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Sustainability of Waste Management Systems - Energy Recovery

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1 Definition/description

Energy recovery from waste represents an economically, socially, and expectedly environmentally acceptable option of waste management. Energy recovery is widely represented by waste incineration, gasification, pyrolysis, and anaerobic digestion. Sustainability of all energy recovery methods is not only determined by the recovery processes themselves but by a wide range of components of the energy recovery systems, such as waste properties, operating conditions, types of products, and demand on them, to name a few. For example, biowaste is more suitable for anaerobic digestion than incineration. At the same time, incineration of waste without the possibility to utilize heat produced neither as district, nor process heat, could have a higher impact on the environment than its gasification or pyrolysis. When systematically assessing energy recovery methods, the types of products being derived (electricity, heat, chemicals, biogas, monomers, oils, etc.), and the alternatives substituted on the market plays one of the most important roles in the sustainability of energy recovery from waste.

2 Synonyms

Energy recovery	Waste-to-energy

3 Introduction

Waste generation during industrial production and consumption is a fact of life. This can be compared to a metabolic waste generation by living organisms during their life-sustaining activities. As nature has gone through a long course of evolution, biological processes emerged to treat the metabolic waste and allow for the biological cycles of nutrients and other elements. On contrary, waste generated by industrial or man-made processes and activities oftentimes cannot be treated the same way by nature and such waste requires special management provided by humans.

To enable proper handling of waste, waste management was proposed as a solution. The term “waste” is used to refer to any waste generated as a part of anthroposphere, as opposed to the waste generated during natural activities occurring without human interaction. The term “waste management” is used to refer to any activity related to management of waste from the place of its generation, or even beyond when talking about waste prevention, to its final disposal in the environment without any further interaction by humans be it in a solid, gaseous, or liquid form. Waste management includes not only technological solutions, but also legislative, political, societal, economic, and environmental aspects as illustrated in Figure 1.

Lately, the increasing awareness of the destructive impacts of humans on this planet led to a special emphasis on the environmental pillar of sustainability. By environmentally sustainable waste management, a system in which the consumption of virgin raw materials in any sector of the economy is minimized by reusing, recycling, or recovering valuable substances from waste, while decreasing the environmental impact is determined. Sustainability of waste management could be improved in all its aspects and should be an overarching aim of the entire waste management system and not considered for each phase of waste management independently. Such systematic thinking can be supported by using the approach of life cycle assessment (LCA).

Energy recovery from waste is an efficient measure on the path towards sustainability because it serves multiple functions. First, energy recovery allows for minimization of waste volumes ending up in landfills, which reduces the generation of landfill gas which contains a strong greenhouse gas – methane, reduces risks of landfill fires which release toxic emissions to the atmosphere and reduces the risks of soil and water pollution caused by landfill leachate. Second, energy recovery results in the destruction of hazardous substances contained in the waste. Third, energy recovery from waste allows for the production of heat, electricity, or fuels, which can be used to avoid generation of equivalent products from other sources, often fossil. Also, waste-to-energy is defined a specific role towards implementation of the EU action plan for the circular economy (European Commission, 2017). Therefore, energy recovery is considered a suitable measure towards providing a sustainable disposal option to various waste, yet the factual statements can only be made based on the results of environmental, as well as social and economic, impact assessments.

On the other hand, energy recovery from waste also possesses certain environmental burdens. The highest risks are related to the formation of toxic air-borne emissions, as well as the generation of solid waste, such as slag, ash, and air pollution control residues, which can be toxic in nature depending on the waste being incinerated. These impacts and risks can be minimized and controlled by using advanced technologies and scientific know-how. However, the use of advanced technologies for air pollution control or ash management might be costly and require materials and energy inputs to their operation. Therefore, the environmental sustainability of energy recovery technologies should be analysed.

In this term of Encyclopedia, the sustainability aspects related to energy recovery from waste are being discussed. Environmental sustainability was given a focal point, while the economic and social pillars of sustainability were excluded from this term of Encyclopedia. Energy recovery encompasses all methods of converting waste into energy. Those methods include thermal methods, such as incineration, gasification, and pyrolysis, biological methods, such as anaerobic digestion, fermentation, as well as chemical methods, such as esterification (World Energy Council, 2016). Landfill gas recovery is also considered as an energy recovery option, yet this method is not intentionally meant for direct energy recovery from waste, rather as an option of reducing the environmental impact of waste landfilling.

