

Possible environmental impacts of Salihli and Turgutlu Biomass Power Plant (Manisa/Turkey)

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Received: 22 November 2022 / Accepted: 21 June 2023

Abstract. Biomass energy is obtained from biomass sources consisting of plant and animal origin elements. Biomass refers to all organic matter existing in the biosphere, whether of plant or animal origin, and materials obtained through their natural or artificial transformations. Technological advances can significantly increase the efficiency of biomass energy production and use. Bioenergy production involves some environmental risks that need to be carefully considered and managed. In order to avoid some risks and not to endanger biodiversity, practices aimed at protecting the environment are used while producing bioenergy. In this article, we wanted to draw attention to the possible environmental effects of biomass production technologies. For this purpose, two different biomass production technologies that are still production test (Salihli and Turgutlu Biomass Power Plant) were examined. The usage areas of these Biomass Power Plants (BPPs) were examined and it was aimed to reduce the possible effects on the environment and to minimize the concerns of the society.

Keywords: Biomass Power Plant, Bioenergy, Energy supply, Environment, Salihli and Turgutlu.

1 Introduction

Biomass is the world's fourth-largest energy source, following coal, oil, and natural gas [1]. In light of rising fossil fuel prices, the energy supply-demand imbalance, energy security, environmental concerns, and the need to reduce greenhouse gas emissions, biomass as a source of energy has emerged as a critical and intriguing topic [2, 3]. According to a projection by the World Energy Council, bioenergy will account for 25% to 33% of global energy supply by 2050 [4]. As bioenergy production methods evolve and technologies advance, biorefineries will be able to create a varied range of food and animal-based products. The land footprint linked with individual items becomes less relevant and more difficult to identify. Biomass is a carbon carrier that may be utilized to make bioenergy and is considered one of the most plentiful and available wastes [5]. Raw biomass, on the other hand, is less attractive due to a number of limitations, including high moisture content, low energy density, hydrophilicity, and high alkali content, all of which make transportation, storage, and use of the biomass difficult [6]. Thermochemical and biochemical conversion technologies [7], such as pyrolysis [8, 9], gasification [10], hydrothermal carbonization, and anaerobic digestion are used to tackle these barriers. Because of their lower temperatures

and ability to cope with high moisture content biomass, anaerobic digestion and hydrothermal carbonization are highly considered among these technologies. Microorganisms break down biodegradable material in the absence of oxygen in anaerobic digestion, which is a set of activities. Biogas, a mixture of methane, carbon dioxide, and traces of other gases, is the principal byproduct of anaerobic digestion [11]. Digestate is a by-product of anaerobic digestion that comprises of leftover indigestible material and dead microorganisms, in addition to biogas. Biomass can also be burned directly to generate energy. Although thermochemical (like hydrothermal carbonization) and biochemical (like anaerobic digestion) processes have received a lot of attention in recent years, direct combustion (where raw biomass is burned in excess air to produce heat) is perhaps the most straightforward way to convert biomass to bioenergy [12–14]. As a result, the suggested biomass-to-bioenergy conversion systems should be compared against direct burning. It is estimated that Turkey's biomass waste potential is approximately 8.6 million tons of oil equivalent (MTEP) and the amount of biogas that can be produced is 1.5–2 MTEP. According to the Biomass Energy Potential Atlas (BEPA) data prepared by the Ministry of Energy and Natural Resources to determine the biomass energy potential, the total economic energy equivalent of our waste is around 3.9 MTEP/year [15]. As of the end of December 2020, the installed power based on biomass energy, which is

