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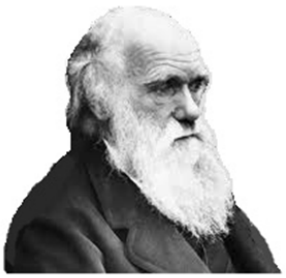

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Biogas Production from Sustainable Feedstock as a Green Renewable Energy: A Review

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ABSTRACT

In order to meet the growing demand for energy and to reduce the dependency on non-renewable energy sources, a renewable alternative energy source is needed. For decades, the development of renewable energy has been performed to meet a qualified source for alternative energy, including biomass, solar, geothermal, hydropower, sea and wind. One of promising form of renewable energy is biogas because it can be derived from evergreen feedstock that available widely. It even can use animal waste, agricultural waste, industrial waste, food waste as it raw materials, thus supporting clean and sustainable energy. Biogas is a form of gaseous bioenergy produced from the decomposition of organic matter or biomass by methanogenic bacteria in an anaerobic system. Research has been conducted to find the best raw materials as the source for biogas production. Here we will discuss type of natural feedstock that have been used as the raw materials for biogas production. Several type of raw materials including natural feedstock and waste were discussed to give a glimpse of sustainability in the generation of this biogas energy.

***Keywords*:** Biogas, feedstock, natural resources, renewable energy

1. INTRODUCTION

The world population almost reached 7.6 billion in mid-2017 with an increase of 1.10% / year or equivalent to 83 million people per year. By 2030, the world population is projected to increase to 8.6 billion and increase further in 2050 to 9.8 billion and 11.2 billion by 2100 [1]. The current population of Indonesia (as the 4th most populous country in the world) is 264

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million people with a population growth rate of 0.74% per year [1], [2]. The increasing population is a challenge for many things including energy (John, et al., 2011).

Global energy demand will continue to increase along with the increase in population. It is projected that in 2015 – 2040 world energy use will increase by 28% [3]. As much as 78.4% of the energy needed globally in 2015 was supplied from fossil fuels which are non-renewable energy sources [4]. This dependence is predicted to continue because fossil fuels are projected to still contribute as much as 77% of energy use in 2040 [3]. In 2016, global primary energy consumption increased by 1% [5]. Indonesia has also experienced an increase in energy consumption from year to year. This condition will continue to deplete national energy reserves. Meanwhile, reserves of crude oil, gas, and coal will run out, respectively, within a period of 23 years, 59 years, and 82 years [6]. What is also concerning is that current energy use is always associated with greenhouse gas emissions. The increase in consumption of non-renewable energy is always associated with an increase in greenhouse gas emissions and is not associated with a carbon fixation process or a reduction in gas emissions. The use of non-renewable energy is closely related to environmental damage.

The increasing demand, the depletion of natural resources, and the emergence of environmental problems due to the use of non-renewable energy sources have urged in-depth exploration to find renewable alternative energy to meet energy needs in the present and in the future [7]. Renewable energy can come from various sources, such as biomass, solar, geothermal, hydropower, sea and wind [8]. However, there are a number of drawbacks to this renewable energy source. Among all forms of renewable energy, biomass energy is the most attractive energy source to be utilized globally. Biomass is any material derived from living things which is a storehouse of chemical energy that can be converted into all forms of energy [4]. The formation of biomass is always related to the absorption of CO2 through the process of photosynthesis. The formation of biomass is related to the process of storing solar energy. Biomass is a renewable energy source. In 2015, the use of biomass energy was recorded at 14.1% or 19.3% of the total use of renewable energy sources globally [4]. One type of renewable energy that can be produced from biomass is biogas.

Biogas is a form of gaseous bioenergy produced from the decomposition of organic matter or biomass by methanogenic bacteria in an anaerobic (PA) system [4]. Raw materials for the formation of biogas can come from many sources, including animal waste, agricultural waste, industrial waste, food waste and others [9]. In addition to producing energy, in the process of its formation, it also produces fertilizer which can be an alternative solution as a substitute for fertilizer. Currently, the price of fertilizer continues to rise [10]. The fertilizer obtained from the rest of the biogas formation is in the form of sludge which contains nitrogen, phosphorus, and potassium so that it is very easy to be processed into fertilizer, both liquid fertilizer and solid fertilizer to fertilize plants [11], [12]. The biogas production process always requires organic biomass which is formed due to the carbon fixation process. When compared with fossil fuels, the use of biogas can reduce the effect of greenhouse gases drastically because it always begins with carbon dioxide fixation which we do not encounter in other energy uses [13].