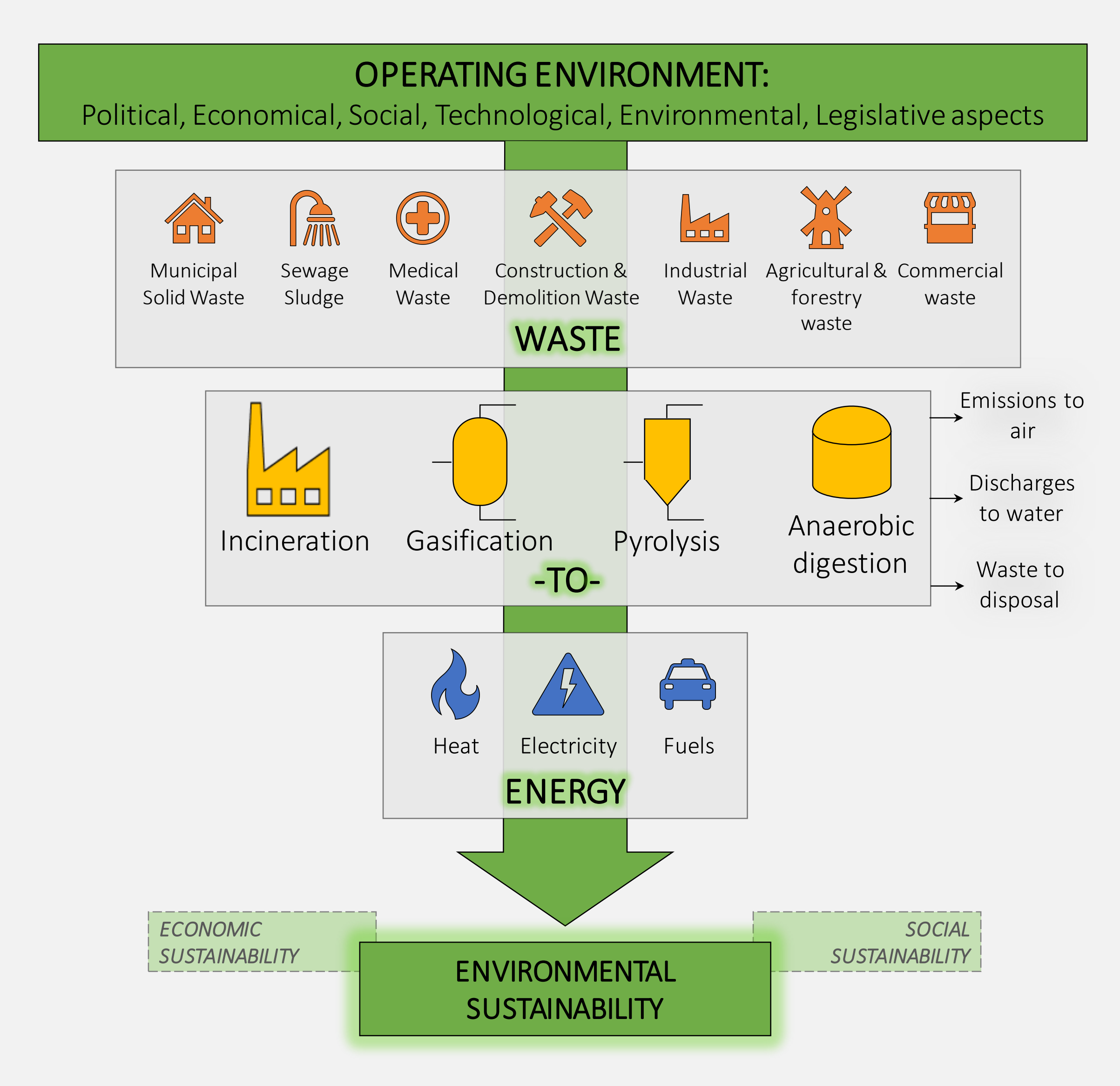


Figure 1. Relation of energy recovery to sustainability through the production of heat, electricity, and fuels from various waste under the impact of various aspects. Social and economic aspects of sustainability are affected by energy recovery but are not included in this term of Encyclopedia.

4 Incineration

Waste incineration is a process of high-temperature (850-1450 °C) thermal treatment of waste which implies full oxidation of combustibles contained in waste with air or another source of oxygen (Figure 2). As a result of waste incineration, waste is converted into solids residues, which are collectively called ash, flue gas, and energy. Two common ways of waste incineration are known: mass-fired incineration and combustion of fuels derived from waste, also known as refuse-derived fuel (RDF) or solid recovered fuel (SRF). SRF is a type of RDF, which is certified according to the standard EN 15359 (2011). Mass-fired incineration is applied to waste generated as such without extensive pretreatment. Mass-fired incineration of MSW would most commonly be performed in grate incinerators, whereas incineration of RDF or sewage sludge would be favoured in fluidized bed boilers because of higher suitability of RDF for the process. Hazardous waste is being commonly incinerated in rotary kilns.

Each of the incineration technologies has its **benefits, drawbacks, and limitations, which affect their sustainability**. Sustainability-related aspects could be related to the waste being incinerated, to the technology used for incineration, to the possibilities for energy recovery and utilization, to the air pollution control (APC) system, to the disposal of solid waste from incineration, such as slag, ash, and APC residues, and to the operating environment. Research work of Liikanen et al. (2017) focuses on the influence of various parameters on the sustainability of waste incineration, among other waste management options. Sustainability of waste incineration depends on the composition of waste being incinerated and its properties. The high content of water decreases the heating value of waste thus reducing the potential for energy substitution with waste, as well as affects the need for auxiliary fuels in the process. The high content of heavy metals and chlorine affect their emissions and release of polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/F). The high content of fossil carbon negatively affects climate change. Finally, variability in the composition and quality of the waste incinerated requires more flexible and efficient flue gas treatment technologies.

Grate incinerators are the most commonly applied technologies for mass-incineration of waste. In grate incineration, combustion occurs in the volume of waste on a moving metallic grate. Grates can be of different types, such as rocking, reciprocating, and travelling, among others. The grates are needed to move the waste from the feeding zone to the ash discharger while enabling its sufficient mixing with air to support combustion. Grate incinerators are suitable for highly heterogeneous waste, and thus, can be used to provide effective treatment to waste otherwise not suitable for incineration in fluidized bed incinerators. Even though the pretreatment of waste is not essential, it can be done to improve waste incineration efficiency and thus sustainability. Pretreatment might include particle size reduction and separation of recyclables, as well as wet and inert materials, yet the certain share of combustibles is also lost during the process. Considering environmental sustainability, the need for pretreatment should be determined based on the energy output of incineration, as well as the possibility to recycle materials separated, mainly metals, as compared to their separation from the bottom ash using magnetic separation for ferrous metals and eddy-current separators for non-ferrous metals. On another hand, the suitability of grate incinerators for highly heterogeneous waste possesses a serious threat on the APC systems, which are required to remove a larger variety of toxic pollutants from the flue gases.

