (2020). Application of molecular techniques in biohydrogen production as a clean fuel. *Sci Total Environ.* 722:137795, DOI: 10.1016/j.scitotenv.2020.137795

Kumar Sharma, A., Kumar Ghodke, P., Manna, S. & Chen, W.-H. (2021). Emerging technologies for sustainable production of biohydrogen production from microalgae: A state-of-the-art review of upstream and downstream processes. *Bioresour Technol.* 342:126057, DOI: 10.1016/j.biortech.2021.126057

Lagdani, O., Tarfaoui, M., Nachtane, M., Trihi, M. & Laaouidi, H. (2021). Modal analysis of an iced offshore composite wind turbine blade. *Wind Eng.* 0309524X211011685

Lin, C-Y. & Lu, C. (2021). Development perspectives of promising lignocellulose feedstocks for production of advanced generation biofuels: A review. *Renew Sustain Energy Rev.* 136:110445, DOI: 10.1016/j.rser.2020.110445

Liu, H., Li, Y., Duan, Z. & Chen, C. (2020). A review on multi--objective optimization framework in wind energy forecasting techniques and applications. *Energy Convers Manag.* 224:113324, DOI: 10.1016/j.enconman.2020.113324

Malik, P., Awasthi, M. & Sinha, S. (2022). A techno-economic investigation of grid integrated hybrid renewable energy systems. *Sustain Energy Technol Assessments*, 51:101976, DOI: 10.1016/j.seta.2022.101976

Mathimani, T. & Mallick, N. (2019). A review on the hydrothermal processing of microalgal biomass to bio-oil – Knowledge gaps and recent advances. *J Clean Prod.* 217, pp. 69–84, DOI: 10.1016/j.jclepro.2019.01.129

Mathimani, T., Sekar, M., Shanmugam, S., Sabir, J.S.M., Chi, N.T.L. & Pugazhendhi, A. (2021). Relative abundance of lipid types among *Chlorella sp.* and *Scenedesmus sp.* and ameliorating homogeneous acid catalytic conditions using central composite design (CCD) for maximizing fatty acid methyl ester yield. *Sci Total Environ.* 771:144700, DOI: 10.1016/j.scitotenv.2020.144700

Micallef, D. & Rezaeiha, A. (2021). Floating offshore wind turbine aerodynamics: Trends and future challenges. *Renew Sustain Energy Rev.* 152:111696, DOI: 10.1016/j.rser.2021.111696

Mielcarek-Bocheńska, P. & Rzeźnik, W. (2019) Ammonia emission from livestock productionin Poland and its regional diversity in the years 2005–2017. *Arch Environ Prot.* 45, pp. 114–121, DOI: 10.24425/aep.2019.130247

Mori, A. (2021) 2 Struggles for energy transition in the electricity system in Asian countries. China's Carbon-Energy Policy Asia's Energy Transit Carbon Leakage, Relocat Halos 23

Moshood, T.D., Nawanir, G. & Mahmud, F. (2021). Microalgae biofuels production: A systematic review on socioeconomic prospects of microalgae biofuels and policy implications. *Environ Challenges*, 5:100207, DOI: 10.1016/j.envc.2021.100207

Musharavati, F., Khanmohammadi, S. & Pakseresht, A. (2021). A novel multi-generation energy system based on geothermal energy source: Thermo-economic evaluation and optimization. *Energy Convers Manag.* 230:113829, DOI: 10.1016/j.enconman.2021.113829

Narwane, V.S., Yadav, V.S., Raut, R.D., Narkhede, B.E. & Gardas, B.B. (2021). Sustainable development challenges of the biofuel industry in India based on integrated MCDM approach. *Renew Energy* 164, pp. 298–309, DOI: 10.1016/j.renene.2020.09.077

Neupane, D., Kafle, S., Karki, K.R., Kim, D.H. & Pradhan, P. (2022). Solar and wind energy potential assessment at provincial level in Nepal: Geospatial and economic analysis. *Renew Energy*, 181, pp. 278–291, DOI: 10.1016/j.renene.2021.09.027

Oliveira, C.Y.B., D'Alessandro, E.B., Antoniosi Filho, N.R., Lopes, R.G. & Derner, R.B. (2021). Synergistic effect of growth conditions and organic carbon sources for improving biomass production and biodiesel quality by the microalga *Choricystis minor* var. minor. *Sci Total Environ.* 759:143476, DOI: 10.1016/j.scitotenv.2020.143476