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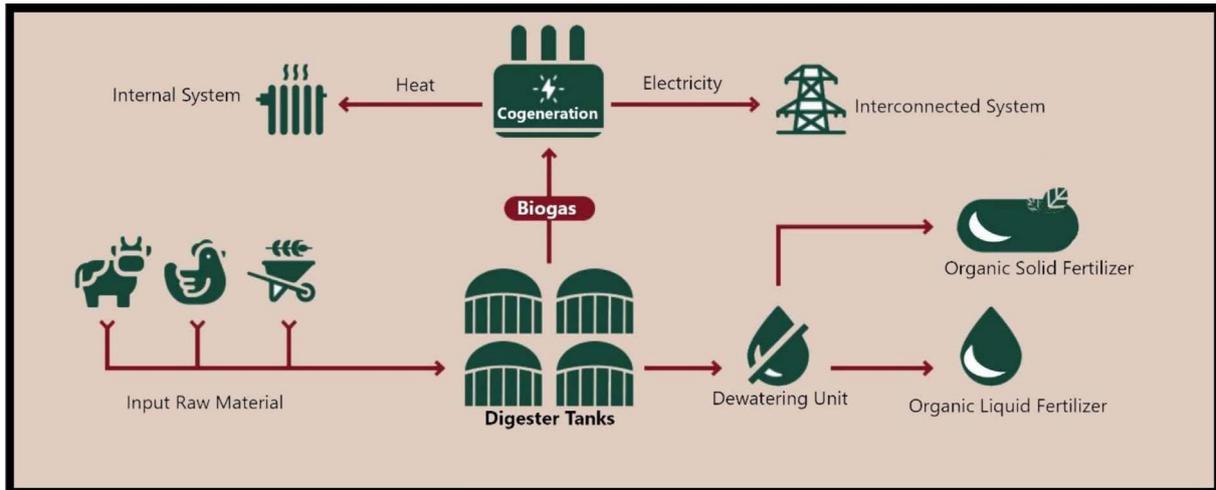


Fig. 1. Energy production methodology in BPPs.

also commonly employed in electricity generation, was 1485 MW (369 MW of which is waste heat), with a 1.80% share of total electricity output. In recent years, the number of BPPs in our country and their share in electricity production have been increasing rapidly. According to the February 2021 statistics of the Chamber of Electrical Engineers, the share of BPPs in electricity generation is around 1.5% in our country. According to the Energy Atlas data, there are still 199 biomass sourced power generation plant in Turkey. In this article, we would like to draw attention to the importance of biomass production technologies in energy production. For this purpose, two different biomass production technologies that are still production test (Salihli and Turgutlu BPPs) were examined. The usage areas of these BPPs were examined and it was aimed to minimize the possible effects on the environment and to minimize the concerns of the society. The flowchart below shows the step-by-step process for energy generation in BPPs (Fig. 1).

2 Material and methods

2.1 Biomass energy technologies

Biomass can be converted to energy in a variety of ways. Biomass energy conversion technologies include thermochemical processes such as pyrolysis, gasification, and combustion, as well as biological processes such as fermentation, anaerobic digestion, and biophotolysis. Depending on the biomass source and the type of energy obtained, each of these processes has its own set of benefits. Biomass energy could be a primary energy source in the future if modern technologies are used to convert biomass and energy conversion efficiency is maintained. Thermochemical conversion techniques applied to biomass are generally thought to be environmentally friendly (as CO₂ neutral and pollutant emissions are very low when compared to coal) economical [16, 17]. Thermochemical conversion technologies

are usually regarded as both environmentally and economically sound [18, 19], as biomass is CO₂ neutral and emits fewer pollutants than coal. Burning biomass fuels, burning fossil fuels, volatile organic compounds, particulate matter, carbon monoxide (CO), and carbon dioxide (CO₂) are all examples of potentially dangerous pollutants (CO₂). CO₂ is a greenhouse gas that is one of the most significant contributors to global warming and climate change [20, 21].

2.2 Study area and biomass collection

The research was carried out in the districts of Salihli and Turgutlu in Manisa province, Turkey's Gediz River Basin (GRB) (Fig. 2). Manisa province that has an important place in the country's economy and where most of the electricity consumption in Turkey takes place. There are geothermal and hydroelectric power plants in the region. In the past, due to the continuous increase in the amount of electricity consumption in the Manisa province, existing power plants and transmission lines were insufficient, and as a result, unscheduled power cuts were experienced due to overloads. Considering that these interruptions cause very important production losses and quality deterioration in the industry and great damage to the facilities, many different power plants (geothermal, wind and solar) under construction in the region. The aim here is to provide clean and safe energy to the province of Manisa. In addition, Manisa province is in a very good position compared to the country in general in terms of animal and plant production values. It is in a very good position both in the country and in the world, especially in the production of grapes. However, it is also important in terms of olive and olive oil production. In addition, the province is in a very good position in terms of livestock value and the poultry production value of the province is quite good. In this respect, it is necessary to take measures that will not damage the fertile agricultural lands of the province during the expansion of the industry, which is quite strong, and the intensification of energy production activities.