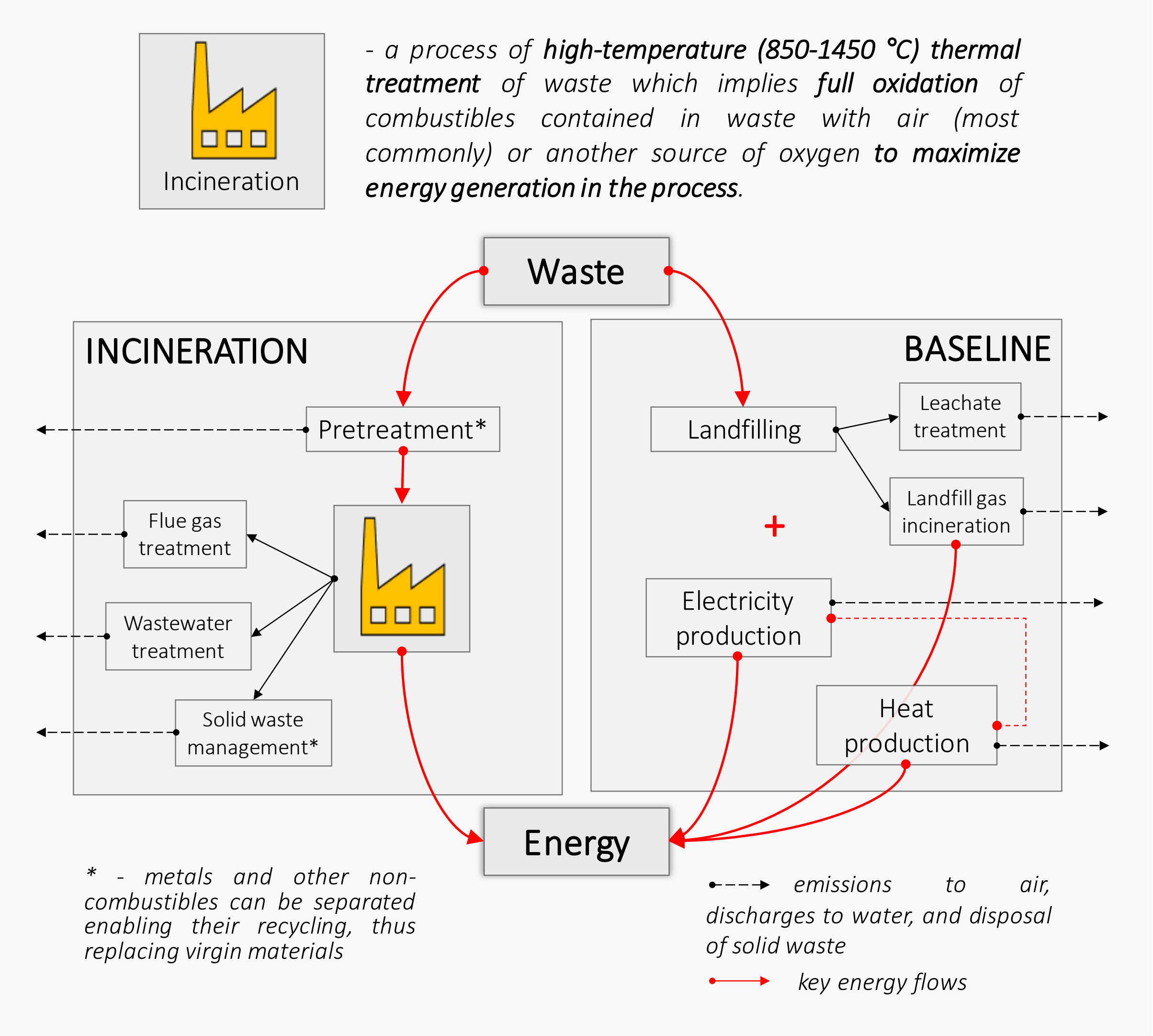
Fluidized bed combustion (FBC) is commonly used to incinerate waste-derived fuels (RDF or SRF). Combustion of waste occurs in a vertical cylindrical or rectangular waste incineration chamber which is filled with fine sand particles which are kept in a fluidized form by blowing air from the bottom of the furnace. Sand particles absorb the heat from waste incineration and the heat is used to dry and heat up the moist waste supplied to the process. Because the waste incinerated is relatively homogeneous, near-complete oxidation of waste is achieved, and it is easy to control the temperatures of combustion. This also helps to control the formation of gaseous emissions, e.g. nitrogen oxides. It is also possible to add limestone to the sand bed for sulphur dioxide emissions reduction. Fluidized bed combustion requires waste to be size reduced and metals to be separated to prevent slagging of the sand bed and fouling of the heat exchangers in the boilers. Better fuel quality also makes it possible to raise the temperature and pressure of the steam generated higher than it can be achieved in grate incinerators. In this way, the electric efficiency of the process is improved. Another benefit of using RDF or SRF instead of mixed waste is a considerably smaller amount of ash generated.

Energy recovery from waste incineration and its effective utilization is the key driver towards the viability and sustainability of this waste disposal method. Energy can be recovered as both heat and electricity. While electricity can be supplied to the grid ensuring its utilization, the local demand on heat by households as district heating or by the industry as steam or thermal energy determines the possibilities for its utilization. Special attention should be given to boilers enabling efficient heat transfer, while other methods to increase energy efficiency, such as preheating of combustion air, water cooling of grates, flue gas condensation, and flue gas recirculation should be considered to increase the overall energy efficiency of incineration. The sustainability of energy recovery is also driven by the type of fuel being phased out when electricity is replaced with that from the waste incineration plant. Avoidance of fossil fuels brings substantial benefits to the process, while incineration of waste in countries where the majority of energy is derived from renewable energy sources might have little sustainability advantages compared to other options of waste recovery and management.