Olsztyńska, I. (2019). Biomass in the fuel mix of the Polish energy and heating sector. *Polityka Energ – Energy Policy J.* 22, pp. 99–118

Ong, E.S., Rabbani, A.H., Habashy, M.M., Abdeldayem, O.M., Al-Sakkari, E.G. & Rene, E.R. (2021). Palm oil industrial wastes as a promising feedstock for biohydrogen production: A comprehensive review. *Environ Pollut.* 291:118160, DOI: 10.1016/j.envpol.2021.118160

Openshaw, K. (2010). Biomass energy: Employment generation and its contribution to poverty alleviation. *Biomass and Bioenergy*, 34, pp. 365–378, DOI: 10.1016/j.biombioe.2009.11.008

Ortolani, A., Persico, G., Drofelnik, J., Jackson, A. & Campobasso, M.S. (2020). Cross-comparative analysis of loads and power of pitching floating offshore wind turbine rotors using frequency--domain Navier-Stokes CFD and blade element momentum theory. *Journal of Physics: Conference Series*. IOP Publishing, p. 52016.

Outlook IIET. (2021). Tracking Progress of Energy Transition in Indonesia. Jakarta Inst Essent Serv Reform

Pichika, S.V.V.S.N., Yadav, R., Geetha Rajasekharan, S., Praveen, H.M. & Inturi, V. (2022). Optimal sensor placement for identifying multi-component failures in a wind turbine gearbox using integrated condition monitoring scheme. *Appl Acoust.* 187:108505, DOI: 10.1016/j.apacoust.2021.108505

Pitchia Krishnan, B., Mathanbabu, M., Sathyamoorthy, G., Gokulnath, K. & Kumar, L.G.S. (2021). Performance estimation and redesign of horizontal axis wind turbine (HAWT) blade. *Mater Today Proc.* 46, pp. 8025–8031, DOI: 10.1016/j.matpr.2021.02.777

Pourrajabian, A., Dehghan, M. & Rahgozar, S. (2021). Genetic algorithms for the design and optimization of horizontal axis wind turbine (HAWT) blades: A continuous approach or a binary one? *Sustain Energy Technol Assessments*, 44:101022, DOI: 10.1016/j.seta.2021.101022

Reilly, L.A. (2020). Exploration of Model-Resolution Dependence of Forecasted Wind Hazards for Small Unmanned Aircraft System Operations. The University of North Dakota ProQuest Dissertations Publishing, 2020. 28085974.

Saha, R., Bhattacharya, D. & Mukhopadhyay, M. (2022). Enhanced production of biohydrogen from lignocellulosic feedstocks using microorganisms: A comprehensive review. *Energy Convers Manag.* X 13:100153, DOI: 10.1016/j.ecmx.2021.100153

Sameeroddin, M., Deshmukh, M.K.G., Viswa, G. & Sattar, M.A. (2021). Renewable energy: Fuel from biomass, production of ethanol from various sustainable sources by fermentation process. *Mater Today Proc*., DOI: 10.1016/j.matpr.2021.01.746

Sangeetha, T., Rajneesh, C.P. & Yan, W-M. (2020). 15 – Integration of microbial electrolysis cells with anaerobic digestion to treat beer industry wastewater. [In:] Abbassi, R., Yadav, A.K., Khan, F. & Garaniya, VBT-IMFC for WT (eds). Butterworth-Heinemann, pp. 313–346.

Saravanan, A.P., Pugazhendhi, A. & Mathimani, T. (2020). A comprehensive assessment of biofuel policies in the BRICS nations: Implementation, blending target and gaps. *Fuel* 272:117635, DOI: 10.1016/j.fuel.2020.117635

Sellevold, E., May, T., Gangi, S., Kulakowski, J., McDonnell, I., Hill, D. & Grabowski, M. (2020). Asset tracking, condition visibility and sustainability using unmanned aerial systems in global logistics. *Transp Res Interdiscip Perspect.* 8:100234, DOI: 10.1016/j.trip.2020.100234

Shakya, S. (2020). Performance analysis of wind turbine monitoring mechanism using integrated classification and optimization techniques. *J Artif Intell.* 2, pp. 31–41.