Fig. 2. Location map of the study area.

3 Biomass conversion techniques of Salihli and Turgutlu BPPs

Among all renewable energy sources, biomass energy has the potential to cause a wide variety of environmental and social aspects (positive and negative) related to the location of the land where the biomass raw material is obtained, the type of raw material and the process used in the power plant. Salihli and Turgutlu BPPs, which have two different biomass conversion techniques, were examined in this context. Because both methods are suited for decentralized biomass utilization, combustion and anaerobic digestion have been proposed as possible conversion pathways for lignocellulosic Low-Input High-Diversity systems biomass [22–28]. In current studies on the use of chicken, cattle manure and agricultural waste biomass, the focus is on combustion [29, 30] or ethanol production [31] in Salihli BPP. The other method, anaerobic digestion, will be used in the Turgutlu BPP.

3.1 Salihli BPPs

Salihli BPP technology is based on the production of steam by burning raw materials (chicken manure and agricultural waste) (Figs. 3a and 3b). The process of releasing heat as a result of combustibles burning in the presence of air or oxygen is known as combustion. This is the most basic way for converting biomass into energy. Combustion is used for space heating in its most basic form, but it can also be utilized to heat steam for power generation. The hot steam

from the 79.649 tons of waste incineration process will be transferred to the steam turbine (and the generator connected to the turbine) to generate 10 MWe of electricity. The power plant is expected to produce 70 GWh of energy annually. With the energy it produces, it will meet the electricity needs of approximately 30.286 households and prevent the emission of 26.670 tons of carbon dioxide per year. It is planned to transport the chicken litter to be used as a waste source in the operation phase of the Salihli BPP, which is currently in the testing phase, from the districts with the highest chicken manure production and to obtain it economically from the surrounding districts. It is planned to use 186.880 tons/year (560 tons/day) of waste in the project. The facility will be operational for 8000 h/year, providing electricity generation and waste disposal. In this context, wastes will be obtained from the surrounding provinces and districts close to the region. In the process of collecting waste from chicken farms in the region, the wastes will be collected by the appropriate covered, impermeable and odor-proof vehicles belonging to the project owner and/or the transportation company to be contracted and/or the subcontractor of the transportation company, and will be transported in accordance with the requirements of the relevant legislation. In the power plant to be operated within the scope of the project, chicken manure, agricultural wastes and other wastes will be burned in a circulating fluidized bed boiler to produce superheated steam and electrical energy will be generated from this steam by means of a steam turbine and a generator connected to it. The generated energy will be transferred to the national electricity grid *via* the switchgear system. The electricity produced will



Fig. 3. View of the Salihli BPP (a), (b).



Fig. 4. View of the Turgutlu BPP (a), (b).

be delivered to the medium voltage line and delivered to the interconnected network. In addition, with the establishment of the said facility, the chicken facilities' litter and especially organic materials in the region will be taken to the facility and disposed of.

3.2 Turgutlu BPP

Turgutlu BPP, which is still in test production, 46,800 m³/day (107.95 tons/day) biogas is obtained in an oxygen-free environment by using 591.5 tons/day of raw materials (chicken and bovine manure) to be supplied to the facility, and electrical energy (4.503 MWe) from the obtained biogas and heat energy (4.473 MWt) is planned to be produced (Figs. 4a and 4b). Also; As a result of the fermentation process in an oxygen-free environment at the facility, liquid fermented product (1.043 tons/day) and 21.6 tons/day solid fermented product are obtained

after performing the hygiene processes. In this respect; within the scope of the planned activity, bovine manure and chicken manure to be used as raw material is not burned in boilers, but fermented products are obtained as a result of biomethanization processes from raw materials in anaerobic digestions. Therefore, due to the characteristics of the selected bioenergy production technology, it is estimated that there will be no dust emission or gaseous emission that will affect agriculture and animal husbandry. The water needed within the scope of the project is met from ground-water wells.