The emissions from the waste incineration process are of large social, as well as environmental, concern for waste incinerators. Various APC systems have been developed and are being used in waste incinerators. Those systems often include a combination of either of the following methods: electrostatic precipitators, bag filters, cyclones, wet scrubbers, semi-wet scrubbers, active carbon injection, selective catalytic and non-catalytic reduction processes, and adsorption processes. These methods enable efficient reduction of dust, nitrogen oxides, sulphur oxides, acids, heavy metals, and chlorinated compounds. Also, process conditions might be varied to influence the emissions of nitrogen oxides, carbon monoxide, heavy metals, and PCDD/Fs. Finally, the content of chloride-based compounds, mercury and other toxic metals in flue gases can be reduced by avoiding those elements in the feeding waste. The regulations concerning waste incineration and its emissions are strict in the EU and other developed countries. The regulations state the limits and measurement demands for a higher number of emission components than the regulations of conventional fuels combustion. In addition, there are regulations for combustion conditions to ensure the destruction of toxic organic compounds in all the process conditions.

Recovery of metals and other incombustibles from mixed waste is one aspect having a significant impact on the sustainability of waste incineration. On one hand, incombustibles contained in the mixed waste can be removed prior to waste incineration. When doing so, other waste fractions will also be lost during the mechanical pre-treatment of mixed waste due to an inefficient separation of different waste fractions. This leads to a decrease in the energy input to the incineration process. Furthermore, the final disposal of rejects, fine, and heavy fractions from the RDF production should be considered since their recycling might be challenging. Removal of incombustibles from waste to produce RDF increases the incineration efficiency. On the other hand, incombustibles can be subjected to incineration in grate incinerators. By doing so, incombustibles will end up in the bottom ash and slag, from where ferrous, non-ferrous, and mineral fractions can be recovered. Therefore, systematic assessment of alternative systems for handling incombustibles in waste should be performed accounting for the separation processes themselves also for the mass and quality of metals and other non-combustibles separated and recycled. Recovery of metals is expected to preserve natural resources which would otherwise be used to produce metals substituted with those recovered from waste.

The operating environment, which includes political, legal, and geographical aspects might be one of the most decisive aspects of the sustainability of waste incineration and other waste-to-energy technologies. The legal aspects affect sustainability in terms of the emission limits, which are getting more stringent with the development of novel APC techniques and increasing social pressure. Political aspects affect sustainability through the country- or region-specific policies on waste management, recycling, and incineration. Geographical aspects determine the availability and proximity of heat consumers, which is an important factor accounting for the high losses of thermal energy during its delivery to the point of utilization. Electricity transmission has a lower dependency on the local market since it can be supplied to the grid and utilized. Finally, when the sustainability of waste incineration is assessed, the potential reduction of the environmental impact is calculated through the avoided electricity and heat production, which would otherwise occur without waste incineration. Oftentimes, marginal electricity and heat sources are accounted for, and not grid mixes. Determination of a marginal electricity or heat source is done through analysis of historical data for a specific area on the generation of electricity and heat. When the electricity grid is carbon-intensive and the efficiency of energy recovery from waste is high, energy recovery from solid waste can have higher benefits than material recycling from the climate change point of view. See Example 8.1 of this term.



*- a process of **high-temperature (850-1450 °C) thermal treatment** of waste which implies **full oxidation** of combustibles contained in waste with air (most commonly) or another source of oxygen **to maximize energy generation in the process**.*