Shanmugam, S., Mathimani, T., Rene, E.R., Geo, V.E., Arun, A., Brindhadevi, K. & Pugazhendhi, A. (2021a). Biohythane production from organic waste: Recent advancements, technical bottlenecks and prospects. *Int J Hydrogen Energy*, 46, pp. 11201–11216, DOI: 10.1016/j.ijhydene.2020.10.132

Shanmugam, S., Sekar, M., Sivaramakrishnan, R., Raj, T., Ong, E.S., Rabbani, A.H., Rene, E.R., Mathimani, T., Brindhadevi, K. & Pugazhendhi, A. (2021b). Pretreatment of second and third generation feedstock for enhanced biohythane production: Challenges, recent trends and perspectives. *Int J Hydrogen Energy*, 46, pp. 11252–11268, DOI: 10.1016/j.ijhydene.2020.12.083

Sharma, M., Singh, J., Baskar, C. & Kumar, A. (2019). A comprehensive review of renewable energy production from biomass-derived bio- -oil. *Biotechnol J Biotechnol Comput Biol Bionanotechnol*, 100:

Sheng, Y., Mathimani, T., Brindhadevi, K., Basha, S., Elfasakhany, A., Xia, C. & Pugazhendhi, A. (2022). Combined effect of CO_2 concentration and low-cost urea repletion/starvation in Chlorella vulgaris for ameliorating growth metrics, total and non-polar lipid accumulation and fatty acid composition. *Sci Total Environ*, 808:151969, DOI: 10.1016/j.scitotenv.2021.151969

Sitarz-Palczak, E., Kalembkiewicz, J. & Galas, D. (2019). Comparative study on the characteristics of coal fly ash and biomass ash geopolymers. *Arch Environ Prot.* 45, pp. 126–135, DOI: 10.24425/aep.2019.126427

Solomin, E.V., Terekhin, A.A., Martyanov, A.S., Shishkov, A.N., Kovalyov, A.A., Ismagilov, D.R. & Ryavkin, G.N. (2022). Horizontal axis wind turbine yaw differential error reduction approach. *Energy Convers Manag.* 254:115255, DOI: 10.1016/j.enconman.2022.115255

Srivastava, R.K., Shetti, N.P., Reddy, K.R., Kwon, E.E., Nadagouda, M.N. & Aminabhavi, T.M. (2021) Biomass utilization and production of biofuels from carbon neutral materials. *Environ Pollut.* 276:116731, DOI: 10.1016/j.envpol.2021.116731

Sudhakar, M.P., Kumar, B.R., Mathimani, T. & Arunkumar, K. (2019). A review on bioenergy and bioactive compounds from microalgae and macroalgae-sustainable energy perspective. *J Clean Prod.* 228, pp. 1320–1333, DOI: 10.1016/j.jclepro.2019.04.287

Sutherland, D.L., McCauley, J., Labeeuw, L., Ray, P., Kuzhiumparambil, U., Hall, C., Doblin, M. & Nguyen, L.N. (2021). How microalgal biotechnology can assist with the UN Sustainable Development Goals for natural resource management. *Curr Res Environ Sustain.* 3:100050, DOI: 10.1016/j.crsust.2021.100050

Ta, D-T., Lin, C-Y., Ta, T-M-N. & Chu, C-Y. (2020). Biohythane production via single-stage fermentation using gel-entrapped anaerobic microorganisms: Effect of hydraulic retention time. *Bioresour Technol.* 317:123986, DOI: 10.1016/j.biortech.2020.123986

Tarique, J., Sapuan, S.M., Khalina, A., Sherwani, S.F.K., Yusuf, J. & Ilyas, R.A. (2021). Recent developments in sustainable arrowroot (Maranta arundinacea Linn) starch biopolymers, fibres, biopolymer composites and their potential industrial applications: A review. *J Mater Res Technol.* 13, pp. 1191–1219, DOI: 10.1016/j.jmrt.2021.05.047

Thanarasu, A., Periyasamy, K. & Subramanian, S. (2022). An integrated anaerobic digestion and microbial electrolysis system for the enhancement of methane production from organic waste: Fundamentals, innovative design and scale-up deliberation. *Chemosphere*, 287:131886, DOI: 10.1016/j.chemosphere.2021.131886

Thanigaivel, S., Priya, A.K., Dutta, K., Rajendran, S. & Vasseghian, Y. (2022) Engineering strategies and opportunities of next generation biofuel from microalgae: A perspective review on the potential bioenergy feedstock. *Fuel*, 312:122827, DOI: 10.1016/j.fuel.2021.122827

Tuan Hoang, A. & Viet Pham, V. (2021). 2-Methylfuran (MF) as a potential biofuel: A thorough review on the production pathway from biomass, combustion progress, and application in engines. *Renew Sustain Energy Rev.* 148:111265, DOI: 10.1016/j.rser.2021.111265

Update AM (2017) Global wind report. Glob Wind Energy Council.