2. BIOGAS

Biogas is a gas produced from the breakdown of biologically organic matter carried out in conditions without oxygen or anaerobic [14]. Biogas production occurs when methanogenic

bacteria successfully break down organic matter in conditions without oxygen. However, methanogenic bacteria are microorganisms that are quite sensitive to environmental changes in the digester, so that fluctuating temperature changes can reduce the activity and growth of methanogenic bacteria in the digester which will have an impact on the level of biogas production [15].

Sources used to produce biogas include animal waste, agricultural waste, sludge, sewage sludge, industrial by-products, wastewater, and others. Cow and pig waste in the form of manure is often used as the main source to produce biogas because it contains microorganisms needed to degrade the substrate and produce biogas [16] The characteristics of biogas are that it has a combustion temperature in the range of 650 – 750 °C, about 20% lighter than air, has no odor after burning, and is blue in color similar to liquid petroleum gas (LPG) [15].

Table 1. Biogas Composition

Compound	Content (% / Volume)
Methane ($\mathbf{CH_4}$)	55 – 65
Carbon Dioxide ($\mathbf{CO_2}$)	35 – 45
Hydrogen Sulphide ($\mathbf{H_2S}$)	0 – 1
Nitrogen ($\mathbf{N_2}$)	0 – 3
Hydrogen ($\mathbf{H_2}$)	0 – 1
Oxygen ($\mathbf{O_2}$)	0 – 2
Ammonia ($\mathbf{NH_3}$)	0 – 1

Biogas can be referred to as low level natural gas because it only contains about 55 – 65% methane and the rest is other gas content (Table 1), while natural gas contains 90 – 95% methane [16]. Other ingredients that are usually present in very small amounts in biogas include chlorine, fluorine, mercaptans, carbon monoxide, benzene, toluene, ethylbenzene, xylene, cumene (BTX), and polycyclic aromatic hydrocarbons (PAH) [17]. As can be seen in Table 2, each type of component present in biogas has an influence on the quality of biogas. The higher the number of C atoms in the substrate, the higher the concentration of methane contained in the biogas produced [17]. Meanwhile, if there is a high amount of liquid in the bioreactor, the concentration of CO_2 dissolved in the water will also be high so that it will reduce the CO_2 content in the biogas [17].

Biogas is included as a type of renewable and sustainable energy that can be used to replace conventional energy sources (fossil fuels, oil, etc.) which have a negative impact on the environment and the depletion of their numbers is much faster than their formation [16]. Unlike other renewable energy, biogas can be produced from simple technology and is not limited by geographic area. In addition to producing energy, biogas also manages organic waste and produces fertilizers to fertilize plants [16].

Table 2. Effect of Each Component to the Quality of Biogas

Component	Volume	Effect
Water vapor	1 – 5%	Causes corrosion of piping systems and other equipment, risk to freeze piping and nozzle
CO_2	25 –50%	Lowers heating value, damages alkaline fuel cells if the gas is wet it can corrosion
H_2S	0 – 0.5%	If it exceeds the upper limit (0.05%) it can cause corrosion in the piping system and other equipment, whereas if it is used for combustion activities, if it exceeds the upper limit (0.01%) it has the potential to occur incomplete combustion resulting in H_2S and SO_2
N_2	0 – 5%	Reduces calorific value, improves anti-knock of engines
Siloxane	0 – 50 mg/m^3	Damages and abrasive to engines
ash	>5 μm	Blocks nozzles and fuel cells
NH_3	0 - 0.05%	Improves fuel properties due to anti-knock in the engine, NO damages cell x after combustion

In general, as long as the biomass to be used contains carbohydrates, proteins, fats, cellulose, and hemicellulose as the main components, the biomass can be used as raw material for biogas formation [17]. A number of criteria that need to be considered in selecting raw materials, among others, are free from pathogens and other harmful organisms, contain only a few impurities, and do not contain harmful substances so that the PA process can take place optimally [17]. The concentration of methane produced will vary greatly depending on the content of the feedstock used, as shown in Tables 3 and 4.

Table 3. Biogas Production from Variety of Sources.

