General Overview of the Operation, Efficiency, and Emissions of Waste-to-Energy Technologies

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Abstract: The amount of waste generated in the Western Balkans region has been steadily increasing throughout the years, with a current amount of 1000 kg generated waste per capita with a recycling rate below 3%. This brings the necessity to analyse different types of waste regarding their calorific value, particle size and moisture content to determine the capacity to use them as low-cost renewable fuels in waste-to-energy (WtE) facilities. By studying the mode and conditions of operation, and process efficiency of different WtE conversion technologies, the suitability of each technique for generating electricity, heat or fuel can be defined. The WtE technology market is presented by providing specific examples of real plants installed around the world, accenting the advantages and shortcomings of each case. Results obtained from the literature review performed show that WtE processes encourage a circular economy by transforming waste management into a resource management system. Finally, WtE contributes to the reduction of landfill waste by its exploitation for renewable energy generation representing a sustainable process. However, some limiting factors remain to be surpassed for these techniques to pair up with conventional energy systems.

Keywords: Circular economy, Waste, Waste-to-energy technology.

1. Introduction

With the increase of the "throwaway culture" and the limitation of the world's resources, it is necessary to expand public awareness of the adverse effects that our actions have on the planet and to move towards the concept of a circular economy. Recovering energy from waste and converting it into usable electricity, heat or fuel is done through waste-to-energy (WtE) technologies [1]. WtE contributes to the circular economy strategy considering that it produces renewable energy, replacing finite resource consumption with sustainable development through products lasting longer and recovering materials from products when their life is finished [2]. Additionally, WtE technologies lead to a minimisation of waste and production of electricity with reduced carbon emissions by offsetting the energy need from fossil fuels [3].

The increase in waste generation is predicted to reach 2.2 billion tons per year by 2025, according to Worldbank [4]. In North Macedonia, the generation of municipal solid waste (MSW) has increased constantly throughout the last 10 years. The composition of the MSW in the Polog Region is given in the graph below.

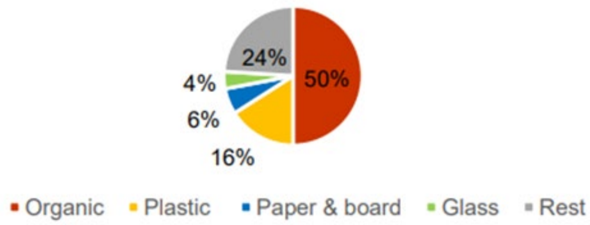

Figure 1. Composition of MSW for Polog Region [5]

In 2010 the amount of generated MSW was 351 kg/inhabitant, whereas in 2020, this number reached 452 kg/inhabitant. The total MSW generated in 2020 was above 900,000 tons. For comparison, the total amounts of other waste generated in 2018 are presented, when industrial waste produced was around 530,000 tons, mining waste 160,000 tons, and hazardous waste 20,000 tons. The devastating fact is the recycling rate of MSW in Macedonia, representing less than 1% of all MSW generated. The remaining amount is landfilled. The only compliant municipal waste landfill is Drisla serving the capital Skopje with an area of 76 hectares.

The landfill has a monitoring system for leachate and landfill gas, a system for collecting leachate, perimeter fencing and video surveillance. The rest of the landfills in the country, which are around 54, are uncontrolled sites. According to an EU study, 16 out of 54 are categorised as high risk in environmental terms and 17 as medium risk [5]. This presents a challenge for appropriate waste management by eliminating waste in the best possible manner. Achieving sustainable waste management can be done by coupling the energy consuming and energy producing sectors through WtE technologies, where waste is considered as a source of material for energy production substituting traditional fuels such as coal, oil and gas [6].

Waste management in Europe is regulated by Directive 2008/98/EC, which represents a legal framework for waste management, establishing hierarchy and priority in waste management by reducing, reusing, recycling, valorisation from the energy aspect, and disposal or controlled landfilling. This means that incineration or combustion has priority over disposal because the waste can be used as an energy source if it cannot be recycled or by-products can be extracted [7].