Velusamy, K., Devanand, J., Senthil Kumar, P., Soundarajan, K., Sivasubramanian, V., Sindhu, J. & Vo, D.V.N. (2021). A review on nano-catalysts and biochar-based catalysts for biofuel production. *Fuel*, 306:121632, DOI: 10.1016/j.fuel.2021.121632

Wang, L., Liu, X. & Kolios, A. (2016). State of the art in the aeroelasticity of wind turbine blades: Aeroelastic modelling. *Renew Sustain Energy Rev.* 64, pp. 195–210, DOI: 10.1016/j.rser.2016.06.007

Whangchai, K., Mathimani, T., Sekar, M., Shanmugam, S., Brindhadevi, K., Hung, T.V., Chinnathambi, A., Alharbi, S.A. & Pugazhendhi, A. (2021). Synergistic supplementation of organic carbon substrates for upgrading neutral lipids and fatty acids contents in microalga. *J Environ Chem Eng.* 9:105482, DOI: 10.1016/j.jece.2021.105482

Wicker, R.J., Kumar, G., Khan, E. & Bhatnagar, A. (2021). Emergent green technologies for cost-effective valorization of microalgal biomass to renewable fuel products under a biorefinery scheme. *Chem Eng J.* 415:128932, DOI: 10.1016/j.cej.2021.128932

Wijayasekera, S.C., Hewage, K., Siddiqui, O., Hettiaratchi, P. & Sadiq, R. (2022). Waste-to-hydrogen technologies: A critical review of techno-economic and socio-environmental sustainability. *Int J Hydrogen Energy*, 47, pp. 5842–5870, DOI: 10.1016/j.ijhydene.2021.11.226

Wójcik, M. & Stachowicz, F. (2019). Influence of sewage sludge conditioning with use of biomass ash on its rheological

characteristics. *Arch Environ Prot.* 45, pp. 92–102, DOI: 10.24425/aep.2019.126425
Wu, L., Wei, W., Song, L., Woźniak-Karczewska, M., Chrzanowski, L. & Ni, B.J. (2021). Upgrading biogas produced in anaerobic digestion: Biological removal and bioconversion of CO_2 in biogas. *Renew Sustain Energy Rev.* 150:111448, DOI: 10.1016/j.rser.2021.111448
Xu, L., Zhang, Q. & Shi, X. (2019). Stakeholders strategies in poverty alleviation and clean energy access: A case study of China's PV poverty alleviation program. *Energy Policy*, 135:111011, DOI: 10.1016/j.enpol.2019.111011
Yin, Z., Zhu, L., Li, S., Hu, T., Chu, R., Mo, F., Hu, D., Liu, C. & Li, Bin. (2020). A comprehensive review on cultivation and harvesting of microalgae for biodiesel production: Environmental pollution control and future directions. *Bioresour Technol.* 301:122804, DOI: 10.1016/j.biortech.2020.122804
Zhang, L., Wang, J., Niu, X. & Liu, Z. (2021). Ensemble wind speed forecasting with multi-objective Archimedes optimization algorithm and sub-model selection. *Appl Energy*, 301:117449, DOI: 10.1016/j.apenergy.2021.117449
Zhao, S., Yao, L., He, H., Yiping, Z., Lei, H., Yujia, Z., Yajing, Y. & Jianli, J. (2019). Preparation and environmental toxicity of non-sintered ceramsite using coal gasification coarse slag. *Arch Environ Prot.* 45, pp. 84–90, DOI: 10.24425/aep.2019.127983
Zheng, Y., Zhang, Q., Zhang, Z., Jing, Y., Hu, J., He, C. & Lu, C. (2021). A review on biological recycling in agricultural waste--based biohydrogen production: Recent developments. *Bioresour Technol.* 126595, DOI: 10.1016/j.biortech.2021.126595
Zhuang, X., Liu, J., Wang, C., Zhang, Q. & Ma, L. (2022). A review on the stepwise processes of hydrothermal liquefaction (HTL): Recovery of nitrogen sources and upgrading of biocrude. *Fuel*, 313:122671, DOI: 10.1016/j.fuel.2021.122671