Raw Material	**Methane Yield (%)**	**Biogas Yield (m^3/tFRM*)**
Liquid bovine manure	60	25
Liquid pig manure	65	28
Bovine manure	60	45
Sewage sludge	-	47

Horse manure	-	56
Pig manure	60	60
Fruit waste	-	74
Poultry manure	60	80
Beets	53	88
Organic waste	61	100
Municipal solid waste	-	101.5
Sweet sorghum	54	108
Food waste	-	110
Animal feed beets	51	111
Grass silage	54	172
Corn silage	52	202

*tFRM = total fresh raw material

Table 4. Gas Production.

Raw Materials	**Liter Gas / kg TS**	**CH_4 (%)**	**CO_2 (%)**
Protein	700	70 – 71	29 – 30
Fat	1200 – 1250	67 – 68	32 – 33
Carbohydrate	790 – 800	50	50

3. SOURCES OF SUSTAINABLE FEEDSTOCK FOR BIOGAS PRODUCTION

3. 1. Animal manure

The livestock sector has a number of negative impacts on the environment. This is evidenced by the involvement of the livestock sector which contributes as much as 18% of global greenhouse gas emissions and many of these emissions come from animal waste globally which is estimated at 13 billion tons/year. In order to treat this waste, animal manure is often used as raw material for biogas production to overcome environmental problems and energy needs. Utilization of animal manure (pigs, bovines, poultry, horses, and others) in the formation of biogas can produce two products, namely biogas as energy and *digestate* as fertilizer for plant fertilization [18], [19]. The characteristics that make animal manure have a high potential

to act as raw material for biogas production include, among others, having a carbon-nitrogen (C:N) ratio of 25:1, rich in nutrients, containing anaerobic microorganisms, easy to find, inexpensive, and has a high capacity. as a buffer, and maintain the stability of the PA process when the digester pH decreases significantly. Meanwhile, the lack of animal manure, namely the *dry matter* (DM) content provides low methane yields per unit volume of raw materials, high biomass logistics costs, contains high enough lignocellulose which can interfere with the PA process, and cannot support economic sustainability when using *mono-digestion.*

3. 2. Plants

Biomass used in plants can be divided into two, namely plant waste and energy plants. In general, plant waste (harvest residues, plant parts, low-quality plants, etc.) is not used in *mono-digestion*, so plant waste is often mixed with other types of raw materials such as animal waste. Before being put into the digester, most plant wastes need to receive pre-treatment to break down the lignocellulosic content contained in it so that anaerobic microorganisms in the digester can utilize the plant waste as nutrition. Plant waste proved to be digestible well, when the particle size of the waste was reduced to 1 cm [20].

Table 5. Type of Plants as Raw Materials for Biogas Production.

Energy	**Methane (YieldVS)**
Corn (whole part)	205 – 405
Grass	298 – 467
Clover grass	290 – 390
Sunflower	154 – 400
Potatoes	275 – 400
Sweet	236 – 281
Feed	420 – 500
Barley	353 – 658
Triticale	337 – 555
Alfalfa	340 – 500
Ryegrass	390 – 410
Nettle	120 – 420
Straw	242 – 324
Leaf	417 – 453

Several types of plants are also cultivated to produce energy. These plants are often referred to as energy plants (Table 5). Energy plants that are often used as raw materials for biogas production are corn and beets.

However, there are a number of obstacles when using energy plants as raw materials, among others, the need for fertilizers, pesticides, energy for harvesting and logistics is high, requires a large enough fertile land, and the age of the plant.

Methane production and digestibility of plants will decrease with increasing age of plants due to an increase in cellulose content. Meanwhile, the ability of plant storage will be more difficult when the plant is not yet mature due to the high water content of the plant [21].

3. 3. Industrial waste

Industries that process agricultural raw materials such as food and beverage, animal feed, dairy, pharmaceutical, cosmetic, biochemical, slaughterhouses and others, produce industrial waste that is homogeneous, easy to digest, and rich in fat, protein, or sugar.

In biogas production activities, industrial organic waste is often mixed with other raw materials such as animal manure to increase the production of methane gas. This can create a sustainable economy for the industry and increase the stability of the biogas production process due to the lack of sensitivity to inhibitors such as ammonia and sulfides. Industrial organic waste can produce 30-500 of m^3 methane per m^3. of raw material This value proves that industrial waste produces more methane than animal waste.