2. Background

In the Western Balkan region, the most frequent situation is waste disposal in open dumpsites or uncontrolled landfills, which presents environmental risk through possible emissions to air, soil, and underground water. Air emissions are caused by degradation of microbes from waste in anaerobic conditions forming natural gas or methane, which has a 25 times greater side effect on the environment compared to CO2 being responsible for generating 3-4% of the global emissions of anthropogenic greenhouse gas (GHG) emissions. Emissions into the soil and underground water from landfills are generated from leachate because of rains penetrating the degrading waste, which may contain hazardous chemicals and toxic materials and present a high environmental risk. An emerging problem is the additional area of land required resulting from the annual growth of waste generated for creating landfills proportional in size to the amount of waste being disposed of [3].

Questionable sustainability and high GHG emissions of fossil fuels, oil, coal, and natural gas, require the development of renewable technologies with cheap or zero-cost sources [8]. Considering that waste presents an important and underutilised feedstock which is expected to increase in quantity in the near future, it can be used as a renewable fuel for power or heat generation through WtE technologies [9]. The suitability of one waste type for use as fuel depends on its calorific value, particle size and moisture content, considering the heterogenous nature of different waste types [3]. Waste that can be used in WtE processes is broad in range, including MWS composed of food, paper, pulp, plastics, wood, and yard waste; agricultural waste, such as animal waste, manure slurries from livestock, crop waste; as well as medical and pharmaceutical waste [9]. The food supply system is not affected by municipal, agricultural, and industrial waste and can reduce CO2 emissions by being used for power generation leading to improved waste management [3]. According to [10], WtE plants can reduce waste volume by 87%. All the above-mentioned waste types can be used straight in WtE processes using direct incineration technology. Whereas higher quality fuels generated from waste are Refuse Derived Fuel (RDF) and Solid Recovered Fuel (SRF). These fuels are produced from any solid or liquid waste by separating non-combustible materials, removing moisture and forming a combustible mix in the homogenous and pelletised form, being suitable as fuel material having a higher calorific value than regular waste [3]. RDF can be produced from both hazardous and non-hazardous waste, whereas SRF is generated only from non-hazardous waste and presents an alternative to fossil fuel. RDF and SRF are used for electricity and heat production, while the main difference is that SRF has a greater calorific value than RDF [7].

3. Discussions

WtE systems differ in the way the waste-to-fuel conversion process takes place. They can be divided into four main categories, thermal, mechanical-thermal, thermo-chemical and biochemical. Thermal conversion is realised by direct combustion of the waste. The mechanical-thermal process is based on pulverisation and drying, resulting in RDF. Thermo-chemical conversion includes technologies for torrefaction, plasma treatment, gasification and pyrolysis, while biochemical conversion is accomplished through processes of composting, ethanol fermentation and anaerobic digestion. The direct combustion or incineration process can be additionally divided into fixed or fluidised bed combustion, as the gasification process, which can be fixed, fluidised or moving grate gasification [11]. Recent technologies are considered hydrothermal, including hydrothermal processing and carbonisation. Despite the combustion process where the waste undergoes direct incineration, every other waste processing method generates solid, liquid or gaseous fuel that burns in boilers where steam is produced and used for heat and electricity production.

3.1. Incineration

The incineration process is done by the process of confined and controlled burning inside a combustion chamber in a boiler generating steam that rotates a turbine connected to a generator used for electricity production. The waste used for direct incineration does not have to be sorted before entering the combustion chamber. The burning process is done in conditions of excess air in order to achieve better turbulence and mixing in all parts of the waste due to its inconsistent nature [1]. For using waste as fuel in the incineration process, the calorific value of the feed has to be at least 7 MJ/kg. If there is significant moisture content in the waste, additional treatment methods must be implemented [12]. The efficiency of electricity generation from incineration is in the range of 15-27%, and the combustion emissions are around 250-600 kg CO_2/ton of waste processed [13]. Other pollutants, such as flue gas, are emitted during combustion. A typical method of conventional incineration is fluidised bed combustion, used for burning homogeneous solid-gas mixture, applied for incineration of waste with higher moisture content and lower calorific value. This process uses sand and preheated air, which allows better heat transfer between the waste mixture and the heat exchange surfaces by ensuring a uniform temperature in the boiler [3].