** - metals and other non-combustibles can be separated enabling their recycling, thus replacing virgin materials*

emissions to air, discharges to water, and disposal of solid waste

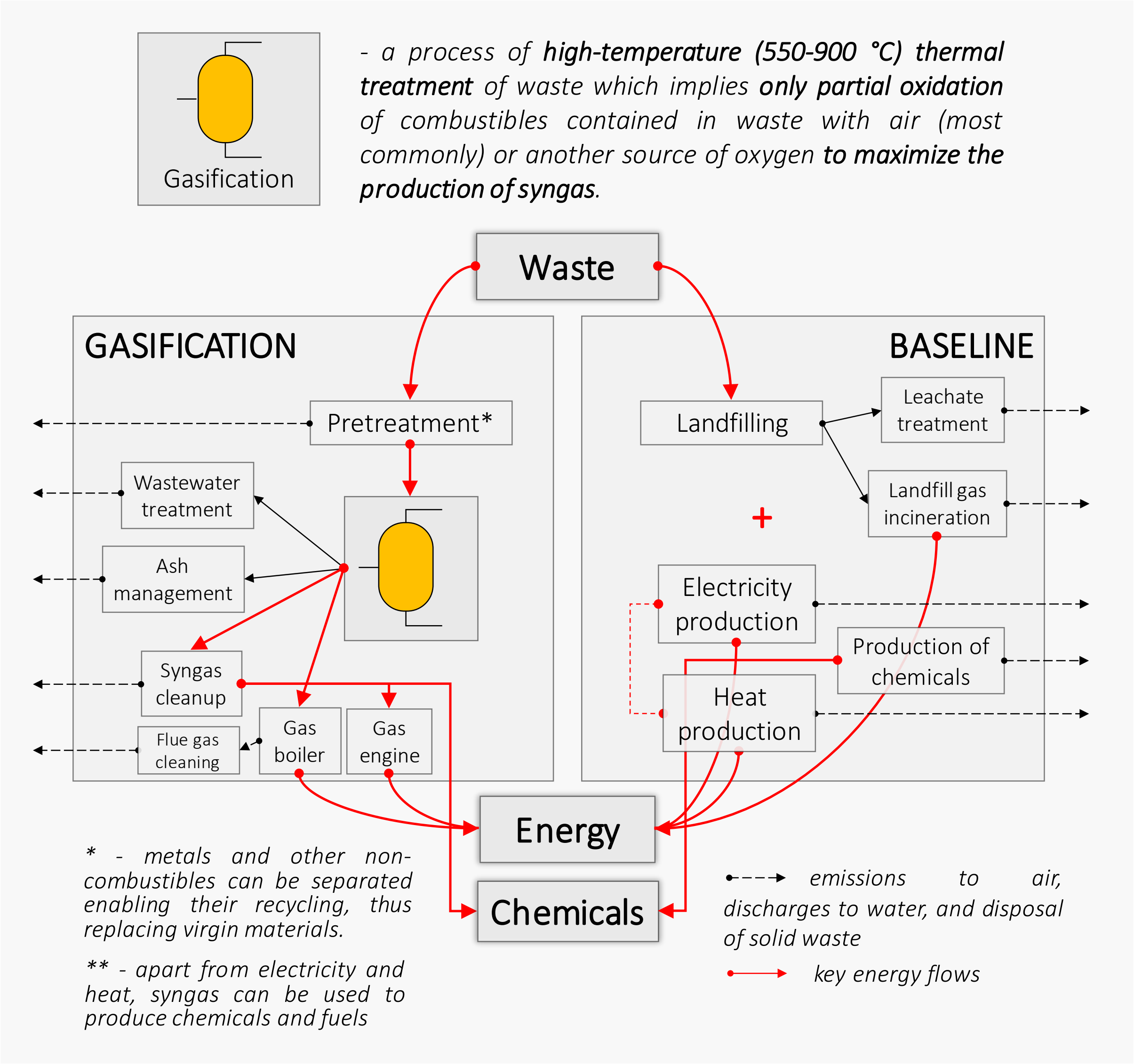
key energy flows

Figure 2. Key components of the waste incineration system affecting sustainability, as well as the key components of the baseline scenario, which is assumed to be landfilling and production of substituted electricity and heat.

More detailed discussion on the sustainability of waste incineration, as well as any other energy recovery methods, includes consideration of various aspects. One of the aspects is the type of electricity and heat displaced on the market, i.e. so-called consequential vs. attributional approaches. Another aspect is the use of the zero-burden approach considering that waste carries no burden from the preceding life cycle stages. With the increasing trend of the circular economy, waste should rather be considered as a resource, thus carrying certain debit from the previous life cycle stages. Consideration of the baseline scenario also has significant impacts on the results. For example, landfilling of organic waste is banned in some European countries making landfilling only a hypothetical option. More considerations on the LCA of waste management can be found in another term of this Encyclopedia (see Chap. .. Environmental Impact Managt with Life Cycle Assessment).

5 Gasification

Waste gasification is a process of high-temperature (550-900 °C) thermal treatment of waste which implies only partial oxidation of combustibles contained in waste with air or another source of oxygen (Figure 3). As a result of waste gasification, waste is converted into fuel gas, which is also referred to as syngas or producer gas, and ash. Syngas mainly consists of carbon dioxide, hydrogen, carbon monoxide and methane, while the presence of particulates, tars, acids, and other impurities is possible. Unlike waste incineration, waste gasification is performed to only partially oxidize waste which is required to generate enough heat for the self-supporting gasification process. Air is usually supplied at 20-30% of the stoichiometric need. Arena (2012) elaborates on waste gasification in more details.



- a process of **high-temperature (550-900 °C) thermal treatment** of waste which implies **only partial oxidation** of combustibles contained in waste with air (most commonly) or another source of oxygen **to maximize the production of syngas**.

* - metals and other non-combustibles can be separated enabling their recycling, thus replacing virgin materials.

** - apart from electricity and heat, syngas can be used to produce chemicals and fuels

emissions to air, discharges to water, and disposal of solid waste

key energy flows

Figure 3. Key components of the waste gasification system affecting sustainability, as well as the key components of the baseline scenario, which is assumed to be landfilling and production of substituted electricity, heat, chemicals and fuels.