The use of industrial waste as raw material is very dependent on the process that produces the waste. Industrial waste has the potential to contain pollutants (biological, chemical, or physical), pathogens, heavy metals, or persistent organic compounds that can pollute the environment or even interfere with human health when digestate is used as plant fertilizer [22].

3. 4. Urban waste

Urban waste can be divided into two types, namely organic waste that is separated (household waste such as food waste, plantations, and others) and *sewage sludge*. The large amount of household waste that is not utilized, makes this biomass has great potential to be used as a source of raw materials. Similar to industrial waste, the separated organic waste is often used in *co-digestion* with animal waste with the aim of increasing methane production.

This type of biomass has many benefits to the environment, such as reducing the flow of waste to landfills and incineration, there is no competition for land use, does not have a sustainable negative impact, and increases public awareness of waste. In addition, the methane produced is quite high considering the high level of biodegradability of household organic waste.

On the other hand, the use of biomass also has quite a number of shortcomings, including the amount of impurities in organic waste is a maximum of 0.1%, tends to have many pathogens, high costs because they have to collect certain wastes, and awareness from all *stakeholders* so that waste can be separated completely. Meanwhile, the ability of *sewage sludge* is quite similar to animal manure in producing methane gas.

However, the high content of chemical and biological pollutants contained in it is an obstacle in using this raw material. In order to increase the biogas produced from *sewage sludge*, this raw material is often used through *co-digestion* with animal waste or household and industrial waste [23].

3. 5. Aquatic biomass

Aquatic biomass consists of macroalgae and microalgae. Seaweed which is a member of macroalgae is known to contain many types of carbohydrates, has a high biomass yield, and plays an important role in maintaining aquatic biodiversity. Meanwhile, in general, microalgae are unicellular organisms that can photosynthesize, are rich in lipids, and can be found in fresh or marine water.

One of the microalgae that are considered most suitable for producing high value materials and fuels such as biogas and other forms of energy is diatoms. The disadvantage of using microalgae as raw material is that it has a low DM content and for some problems requires the right technology which is still in the research stage. Utilization of aquatic biomass is considered appropriate because in addition to the potential to produce energy, this biomass can be used to reduce a number of environmental problems, such as remediating wastewater and reducing greenhouse gas emissions. Microalgae also produce high biomass and have great potential to be used as raw materials for energy production considering that natural resources such as oil reserves are dwindling [24], [25].

4. ADVANTAGES AND DISADVANTAGES OF BIOGAS

Biogas is a renewable and sustainable energy produced from biomass which acts as an alternative energy source that can replace non-renewable energy sources, increases the level of energy balance or independence of a country, provides jobs, optimizes waste that is not used properly, save costs incurred to deal with environmental waste, conserve natural resources, and protect the environment [26].

Biogas can be used as an alternative fuel for vehicles, but the gas must contain more than 97% of methane obtained by *scrubbing*. Gas that has been cleaned of these impurities (carbon dioxide, water, etc.) is referred to as enriched 4 biogas [16]. The use of biogas can reduce greenhouse gas emissions.

Although the combustion of biogas produces greenhouse gases such as carbon dioxide, if the source of the substrate in the formation of biogas is biomass such as plants or microalgae, there will be many plants and microalgae developed so that they have the potential to absorb the carbon dioxide gas.

Meanwhile, if the substrate used is livestock waste such as animal manure, the biogas production activity also reduces methane and nitric oxide emissions, which have stronger heat capture power than carbon dioxide by 23 and 296 times, respectively. The decrease in greenhouse gas emissions will play a role in mitigating global warming [26].

Biogas is a very flexible energy because it can be used for various applications such as for cooking, lighting, or for use in combined heat and power generation (CHP) systems, transportation fuels, and fuel cells [26]. When compared to other types of biofuels, biogas requires the lowest process water. This is a fairly important factor considering that in the future it is expected that there will be water shortages in many areas of the world. The application of biogas technology using anaerobic digestion can reduce the source of odors that are the source of the arrival of flies from the accumulation of livestock, agricultural, and other waste up to 80% [26].

Biogas can provide additional income for farmers or ranchers who implement biogas technology.

From a social perspective, they help solve environmental problems by utilizing agricultural or livestock waste by providing alternative renewable energy sources in the form of biogas.substrate or what is known as *digestate*can be used as soil fertilizer because it contains many nutrients in the form of nitrogen, phosphorus, potassium, and various micronutrients.