3.2. Gasification

During fixed bed gasification, waste is inserted on the top of the reactor and undergoes several processes, starting from drying, preheating, gasification, combustion, and melting. The drying and preheating process removes the moisture from the feed at temperatures of around 300–400 °C. During the gasification process, waste is mixed with oxygen and/or steam at 400–1700 °C delivering a product which is gas or synthesised gas, also known as syngas. The next step is done at the temperature section, where the remaining solids from the feed are combusted and melted at around 1700–1800 °C [3]. Syngas can be used for the production of different products like fertilisers or fuels or for electricity production. For the electricity production process, syngas combusts in a gas turbine, meaning that gasification as a process is followed by combustion leading to similar emissions. The main difference between fixed and fluidised bed gasification is that the amount of air or oxygen inserted is lower during fluidised bed gasification. At the same time, the reactor configuration has a similar layout and works on the same principle. The temperature throughout the reactor is uniform, with a reasonable heat transfer rate. The difference between fluidised bed combustion and gasification is in the residues produced/ remaining, considering that fluidised bed combustion produces larger amounts of bottom ash and fly ash compared to fluidised bed gasification. The newest gasification technology is plasma gasification, where syngas is produced in a plasma reactor with a little amount of oxygen at temperatures from 1300 °C and higher. Later the syngas is treated with plasma at temperatures greater than 3000 °C delivering cleaned syngas without toxic emission and tars. The syngas is treated and cooled before using it as fuel for running a gas turbine for electricity production. The by-product from plasma gasification is vitrified slag [3].

3.3. Pyrolysis

In the pyrolysis process, shredded MSW together with other fuels, such as tires, industrial waste or dried sludge, is inserted into a rotary kiln. The retention time of the waste is longer compared to other WtE processes. The waste is being heated at temperatures from 500 °C and above without the presence of oxygen, generating syngas as a product. After the pyrolysis process, the following steps are gasification or combustion, where at temperatures above 1000 °C, steam is produced to run a steam turbine for electricity generation. A by-product from the pyrolysis process is flue gas that passes through the gas cooler or shock cooler to prevent forming of dioxins and furans and bag filters to remove NOx, Sulfur and other particulates. Compared to incineration, the pyrolysis process has a lower level of emissions, producing only slag and no bottom ash and fly ash [3].

3.4. Anaerobic digestion

Anaerobic digestion (AD) is a process where organic waste that has higher water content, like food, animal products, and sewage, is placed in a tank in the absence of oxygen. It passes through a series of microbial processes and decays into biogas, mainly composed of carbon dioxide and methane. Before using biogas as vehicle fuel or placing it into natural gas pipelines, it has to undergo purifying treatment techniques. The capital costs for the cleanup of biogas can be decreased by using anaerobic membrane bioreactors that can additionally produce biogas with more methane. Same as in the previously mentioned processes, the process following anaerobic digestion in order to produce heat and electricity is combustion [9]. AD has great potential through saving 0.22-0.35 million tons of CO2 by treating 5.5 million tons of food waste, compared to composting [14].

3.5. Operational plants

The largest market for WtE technologies is in Europe, covering 47.6% of the world's installed WtE plants. Japan leads the Asia Pacific region, covering 60% of the region with WtE techniques, and is followed by China [12].

In Europe, most WtE plants are installed in France, Denmark, Italy, Germany and Sweden. As cold countries, Sweden and Denmark have combined heat and power (CHP) WtE plants that generate more than 100 kW of energy. In Naples, Italy, there is a WtE combustion plant incinerating 650,000 tones/year. Sweden and Germany are founders of WtE technologies, and an interesting fact is that they import deficit waste from neighbouring countries [12]. Germany gradually converts its waste management system into a resource management system, considering that WtE plants generated 320 PJ of energy in 2015, accounting for around 3.7% coming from waste energy [6]. In Manchester, UK, a WtE gasification plant is in operation for the treatment of industrial, commercial and MSW with a capacity of 78,000 tons/year. Small scale WtE plant with plasma gasification technology is used in Teesside, UK, with a capacity of 270 tons per day. The biggest WtE plant in Norway has a capacity of 215 tons/day for the treatment of MSW using grate gasification technology. In Japan are located the most contemporary WtE thermal treatment plants processing around 39 million tons of waste per year. The bubbling fluidised bed gasification technique is used by Kobelco commercial WtE plants having capacity to treat 98–525 tons/day and to produce power of 220–457 kWh/ton of MSW. Whereas Shin-moji plant is the largest gasification plant treating 720 tons MSW per day, generating 784 kWh per ton. The efficiency of the plant is 17.7%. Fluidised bed combustion is used at Sumitomo Foster Wheeler in Japan with a power capacity of 1452 kWh per ton of treated waste and an efficiency of 24.8% [3]. In China, the most common WtE technique is incineration using a circulating fluidised bed (CFB) with 28 plants in total. The newest facility is in construction in Shenzhen that would be able to process 5000 metric tons/day, becoming the largest WtE plant in the world. In India, 14 plants are commissioned, but only four are in operation using RDF and dry AD technology. Due to the efficiency of the dry AD technique, four new WtE plants are being installed [12]. WtE technologies are also being developed in Abu Dhabi. In the USA, the WtE plants use combustion technology, such as Novo Energy, processing 66,000 tons/year, and gasification technology, such as IST energy in Massachusetts, treating around 200 lb of dry waste per hour. Canada improved incineration with plasma gasification WtE technology.