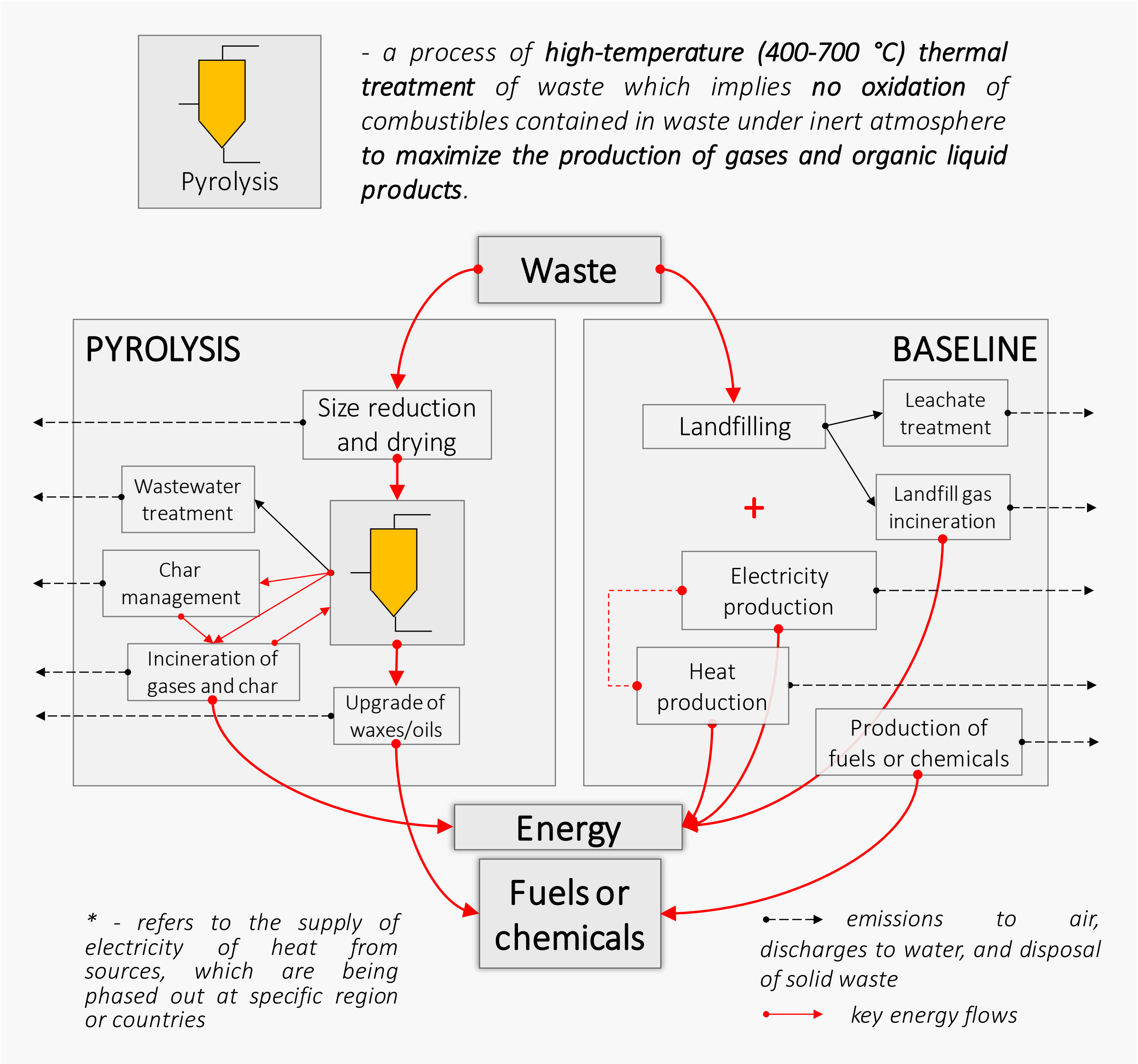
As with waste incineration, there are several factors which affect the sustainability of waste gasification. Waste should be rather uniform and preferably have a particle size of below 100 mm. Therefore, the quality and composition of waste determine their applicability for the process as such. Oftentimes, waste needs to be size-reduced and non-combustibles be removed prior to gasification. The gasification process is energetically self-sufficient meaning that no external energy is needed for the process. Furthermore, no specific and dedicated air pollution control system is needed since the fuel gas could be sent to further clean-up to remove acidic compounds, tars, particles, and other impurities. Air pollution control is, however, needed after the combustion of fuel gas, yet the requirements for its incineration could be lower than during incineration provided that producer gas has been cleaned up properly.

There are certain benefits of waste gasification over incineration. Firstly, higher energy efficiencies could be achieved when fuel gas is combusted in gas boilers which have higher efficiencies when compared to conventional waste incineration boilers. Secondly, the fuel gas is an intermediate product, which can be stored, transported, and utilized in places with the highest demand, thus enabling the substitution of fossil fuels. This is an advantage since the substitution of electricity and heat during waste incineration might not always result in avoided environmental impact.

Gasification can be used also for co-combustion purposes. Waste can be gasified and the fuel gas can be combusted in an existing plant burning conventional fossil fuels. With the fuel gas from waste, it is possible to replace fossil fuels without changing the whole process and without supplying solid waste to the conventional furnace.

6 Pyrolysis

Waste pyrolysis is a process of high-temperature (typically around 400-700 °C) thermal treatment of waste which implies heating of combustibles contained in waste in an oxygen-free environment (Figure 4). As a result of waste pyrolysis, waste is converted into organic liquid products, such as oils and waxes, which are condensed from produced gas, non-condensable flammable gases, and char. The pyrolysis conditions can be adjusted to maximize the yield of a specific component. Pyrolysis has been mostly practised to dispose of tires, plastic, or dried sewage sludge. Pyrolysis gained less attention to the treatment of MSW due to its high moisture content, high heterogeneity and large particle size, yet some experimental research has been performed. Chen et al. (2014) elaborate on MSW pyrolysis in detail. Martínez et al. (2013) and Williams (Williams, 2013) explain the pyrolysis of tires. Inguanzo et al. (2002) discuss the pyrolysis of sewage sludge, while Anuar Sharuddin et al. (2016) explains the pyrolysis of plastic waste.



*- a process of **high-temperature (400-700 °C) thermal treatment** of waste which implies **no oxidation** of combustibles contained in waste under inert atmosphere **to maximize the production of gases and organic liquid products**.*

** - refers to the supply of electricity of heat from sources, which are being phased out at specific region or countries*

emissions to air, discharges to water, and disposal of solid waste

key energy flows

Figure 4. Key components of the waste pyrolysis system affecting sustainability, as well as the key components of the operating environment expressed through the baseline scenario, which is assumed to be landfilling and production of substituted electricity, heat, fuels and chemicals.