4 Potential environmental impacts of BPP

In the Salihli BPP, which is in the testing phase, production test is carried out with the combustion process. On the

other hand, in the Turgutlu BPP, production test is carried out by anaerobic digestion process. It has been understood that raw materials (chicken and bovine manure), location and agricultural wastes in production test have significant effects on harvest time and energy efficiency. The dry matter yield and ash content, as well as the substrate-specific methane yield for anaerobic digestion and moisture content for combustion, dictate this for both. It has an impact on biomass quality in raw products, in addition to harvest time (chicken, bovine manure and agricultural waste). Incineration is best for raw materials with low moisture, ash, and critical element content at harvest, while anaerobic digestion is best for raw materials with low lignification and digestibility.

4.1 Land use

Bioenergy production involves some risks that need to be carefully managed and carefully managed in terms of land use. Changes in land use, such as the destruction of agricultural land to create space for energy production, can reduce the benefits of bioenergy use while causing some downsides. Manisa province, located in the GRB, is an important agricultural and industrial center. Total irrigable land size is 110,000 ha. The main agricultural products in the basin are grapes, cotton, corn and olive. Apart from these three products, which make up approximately 90% of the cultivated areas, fruit, vegetables, cereals, *etc.*, are grown in the basin, such crops are also planted; however, the total cultivation rates of these crops throughout the basin remain in small percentages. Due to the climatic characteristics of the basin, agriculture depends on irrigation. Large amounts of water and land are required to implement a significant biomass energy generation program. Horticulture is a huge water user, requiring several orders of magnitude more water per hectare than is required for home and industrial purposes. Today, in many watersheds and areas such as the GRB, it is seen that products with high water needs are grown intensively. This type of agricultural production, which is not suitable for the climatic conditions of the regions, causes the destruction of limited water assets and water-dependent habitats, while causing great damage to production in the medium and long term. While water scarcity reduces crop yields, rural migration is increasing in many basins with decreasing crop productivity. The use of groundwater in Salihli and Turgutlu BPP is considered to be a significant disadvantage.

4.2 Soil quality

The GRB is one of the locations in Western Turkey where agricultural activity is significant. Erosion and soil deterioration have long been major issues in the basin's agricultural areas. The use of agricultural products or chicken and bovine manure for bioenergy production can bring risks of lower soil quality and depletion of beneficial nutrients in the soil. On the other hand, the positive effect of waste treatment on soil quality is its use as fertilizer. The use of suitable biomass raw materials with sustainable practices in the GRB can contribute to the rehabilitation of degraded lands and this can increase soil quality. It can be said

that the environmental risks and potential benefits of bioenergy production differ according to factors such as raw materials, management system, technology used and operating region.

4.3 Greenhouse gas emissions

The production of biomass is simply one aspect of biomass-based energy systems; the conversion of biomass to usable energy is a second and equally significant aspect. Direct combustion and pyrolysis are two of the most extensively utilized biomass conversion processes. It is now widely acknowledged that using biomass in this way produces not just greenhouse gas emissions but also several highly hazardous air pollutants [21]. One of the most essential concepts examined in bioenergy production is the reduction of greenhouse gas emissions. Because of their vast quantities and diverse production methods, CO₂ and N₂O are two of the most important greenhouse gas emissions [32, 33]. Many studies have shown that net CO₂ emissions from the direct use of biofuels are significantly lower than those from the use of fossil fuels [32, 34, 35]. Liu *et al.* [36] calculated that substituting fossil fuel with switch grass will reduce CO₂ emissions by 29 million tons CO₂-eq per year on marginal land. Greenhouse gas emission unlike fossil-based systems, bioenergy production and use is generally considered to be "carbon neutral," as the growth and decay of biomass is part of a natural cycle. Although the evaluations show that bioenergy production causes much lower emissions (about 80–85%) than fossil fuels, this is not the case if bioenergy raw materials are not produced with sustainable methods. The use of biomass raw materials with low greenhouse gas emissions and further efficiency improvements in the management and processing stages ensure optimum reduction of greenhouse gas emissions in the value chain.