WtE plants produce and use electricity for powering the equipment, such as fans, cranes and air pollution control. The amount of energy consumed depends on the configuration of the plant and the limit air emission values. In order to achieve lower emissions, higher electricity is needed. The mean value for electricity usage at the WtE plant is 65-185 kWh/ton of waste treated. The electricity that can be recovered from the operation of the WtE plant ranges from 0% to 30%. The highest electricity recovery is achieved at the Amsterdam WtE plant, with 31% electricity recovered. In comparison, the heat recovery from WtE processes is in the range of 5% to 85% when no condensation of flue gasses is installed and even above 90% when there is flue gas condensation. Also, from WtE processes, scrap metal can be recovered, and in the best cases, 60% of non-ferrous metals and 85% of magnetic iron can be recovered from the waste. Consequently, there is an environmental benefit from recovering metals, considering that it saves around 1.5 kg CO_2/kg recovered iron and 10 kg CO_2/kg recovered aluminium [13].

3.6. Prospects for WtE technologies implementation in the Republic of North Macedonia

In the Republic of North Macedonia there is no municipal waste incineration plant, but the cement factory in Skopje "Usje" uses different waste types as alternative fuels. This is prescribed and allowed by the A-Integrated Environmental Permit (A-IPPC Permit) for compliance with an operation plan [15]. The use of alternative fuels in the cement kilns in the company started at the end of 2018. The reason was to partially replace the use of fossil fuels by 15% in the first phase [16]. The waste types planned to be used as fuel are prescribed in the IPPC Permit and include biomass suck as agricultural waste (rise husk), waste from fruit and vegetable processing, wood processing waste, waste from the processing of pulp, paper, cardboard; wood; textile; RDF; plastics; paper; packaging [15].

Hazardous and medical waste incinerator in Macedonia is operated by the compliant municipal waste landfill Drisla in Skopje. The incinerator was donated by the British Government in the year 2000 and has maximum capacity of 1 ton/day. It is primarily intended for burning medical waste and expired medicines. The medical waste is waste that is created in medical and health institutions, which is a product of used means and materials in the diagnosis, treatment, treatment and prevention of diseases in humans and animals. However, other types of waste can also be burned in it at the request of legal and physical persons. For the normal functioning of the incinerator the landfill Drisla has main project, filter, steel canopy, fence, 10-ton handling fuel tank, ladder and platform, concrete slab, buffering of the manipulative plateau and borders, employee facility, lightning rod installation and aggregate [17].

A plasma waste gasification plant is planned to be built in Negotino. The investment costs will be around 327 million EUR. The plant will produce natural gas from waste, such as plastics, paper, glass, and iron, which will then be used for electricity generation. The slag that would be left as a by-product will be processed and used in construction [18].

Plant for thermal decomposition of plastics and plastic waste is operating in North Macedonia, in the Municipality of Zelino. The processing capacity is 600 tons/day and the waste types processed are waste from plastics, waste plastic, particles and pieces of plastic, plastic packaging, plastics, and rubber. The products generated from the process are pyrolytic oil, pyrolytic gas (sin-gas), carbon black, and electricity. At 330 °C the percentage of obtained pyrolytic oil is around 38.5%, whereas the percentage increases with temperature being higher to 76.0% at 425 °C [19].