Digestate has a better role than using animal manure directly as fertilizer because it has higher homogeneity and availability of nutrients, better C/N ratio and significantly reduces odor [18]. Biogas technology players, especially breeders and farmers who use their waste to produce biogas, can also save on spending on electricity and gas because a two cubic meter *biogas plant* equivalent to 26 kg of LPG, 37 L of kerosene, 88 kg of charcoal, and 210 kg of wood. fuel per month [15].

But in general, biogas as well as other renewable energy has weaknesses in its application which in the end can hinder its use. These weaknesses include:

Table 6. Variety Source of Renewable Energy and Its Weakness.

Sources of	Weakness	References
Sun	Weather dependent, high maintenance costs, competitive land use, high energy storage	[27]
Biomass	Competition in land use, high transportation costs, high maintenance costs, competition for waste stocks as fertilizer	[27], [28]
Geothermal	not widespread, require large areas of land, can produce harmful gases and minerals	[29], [30]
Hydropower	initial investment among other technologies, destroys river flora and fauna, disrupts river functions, alters water flow	[27], [31]
Sea	Dependent on waves/tidal, wildlife disturbed by underwater turbines , higher costs compared to fossil fuels, problems transporting energy to land, can cause damage to marine ecosystems near the coast of	[32]
Wind	High development costs, difficult maintenance, depending on weather, wildlife in the vicinity can be disturbed, noise pollution, land use competition, need energy storage space	[27]

5. CONCLUSIONS

In general, the use of biogas as a green and sustainable renewable energy is promising to be further developed. Biogas production can sustain as it uses raw materials that can be found anywhere and even utilized waste. Variety of feedstock have been used as raw materials for biogas production, including animal manure, plants, industrial waste, urban waste and aquatic biomass. This can be a solution for waste management integrated with energy generation to create a green system for energy. Further study on how to efficiently scale up the process and manufacture the feasible biodigester is needed to better manage and predict the application of biogas as our new source of energy.

References

[1] U. Nations, D. of Economic, and P. D. Social Affairs, World population prospects: the 2017 revision, key findings and advance tables, *Work. Pap.* No. ESA/P/WP/248 ed, 2017.

[2] A. Sugiyono, L. M. A. Anindhita, A. Wahid, and Adiarso, Indonesia Energy Outlook 2016: Energy Development in Supporting Green Industry, Cent. Technol. Energy Resour. Chem. Ind. Agency Assess. Appl. Technol. (BPPT), Jakarta, 2016.

[3] J. Conti, P. Holtberg, J. Diefenderfer, A. LaRose, J. T. Turnure, and L. Westfall, International energy outlook 2016 with projections to 2040," 2016.

[4] J. L. Sawin *et al.*, Renewables 2017 global status report, 2016. ISBN 978-3-9818107-6-9

[5] B. Dudley and others, BP statistical review of world energy, *BP Stat. Rev. London, UK, accessed Aug*, vol. 6, no. 2018, p. 116, 2018.

[6] F. R. Widyastuti, P. Purwanto, and H. Hadiyanto, Potensi Biogas Melalui Pemanfaatan Limbah Padat Pada peternakan Sapi Perah Bangka Botanical Garden Pangkalpinang, *Metana*, vol. 9, no. 02, 2013.

[7] A. C. Wilkie, Biomethane from biomass, biowaste, and biofuels, in *Bioenergy*, 2008, pp. 195–205.

[8] O. Edenhofer *et al.* IPCC special report on renewable energy sources and climate change mitigation, Prep. By Work. Gr. III Intergov. Panel Clim. Chang. Cambridge Univ. Press. Cambridge, UK, 2011.

[9] R. L. Grando, F. V. da Fonseca, A. M. de Souza Antunes, and others, Mapping of the use of waste as raw materials for biogas production, *J. Environ. Prot. (Irvine,. Calif).*, vol. 8, no. 02, p. 120, 2017.

[10] D. Mulyono, Pemanfaatan Kotoran Ternak Sebagai Sumber Energi Alternatif dan Peningkatan Sanitasi Lingkungan, *J. Teknol. Lingkung.* vol. 1, no. 1, 2011.