4.4 Water quality

Bioenergy production has a significant impact on water quantity, owing to the potential water consumption of bioenergy crops and the modification of land use. With the land-based use of biomass resources, there is a risk of depletion or pollution of water resources in and around the production area. On the other hand, the use of wastewater for bioenergy production and the use of algae for biofuels also have many benefits, such as cleaning polluted or nutrient-rich water streams. Appropriate biomass raw materials used with sustainable practices can contribute to the rehabilitation of degraded lands, resulting in the protection of watersheds. Considering the water resources in the GRB, the recharge area of the underground waters in the region is the elevations in the south and north, and the discharge area is the Salihli Plain. The elevations in the south and north of the basin play an important role in feeding groundwater. Gediz River and Alaşehir Stream are fed by surface and underground waters.

4.5 Hot water resources

Many hot water resources occur along GRB starting from Alaşehir-Sarıgöl in the east. The measured reservoir



Fig. 5. Social responses near the project site (a), (b).

temperature is 215 °C in Alasehir, 155 °C in Salihli, and 85 °C in Urganlı geothermal system. Accordingly, temperatures in GRB decrease from east to west. The thermal waters of Alaşehir, Salihli and Urganlı geothermal systems are alkaline where carbonate alkalinity > non carbonate alkalinity. They are very soft waters which is rarely found in the nature. According to the classification nearly whole waters' type is sodiumbicarbonated.

4.6 Loss of natural biodiversity, habitats and wildlife

The conversion of natural ecosystems into energy-crop plantations will alter wildlife and other biota's habitat and food supplies. Many favored habitats and mating locations for various mammals, birds, and other biota will be lost if forests and wetlands are altered. Monoculture plantations with fast-growing trees limit vegetation diversity and the importance of areas as wildlife habitats for many species. To maintain productivity, these monocultures require more energy inputs in the form of pesticides and fertilizers than climatic forests. Profitable plantations have trees that are 2–3 times as dense as wild forests, which may lead to increased pest problems. The risk to biodiversity impacts is largely associated with the production of land-based biomass resources. One of the potential negative effects of land-based bioenergy production is the conversion of biodiversity-rich lands, as also addressed in land use. The lands used for bioenergy production can cause a decrease or increase in biodiversity, and therefore it is of great importance to take the necessary precautions in bioenergy production. The effects of using biomass are interrelated.

4.7 Social-economic impacts

The most important societal consequences will be changes in employment and an increase in workplace health and safety [37]. It is estimated that total employment will increase if biomass resources are used to meet the country's energy needs. Cutting, harvesting and transporting biomass resources and operating conversion plants will require a workforce in the production of livestock and agricultural products. However, the social community thinks that biomass energy will harm the environment and human health.

Therefore, they are protesting the work done near the project site (Figs. 5a and 5b). It has an impact on many issues such as bioenergy production and use, soil and water quality, land tenure and safe working conditions. For this reason, it should be done with controlled methods, taking into account the results of bioenergy production and use.

5 Results and discussion

Biomass can be used to generate energy in several ways. Thermochemical processes like pyrolysis, gasification, and combustion, as well as biological processes like fermentation, anaerobic digestion, and biophotolysis, are all examples of biomass energy conversion technologies. Depending on the biomass source and the type of energy obtained, each of these processes has its own set of benefits. Salihli and Turgutlu BPPs that will generate energy through combustion and anaerobic digestion biomass energy methods were evaluated in this study. Direct combustion is an efficient method of converting biomass into energy. The process of releasing heat as a result of the combustion of flammable materials in the presence of air or oxygen is known as combustion. It is the most basic method of utilizing biomass for energy. Combustion, in its most basic form, is used for space heating, but it can also be used to heat steam for electricity generation. This method will be used by Salihli BPP to generate energy. Anaerobic digestion is a process in which bacteria break down organic material in the absence of oxygen, producing a solid residue and methane-rich biogas. The methane can then be captured and used to generate energy. Likewise, solid residue can be burned to generate energy. This method will be used by Turgutlu BPP to generate energy. Anaerobic digestion has received more attention in biochemical conversion technologies than combustion due to its high yield and efficiency. Thermal conversion techniques for biomass are generally regarded as both environmentally friendly and cost-effective. Biochemical conversion technologies are generally regarded as eco-friendly. Because biomass is CO₂ neutral, pollutant emissions are reduced. Bioenergy has numerous environmental and socioeconomic benefits. When agricultural and animal wastes are used to generate biomass energy, the

chemical composition of the fuel must be thoroughly analyzed.