In the village Novaci, close to the city of Bitola in North Macedonia is located the country's first biogas plant using anaerobic digestion technology to produce 3 MW power. The plant uses agricultural manure from the cow farm agricultural combine "Pelagonia". By joint fermentation with feed corn biogas is obtained and then used to produce green energy. The investment was around 20 million EUR. In the coming period the agricultural combine "Pelagonija" plans to build a second biogas plant in the village of Porodin. This plant will have the same capacity as the one opened yesterday in Novaci. Construction of greenhouses for the two power plants is planned in order to fully utilise the heat obtained from cooling of the generators [20].

3.7. Emissions

The air emissions from WtE plants operation depend on the plant conditions, such as furnace temperature, presence of oxygen and waste residence time, as well as the waste characteristics, such as moisture content [21]. The environmental benefit regarding generated energy from WtE plants compared to the energy from coal is saving around 1000 kg CO2 equivalents per ton waste. Increasing the fossil fuel substitution in WtE plants leads to greater CO2 savings [13]. However, it should be taken into consideration that apart from CO2 emissions there are other air polluting emissions released during operation of WtE plants, such as bottom ash and fly ash containing dioxin and furan. Fly and bottom ash are mainly generated from combustion and are disposed of in landfills which should be special landfills for hazardous waste considering the hazardous nature of dioxin and furan [3]. Fly ash is also released during incineration of biomass but contains other harmful elements, such as lead, cadmium, chromium, and arsenic, harming the environment and human health [7]. The concerning situation is that fly and bottom ash emissions from incineration amount with 23% of the unit total capacity [22]. Research and development in this field is continuously progressing in order to improve the WtE technologies from environmental aspects by the engineers and technology providers.

3.8. Comparison between technologies

Comparing different technologies regarding the amount of waste being processed the order would be the following, grate incineration, fixed bed gasification, and conventional pyrolysis. The range of processed waste for each of these WtE technologies is 555 - 4400 tons per day for grate incineration, up to 720 tons per day for fixed bed gasification, and 555 tons per day for conventional pyrolysis. If analysing the capital costs of WtE technologies, starting the order with most expensive to least expensive, the list would be as follows, plasma gasification, fluidised bed combustion, grate incineration, and pyrolysis. Plasma gasification has highest capital costs over 700,000 USD per ton/day, fluidised bed combustion has 600,000 USD per ton/day, grate incineration has around 450,000 USD per ton/day, and pyrolysis has costs around 280,000 USD per ton/day [3]. Considering the operational costs, highest costs have conventional gasification and conventional pyrolysis followed by Conventional incineration and plasma gasification. The O&M costs for conventional gasification/

pyrolysis are in the range of 45–85 USD per ton/year and for conventional incineration and plasma gasification are in the range of 40-70 USD per ton/year [23]. Analysing the environmental impact lowest or negligible emissions have gasification, pyrolysis and plasma technology. Slag is produced by these processes which van be useful.

Comparison between WtE technologies with detailed data regarding the plant capacity, type of waste used, power production, costs, feed parameters and emissions is given in the Table 1 below [3]