[11] Permana, R., & Andhikawati, A. (2021). Application of Engineered Mussel Foot Protein (MFP) from Some Bivalve Species on Cell and Tissue Culture: Mini Review. *Asian Journal of Biotechnology and Genetic Engineering*, *4*(4), 9-15

[12] K. Rokosz, T. Hryniewicz, and M. Kara, Corrosion studies of austenitic and duplex stainless steels in the environment of ferment of biogas plants, *World Sci. News*, no. 74, pp. 194–208, 2017.

[13] M. E. Montingelli, S. Tedesco, and A. G. Olabi, Biogas production from algal biomass: A review. *Renew. Sustain. Energy Rev.* vol. 43, pp. 961–972, 2015.

[14] S. F. Salleh, M. H. A. Zulkifli, and M. R. Jalani, Production of Biogas Using Dairy Manure as Feedstock and Rumen Fluid as Inoculum, *J. Appl. Sci. \& Process Eng.*, vol. 3, no. 2, pp. 83–89, 2016.

[15] F. N. Macharia, Biogas production for domestic use: A flexible learning course. Commonwealth of Learning (COL), 2015.

[16] M. Balat and H. Balat, Biogas as a renewable energy source—a review, *Energy Sources, Part A*, vol. 31, no. 14, pp. 1280–1293, 2009.

[17] D. Deublein and A. Steinhauser, Biogas from waste and renewable resources: an introduction. John Wiley & Sons, 2011.

[18] J. F. Akpan, I. A. Isong, and E. B. E. Asikong, Anaerobic digestion of organic waste for the production of biogas in Calabar, Cross River State, Nigeria. *World News Nat. Sci.* vol. 24, 2019.

[19] S. E. Noviatri, H. Herawati, L. P. Dewanti, and others, "The relationship between benthic macrofauna community structure and density of Mangrove vegetation in Mempawah Mangrove Park, West Kalimantan, Indonesia. *World News Nat. Sci.* vol. 33, 2020.

[20] S. Megersa, Application of wood rot wild mushrooms in bioethanol production from sawdust of sawmills of Oromia Forest and Wildlife Enterprise, Ethiopia, *World News Nat. Sci.* vol. 29, no. 3, 2020.

[21] E. Żukowski, Agricultural biogas plants as a future in agricultural waste management, *World Sci. News*, vol. 136, pp. 95–107, 2019.

[22] O. L. Awotedu, P. O. Ogunbamowo, B. F. Awotedu, and O. S. Ariwoola, Comparative nutritional composition of selected medicinal fruit seeds, *World News Nat. Sci.* vol. 29, no. 3, 2020.

[23] E. O. Ayadinuno, U. B. Njoku, and O. U. Akakuru, Sustaining a Healthy Environment whilst Utilizing Wastes as Energy Sources: Physicochemical Analysis of Solid Wastes in Awka, Nigeria, *World News Nat. Sci.* vol. 36, pp. 75–87, 2021.

[24] D. Wahyu, D. Hindarti, and R. Permana, Cadmium toxicity towards marine diatom Thalassiosira sp. and its alteration on chlorophyll-a and carotenoid content, *World News Nat. Sci.* vol. 31, 2020.

[25] R. Permana, Y. N. Ihsan, and A. Rizal, Bioremediation Enhancement of Oil-Polluted Water by Bacterial Immobilization: A Review, *World Scientific News* vol. 159, 210–223, 2021

[26] T. Al Seadi, B. Drosg, W. Fuchs, D. Rutz, and R. Janssen, Biogas digestate quality and utilization, in The biogas handbook, Elsevier, 2013, pp. 267–301.

[27] F. Adra, Renewable Energy: An Eco-friendly Alternative? Friedrich-Ebert-Stiftung, Ghana Office, 2014.

[28] N. Sriram and M. Shahidehpour, Renewable biomass energy, in *IEEE Power Engineering Society General Meeting, 2005*, 2005, pp. 612–617.

[29] L. Csányi, V. Krištof, S. Kušn\'\ir, M. Katin, and M. Marci, Geothermal energy, Intensive Programme "Renewable Energy Sources" 2010.

[30] Y. Mykytenko and K. Chala, The advantages and disadvantages of geothermal energy, eNUFTIR 2014.

[31] D. Malovic *et al.* Hydroelectric power: a guide for developers and investors, World Bank Group 2015.

[32] P. Meisen and A. Loiseau, Ocean energy technologies for renewable energy generation, *Glob. Energy Netw. Inst.* vol. 27, 2009