It should be noted that biomass energy may have additional environmental impacts. Aside from the impact of bioenergy use on greenhouse gas emissions, there are a number of other environmental impacts that must be considered. In recent years, a bioenergy facility has been built that uses agricultural or animal waste as a fuel source in the GRB. When energy companies use forest wood as fuel in a very uncontrolled manner, it negatively impacts carbon dioxide emissions in the atmosphere. Such actions can lead to deforestation, which in turn leads to habitat loss, soil erosion, loss of natural beauty, and more. However, burning solid, liquid, or gaseous biomass not only contributes to carbon dioxide emissions, but can also release other pollutants and particulate matter into the air, including carbon monoxide, volatile organic compounds, and nitrogen oxides. In some cases, biomass combustion can release more pollutants than fossil fuels. Unlike carbon dioxide emissions, many of these pollutants cannot be captured by new plants. These compounds can cause a number of environmental and human health problems if not properly contained. In addition, plants need water to grow. When energy companies grow trees and other plants for a bioenergy power plant, they use a lot of water for irrigation. This greatly exacerbates drought conditions by affecting aquatic habitats and the amount of water available for other uses (food crops, drinking water, hydropower, *etc.*). Sustainable planning studies should be conducted to make biomass more environmentally friendly. Some of the environmental disadvantages of bioenergy can be mitigated by more sustainable forest management and careful selection of the biomass we use as fuel and how it is obtained. Future investments in bioenergy can be made more ecologically beneficial by utilizing advances in research, technology, and policy development.

6 Conclusion

Because of its huge quantity and renewability, bioenergy has clear benefits over traditional fossil fuels, and so plays a critical role in ensuring global energy security. However, while establishing bioenergy production, it is critical to consider resource and environmental costs. Bioenergy production can have truly negative impacts on land use, soil quality, greenhouse gas emissions, water quality, hot springs, loss of natural biodiversity, habitats and wildlife, removal and loss of nutrients, plant species and social-economic impacts. These effects vary depending on the bioenergy production technology. Turkey has a large potential for bioenergy production, but it is trailing behind and cannot keep up with rising energy consumption. Future study should learn from leading countries in this field, learn more, and derive optimal decision support to help Turkey and other emerging countries guide the growth of bioenergy. The possible effects of combustion and anaerobic digestion systems, which are Biomass conversion techniques, of Salihli and Turgutlu BPPs, which are in the test phase, on the environment have been evaluated. Considering the

environmental effects of biogas production systems, life-cycle analysis including emissions and energy performances generated by biogas production in the analytical approach of the system should be made and positive and negative aspects should be revealed. In addition to all these, the benefits and ease of use of biomass technology should be conveyed to the public as soon as possible. Overall, this study can be informative in planning environmental protection as well as bioenergy development.

Acknowledgments. The author would like to thank the Editor and the anonymous Referees for their very helpful comments and suggestions which have allowed the manuscript to be significantly improved. Additionally, the author would like to give a special thanks to Investment Companies.

Author contribution

The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

Availability of data and materials

All data used to support the findings of this study are included within the article.

Competing interests

The author declare no competing interests.