Table 1. Comparison between WtE technologies

WASTE TO ENERGY TECHNOLOGY OPTIONS	CRITERIA											
	TECHNOLOGICAL					ECONOMIC		QUALITY OF FEED			ENVIRONMENTAL	
	TYPE OF WASTE	CAPACITY (t/d)	NET ELECTRICAL EFFICIENCY	POWER PRODUCTION (kWh/ton)	SPECIFICATION	CAPITAL COST (USD per ton/day)	OPERATION COST (USD per ton/yr)	HEATING VALUE (MJ/kg)	PARTICLE SIZE	MOISTURE CONTENT	EMISSION (Toxic Hazard)	RESIDUE
INCINERATION												
Conventional Incineration	MSW-RDF	185–4400	13.5–30.6%	360–1491	Combustion-Flue Gas Cleaning-Heat Gasifier; Fluidized Bed Technology	70,035–633,213	40–70	5.46–14.8	Any particle size	<65%	Dioxin/Furans (<or = 0.1 ng TEQ/Nm3)	23% ash and excess waste; bottom ash
Grate Incineration	MSW	555–4400	16–30.6%	373–990	Grate fired incineration + dedusting, dry or wet gas cleaning + electricity generation or CHP.	70,035–458,072		5.46–14.8		<65%	< or = 0.1 ng TEQ/ Nm3	
Fluidized Bed Combustion	MSW/ RDF	185–917	13.5–24.8%	360–1491	Fluidized bed combustion technology	203,910–633,213		5.9–13.4		<65%	< or = 0.1 ng TEQ/ Nm3	
PYROLYSIS												
Conventional Pyrolysis	MSW, RDF	5–555	4–24%	104–1294	Pyrolysis; Heat or Power Gasifier	38, 013–276,000	50–80	6.3–24	75–300 mm	10–50%	Negligible (0.0000072 to 0.025 ng TEQ/nm3)	Fused Slag, metal recovery
GASIFICATION												
Conventional Gasification	MSW, RDF	40–720	13–34.8%	220–1730	Gasification; Heat Gasifier; Steam Generation	46,457–673,617	45–85	6.7–18 MJ/kg	100 mm and above	>20%	Minimal to Negligible (0.000072 to 0.08 ng TEQ/Nm3)	Granulated Slag; Treated Fly Ash
Fixed Bed Gasification	MSW, IR, IW, ASR, SS, BA, RDF	200–720	17.7–27%	276–1528	Downdraft Gasification - Direct Melting System - Heat Gasifier	46,457		6.7–18.2	Waste Particle Diameter up to 100 mm	20–42	0.00023–0.08 ng/ TEQ/Nm³	Granulated slag. Ferrous metal recovery. Treated fly ash (0.85–2%)
Fluidized Bed Gasification	MSW, ASR, MPW, IW, MW, RDF, Fly-ash	52–690	13–34.8%	220–1730	Fluidized bed gasification-Gas Cleaning-Heat Gasifier	272,398–673,617		6–18 MJ/ kg	Waste particle >100 mm. Bed particle diameter between 0.05 and 0.5 mm	53.80%	0.000072–0.0015 ng/Nm3	Slag, Metal Recovery, Solidified Fly Ash
Moving Grate Gasification	MSW, RDF	40–215	18.50%	520–625	Atmospheric Pressure - Air Gasifier - Moving Grate - Bottom Ash - Heat Gasifier	190,465		10–14 MJ/ kg	Waste particle >200 mm	No Problem		
Plasma Gasification	MSW, RDF, Any Waste Type	5–274	18.6–25%	934–1386	Plasma Type - Power Gasifier	566,400–704,761	42–63	10–15	No problem in size	No problem	Negligible (0.000013 to 0.009 ng TEQ/Nm3)	Vitrified Slag

4. Conclusions

The World Economic Forum defines WtE to be one of the renewable energy sectors of near future. By using WtE technologies, waste that could end up at landfills is efficiently eliminated by reusing it and returning it to the industrial cycle. The reduction of GHG emissions by WtE technologies is done by generating electricity with lower CO2 emissions compared to conventional power plants, eliminating CH4 emissions generated at landfills, and recovering ferrous and non-ferrous metals from solid wastes increasing the energy efficiency if compared to production of raw materials. These ways complement each other and support the European Waste Framework Directive and the circular economy principles which improve economic growth and support the society and the environment. WtE processes present sustainable processes considering that waste is continuously generated, gathered, and then used in the plants for renewable energy generation. The limiting factors from WtE technologies are that the recycling process can be disincentivised since throwing waste is a simpler option, as well as destroy more useful materials than recover. However, these factors remain to be surpassed for these techniques to pair up with conventional energy systems.

References

[1] United States Environmental Protection Agency, Energy Recovery from the Combustion of Municipal Solid Waste (MSW), 2022, https://www.epa.gov/smm/energy-recovery-combustion-municipal-solid-waste-msw