Sustainability of waste pyrolysis strongly depends on the quality of waste feedstock, which is explained by the need for waste drying and size reduction (Figure 4). Integration of the pyrolysis unit to a combined heat and power plant to incinerate non-condensable gases and char to generate energy which can be supplied to the pyrolysis process itself, as well as on the local market, is a feasible option to improve the sustainability of the process. The majority of the environmental impact does not occur in the pyrolysis unit itself, but elsewhere in the value chain, i.e. during incineration of gases, char, and organic liquid products. Organic liquid products could be further refined to produce fuel and/or chemicals. Therefore, the yield of the organic products, which might be affected by using catalysts, the need for their upgrading, and the fuels being replaced strongly affect the sustainability of the process.

7 Anaerobic digestion

Anaerobic digestion is a process of low-temperature (37 °C for a mesophilic process and 55-70 °C for a thermophilic process) biological treatment of organic waste which implies degradation and stabilization of organics contained in waste under anaerobic conditions (Figure 5). As a result of anaerobic digestion, organic waste is converted into biogas and microbial biomass, i.e. digestate. Anaerobic digestion has been applied e.g. to the treatment of sewage sludge, biowaste, and agricultural waste. Commonly, anaerobic digestion is applied to moist waste consisting of quickly biodegradable organic matter, which was separated from other solid waste.

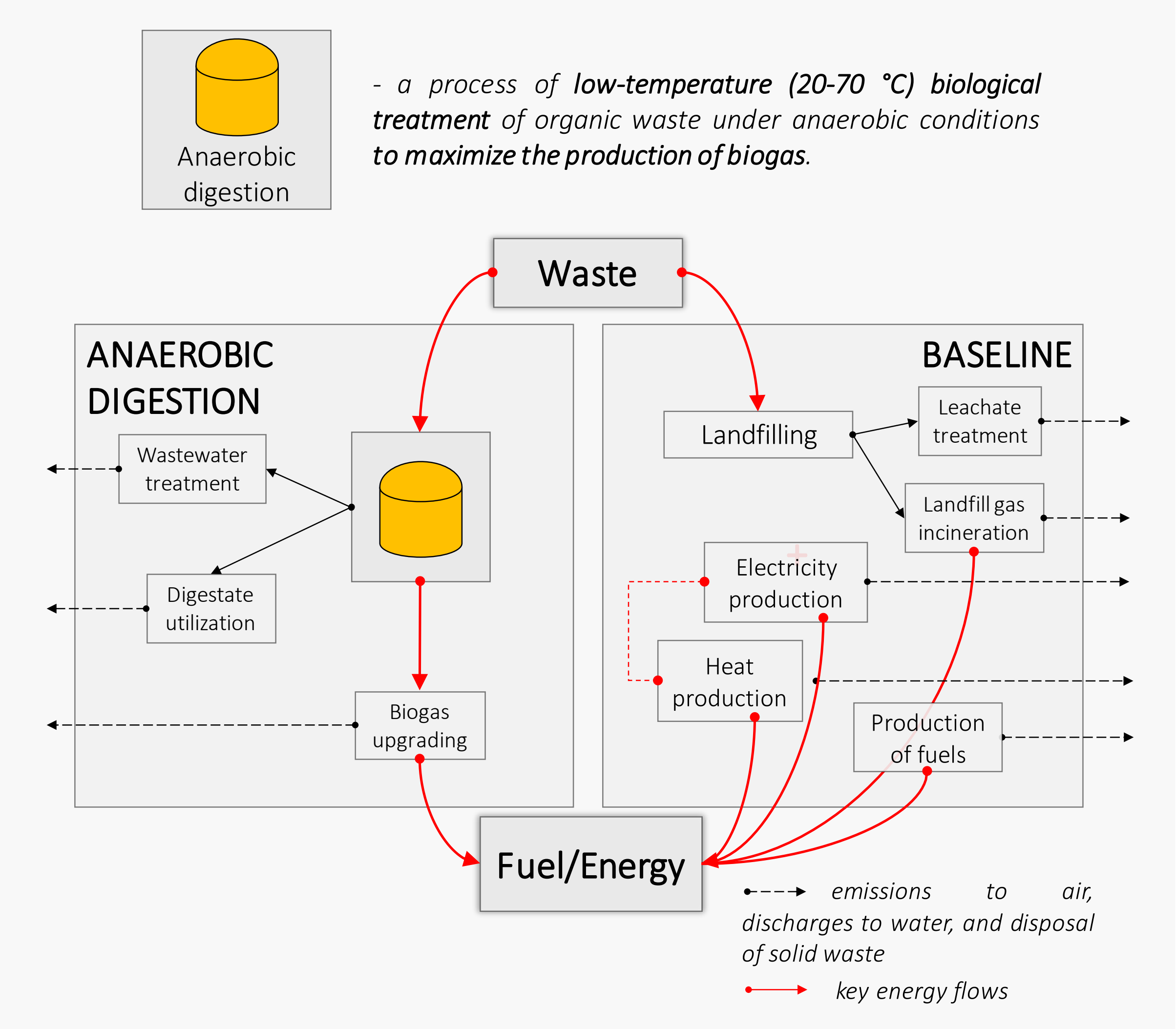


Figure 5. Key components of the waste anaerobic digestion system affecting sustainability, as well as the key components of the operating environment expressed through the baseline scenario.