References

- 1 Geng A., Yang H., Chen J., Hong Y. (2017) Review of carbon storage function of harvested wood products and the potential of wood substitution in greenhouse gas mitigation, *Forest Policy Econ.* **85**, 192–200.
- 2 Alcalá A., Bridgwater A., Vos J. (2011) Biomass fuelled combined heat and power: situation in the UK and the Netherlands, in: Bridgwater A.V. (Ed), *Proceedings of the Bioten Conference on Biomass, Bioenergy and Biofuels 2010*, CPL Press. ISBN (Print) 978-1-872691-54-1, pp. 767–777.
- 3 Enagi I.I., Al-Attab K.A., Zainal Z.A. (2018) Liquid biofuels utilization for gas turbines: a review, *Renew. Sust. Energ. Rev.* **90**, 43–55.
- 4 D'Agosto M., Silva M., Oliveira C., Franca L., Marques L., Murta A., Freitas M. (2015) Evaluating the potential of the use of biodiesel for power generation in Brazil, *Renew. Sust. Energ. Rev.* **43**, 807–817. <https://doi.org/10.1016/j.rser.2014.11.055>.
- 5 Uslu A., Faaij A.P.C., Bergman P.C.A. (2008) Pre-treatment technologies, and their effect on international bioenergy supply chain logistics. Techno-economic evaluation of torrefaction, fast pyrolysis and pelletisation, *Energ.* **33**, 1206–1223.
- 6 Uddin M.H., Reza M.T., Lynam J.G., Coronella C.J. (2014) Effects of water recycling in hydrothermal carbonization of Loblolly Pine, *Environ. Progr. Sustain. Energy* **33**, 1309–1315.