[2] Yamaka, W., Chimprang, N., Klinlumpu, C., The dynamic linkages among environment, sustainable growth, and energy from waste in the circular economy of EU countries, Energy Reports, 8 (2022), 5, pp. 192-198
[3] Satiada, M. A., Calderon, A., Comparative analysis of existing waste-to-energy reference plants for municipal solid waste, Cleaner Environmental Systems, 3 (2021)
[4] Moya, D., Aldás, C., López, G., Kaparaju, P., Municipal solid waste as a valuable renewable energy resource: a worldwide opportunity of energy recovery by using Waste-To-Energy Technologies, Energy Procedia, 134 (2017), pp. 286-295
[5] Andreas von Schoenberg Consulting, Factsheet: Waste management in North Macedonia, 2021, https://www.retech-germany.net/fileadmin/retech/05_mediathek/laenderinformationen/North_Macedonia__Fact_Sheet_final.pdf
[6] Puttachai, W., Tarkhamtham, P., Yamaka, W., Maneejuk, P., Linear and nonlinear causal relationships between waste-to-energy and energy consumption in Germany, Energy Reports, 7 (2021), 3, pp. 286-292
[7] Gil, A., Challenges on waste-to-energy for the valorization of industrial wastes: Electricity, heat and cold, bioliquids and biofuels, Environmental Nanotechnology, Monitoring & Management, 17 (2022)
[8] Iakovou, E., Karagiannidis, A., Vlachos, D., Toka, A., Malamakis, A., Waste biomass-to-energy supply chain management: A critical synthesis, Waste Management, 30 (2010), 10, pp. 1860-1870
[9] Office of Energy efficiency & Renewable energy, Waste-to-Energy, https://www.energy.gov/eere/bioenergy/waste-energy
[10] U.S. Energy Information Administration, Biomass explained Waste-to-energy (Municipal Solid Waste), 2021, https://www.eia.gov/energyexplained/biomass/waste-to-energy-in-depth.php
[11] Gumisiriza, R., Hawumba, J. F., Okure, M., Hensel, O., Biomass waste-to-energy valorisation technologies: a review case for banana processing in Uganda, Biotechnology for Biofuels, 10 (2017), 11
[12] Anthony, A., What are some of the latest waste-to-energy technologies available?, 2017, https://www.prescouter.com/2017/10/waste-to-energy-technologies-available/
[13] WEKA Industrie Medien, Waste to Energy: The Carbon Perspective, 2015, https://waste-management-world.com/artikel/waste-to-energy-the-carbon-perspective/
[14] Energy saving trust, Generating energy from waste: how it works, 2022, https://energysavingtrust.org.uk/generating-energy-waste-how-it-works/
[15] Ministry of Environment and Physical Planning (MOEPP), A-Integrated Enironmental Permit, 2020, https://www.usje.mk/media/xbxdsbmi/a-ippc-usje-2020.pdf
[16] Titan Cementarnica Usje, Alternative fuels and raw materials, https://www.usje.mk/mk/odrzhlivost/zhivotna-sredina/alternativni-goriva-i-surovini/
[17] Депонија Дрисла Скопје, Incineration of medical waste by PE landfill Drisla Skopje, https://drisla.mk/tretman-na-opasen-otpad/
[18] Balkan Green Energy News, Plasma waste gasification project in North Macedonia is getting strategic investment status, 2021, https://balkangreenenergynews.com/plasma-waste-gasification-project-in-north-macedonia-is-getting-strategic-investment-status/
[19] ЕКО ЕНЕРЏИ АГРИ ДИЗАЈН ДООЕЛ Скопје, Notice of intention to implement a project "Plant for thermal decomposition of plastic and plastic waste" in a built facility located on a part of КП 2178 КО Zelino, Municipality Zelino, 2021, https://www.moepp.gov.mk/wp-content/uploads/2018/04/Izvestuvanje-za-namera_Postrojka-za-termicka-dekompozicija-na-plastika-i-plasticen-otpad_Zelino.pdf
[20] Бизнис Вести, Investments of AK Pelagonija of 20 million euros for a biogas plant and the most modern farm in Macedonia, 2016, http://www.biznisvesti.mk/investitsii-na-zk-pelagonija-od-20-milioni-evra-za-biogasna-tsentrala-i-najsovremena-farma-vo-makedonija/
[21] Giraud, R. J., Taylor, P. H., Combustion operating conditions for municipal Waste-to-Energy facilities in the U.S., Waste Management, 132 (2021), pp. 124-132
[22] Liu, C., Nishiyama, T., Kawamoto, K., Sasaki, S., CCET guideline series on intermediate municipal solid waste treatment technologies: Waste-to-Energy Incineration, United Nations Environment Programme, 2020, https://www.iges.or.jp/en/publication_documents/pub/policysubmission/en/10877/WtEI_guideline_web_200615.pdf
[23] Kumar, A., Samadder, S. R., A review on technological options of waste to energy for effective management of municipal solid waste, Waste Management, 69 (2017), pp. 407-422