- 7 Balat M. (2008) Global trends on the processing of bio-fuels, *Int. J. Green Energy*, **5**, 3, 212–238.
- 8 Balat M. (2011) An overview of the properties and applications of biomass pyrolysis oils, *Energy Sources A: Recovery Util. Environ. Eff.* **33**, 7, 674–689.
- 9 Siemons R. (2002) An assessment of biomass gasification and liquefaction (pyrolysis) in view of economic efficiency and sustainability, in *12th European Conference and Technology Exhibition on Biomass for Energy, Industry and Climate Protection*, Amsterdam.
- 10 Schafer H.-J. (1999) *Process and apparatus for coating printed circuit boards*, United States Patent Application, Washington DC.
- 11 Pecchi M., Baratieri M. (2019) Coupling anaerobic digestion with gasification, pyrolysis or hydrothermal carbonization: A review, *Renew. Sust. Energy Rev.* **105**, 462–475.
- 12 Rahdar M.H., Nasiri F., Lee B.A. (2019) Review of numerical modeling and experimental analysis of combustion in moving grate biomass combustors, *Energ. Fuels* **33**, 9367–9402.
- 13 Cherubini F., Peters G.P., Berntsen T., Stromman A.H., Hertwich E. (2011) CO₂ emissions from biomass combustion for bioenergy: Atmospheric decay and contribution to global warming, *GCB Bioenerg.* **3**, 413–426.
- 14 Heidari M., Garnaik P.P., Dutta A. (2019) The valorization of plastic via thermal means: industrial scale combustion methods, *Plastics Energy*, William Andrew Publishing, Norwich, NY, USA, pp. 295–312.
- 15 ETKB (2021) *Ulusal Enerji Denge Tablolari*, <https://www.eigm.gov.tr/tr-TR/Denge-Tablolari/Denge-Tablolari> (Access date: 03.08.2022)
- 16 Kar T., Keles S. (2016) Environmental impacts of biomass combustion for heating and electricity generation, *J. Eng. Res. Appl. Sci.* **5**, 2, 458–465.
- 17 Kar T., Keles S., Kaygusuz K. (2018) Thermal processing technologies for biomass conversion to clean fuels. *J. Eng. Res. Appl. Sci.* **7**, 2, 972–979. ISSN 2147–3471.
- 18 Kovacs H., Szemmelveisz K., Koas T. (2016) Theoretical and experimental metals flow calculations during biomass combustion, *Fuel* **85**, 524–531.
- 19 Mladenovic M., Paprika M., Marinkovic A. (2018) Denitrification techniques for biomass combustion, *Renew. Sust. Energy Rev.* **86**, 3350–3364.
- 20 Abbasi T., Abbasi S.A. (2010) Biomass energy and the environmental impacts associated with its production and utilization, *Renew. Sust. Energy Rev.* **14**, 919–937. <https://doi.org/10.1016/j.rser.2009.11.006>.
- 21 Wu Y., Zhao F., Liu S., Wang L., Qiu L., Alexandrov G., Jothiprakash V. (2018) Bioenergy production and environmental impacts, *Geosci. Lett.* **5**, 14. <https://doi.org/10.1186/s40562-018-0114-y>.
- 22 Obernberger I. (1998) Decentralized biomass combustion: state of the art and future development, *Biomass and Bioenergy* **14**, 33–56.
- 23 Prochnow A., Heiermann M., Plochl M., Amon T., Hobbs P. J. (2009a) Bioenergy from permanent grassland – a review: 2. Combustion, *Bioresource Technol.* **100**, 4945–4954.
- 24 Prochnow A., Heiermann M., Plochl M., Linke B., Idler C., Amon T., Hobbs P.J. (2009) Bioenergy from permanent grassland – A review: 1. Biogas, *Bioresource Technol.* **100**, 4931–4944.
- 25 Appels L., Lauwers J., Degreve J., Helsen L., Lievens B., Willems K., Impe J.W., Dewil R. (2011) Anaerobic digestion in global bio-energy production: potential and research challenges, *Renew. Sust. Energy Rev.* **15**, 4295–4301.
- 26 Hensgen F., Richter F., Wachendorf M. (2011) Integrated generation of solid fuel and biogas from green cut material from landscape conservation and private households, *Bioresource Technol.* **102**, 10441–10450.
- 27 Van Meerbeek K., Appels L., Dewil R., Van Beek J., Bellings L., Liebert K., Muys B., Hermy M. (2015) Energy potential for combustion and anaerobic digestion of biomass from low-input high-diversity systems in conservation areas, *GCB Bioenerg.* **7**, 888–898. <https://doi.org/10.1111/gcbb.12208>.
- 28 Kiesel A., Nunn C., Iqbal Y., Van der Weijde T., Wagner M., Özgüven M., Tarakanov I., Kalina O., Trindade L.M., Clifton-Brown J., Lewandowski I. (2017) Site-specific management of miscanthus genotypes for combustion and anaerobic digestion: a comparison of energy yields, *Front. Plant Sci.* **8**, 347 <https://doi.org/10.3389/fpls.2017.00347>.
- 29 Florine S.E., Moore K.J., Fales S.L., White T.A., Lee Burras C. (2006) Yield and composition of herbaceous biomass harvested from naturalized grassland in southern Iowa, *Biomass Bioenerg.* **30**, 522–528.
- 30 Tonn B., Thumm U., Claupein W. (2010) Semi-natural grassland biomass for combustion: influence of botanical composition, harvest date and site conditions on fuel composition, *Grass Forage Sci.* **65**, 383–397.
- 31 Gillitzer P., Wyse D., Sheaffer C., Taff S., Lehman C. (2013) Biomass production potential of grasslands in the oak savanna region of Minnesota, USA, *BioEnergy Res.* **6**, 131141.
- 32 Dunn J.B., Mueller S., Kwon H-y, Wang M.Q. (2013) Land-use change and greenhouse gas emissions from corn and cellulosic ethanol, *Biotech. Biofuels* **6**, 51.
- 33 Qin Z., Dunn J.B., Kwon H., Mueller S., Wander M.M. (2016) Influence of spatially dependent, modeled soil carbon emission factors on life-cycle greenhouse gas emissions of corn and cellulosic ethanol, *GCB Bioenergy* **8**, 6, 1136–1149.
- 34 Fu J., Jiang D., Huang Y., Zhuang D., Ji W. (2014) Evaluating the marginal land resources suitable for developing bioenergy in Asia, *Adv. Meteor.* **4**, 1–9.
- 35 Wang M., Han J., Dunn J.B., Cai H., Elgowainy A. (2012) Well-to-wheels energy use and greenhouse gas emissions of ethanol from corn, sugarcane and cellulosic biomass for US use, *Environ. Research Lett.* **7**, 4.
- 36 Liu T., Huffman T., Kulshreshtha S., McConkey B., Du Y., Green M., Liu J., Shang J., Geng X. (2017) Bioenergy production on marginal land in Canada: potential, economic feasibility, and greenhouse gas emissions impacts, *Appl. Energy*. **205**, 477485.
- 37 Hoekman S.K., Broch A., Liu X. (2018) Environmental implications of higher ethanol production and use in the US: a literature review. Part I-impacts on water, soil, and air quality, *Renew. Sust. Energy Rev.* **81**, 3140–3158.