Sustainability of anaerobic digestion is determined by many factors, including the energy need for the process, the moisture content of the feedstock, need for feedstock collection and transportation, among others. Berglund and Börjesson (2006) showed that the energy input to biogas production corresponds to some 25-40% of the energy output in biogas produced, but the variation is high depending on heating needs due to varying climate conditions, the yield of biogas, and the level of automation. Most of the energy input is for the heating and electricity supply to the anaerobic digestion process. Application of digestate on land might result in reduced eutrophication and global warming potentials when compared with the use of mineral fertilizers produced using energy incentive Haber-Bosch process. Finally, the upgrade of the biogas is an important step towards sustainability since this biogas can be utilized as a transport fuel, thus replacing natural gas or gasoline.

8 Examples

8.1 MSW management in São Paulo, Brazil

Incineration of MSW with energy recovery in Brazil might have a higher impact on global warming potential (GWP), also referred to as climate change, acidification potential, and eutrophication potential when compared with MSW landfilling equipped with landfill gas recovery and generation of electricity from Brazilian electricity mix (Liikanen et al., 2018). A higher impact from incineration compared to the reference situation was, first, due to an assumption for a high collection rate of landfill gas (64 or 80% depending on the landfill), and second, due to low environmental impact from the Brazilian electricity grid mix (75% of electricity generated is from hydropower). However, when the landfill gas collection rate was decreased to 50%, MSW incineration was more favourable. Similarly, when the type of electrify substituted was changed to natural gas or heavy fuel oil, incineration was more favourable when compared to landfilling. Overall, the production of RDF from MSW and its combustion in a cement kiln to replace coal, as well as anaerobic digestion of an organic fraction was the best scenario in the study.

8.2 MSW management in Hangzhou, China

The MSW management in China could be improved by the production of RDF and efficient recovery of the organic rejects generated therein as highlighted by Havukainen et al. (2017). Production of RDF led to increased efficiency of energy recovery during waste incineration and avoidance of the use of coal as auxiliary fuel to raise the combustion temperatures to the level demanded by legislation and dioxin reduction. However, landfilling of organic rejects could diminish these benefits, so its proper management, e.g. by anaerobic digestion, should be practised. Significant potential towards sustainability of energy recovery from MSW lies in improved source-separation of biowaste and, thus increased energy recovery efficiencies and avoided consumption of auxiliary fuel during waste incineration, which is currently coal.

8.3 MSW management in South Karelia, Finland

Incineration of MSW in the region of South Karelia, Finland, helps to mitigate climate change, yet not under all operating environments as studied by Hupponen et al. (2015). Mitigation of climate change was possible due to avoided emissions from landfilling, as well as avoided emissions from electricity and heat substitution in the waste incineration plants. However, when the heat substituted was mainly derived from biofuels (72%), the reduction of the impact on climate change was significantly lower compared to the cases where heat replaced was derived from natural gas. When comparing different incineration solutions, it is important to take into account the annual efficiency of energy production instead of technical efficiency. For heat recovery, seasonality of heat demand is an important aspect since district heating of buildings is only required during winter time, whereas steam can be utilized in the industry all year round, which increases the total annual efficiency of industrial heat recovery significantly. Effective heat recovery, in general, represents a very important possibility to improve the environmental sustainability of waste-to-energy, which can be seen when comparing the results of waste-to-energy studies done for countries in cold climate and warm climate regions. It is important to realize, that industrial needs for heat exist also in warmer climate zones and this possibility should be utilized more effectively in waste-to-energy.

8.4 Commercial waste management in Finland

Energy recovery from mixed waste and energy waste had the largest global warming reduction potential out of several waste fractions as studied by Hupponen et al. (2018). Apart from incineration, recycling of biowaste, cardboard, polyethylene, paper, metals, and glass was studied. Despite the fact that waste incineration releases substantial amounts of greenhouse gases, large benefits for mitigation of climate change are achieved through substitution of energy, which was derived from hard coal, natural gas, peat, or a Finnish electricity grid mix. While incineration and recycling of all waste fraction resulted in a reduced impact on climate change, recycling of cardboard proved to have higher impacts than the production of cardboard from virgin raw materials. This might be related to the low impact from virgin cardboard production in pulp and paper mill integrates where energy is supplied via combustion of wood and other bio-based residues.

8.5 Ash recycling in Finland

Proper management of thermal residues, which is a collective term used to refer to bottom ash, boiler slag, fly ash, and air pollution control residues, affects the entire sustainability of waste incineration; yet, the impact from thermal residues management has a relatively low impact compared to waste incineration itself. Recycling of bottom ash, boiler slag, and fly ash from incineration of various fuels, including municipal solid waste was studied by Deviatkin et al. (2017a). The studied recycling options included forest fertilization, landfill construction, road construction, and road stabilization, depending on legal and technical acceptability of different types of thermal residues and fuels used in incineration. Each of the studied recycling methods had a reduced impact compared to landfilling across several impact categories, such as global warming potential, ozone layer depletion potential, acidification potential, and eutrophication potential. In some cases, substitution of products manufactured from virgin materials resulted in large avoided impact on climate change, such as substitution of cement, whereas avoided phosphorous fertilizer production led to significant reduction of abiotic resource depletion potential. The impact of ash recycling on toxicity-related impact categories varied significantly from avoided impact to induced one depending on a specific scenario. In most of the cases, leaching from thermal residues was determined by the liquid-to-soil ratio, which was modelled based on precipitation in a specific area, depth of ash disposal, the density of materials, among other parameters.

However, ash recycling might also cause additional impacts on the environment as studied in another paper of Deviatkin et al. (2017b). Advanced treatment of bottom ash allowing efficient separation of ferrous metals, non-ferrous metals, and minerals of four different fractions with consequent utilization of only limited amount of the minerals in the production of cementitious products has a slightly larger non-toxic environmental impact when compared with the production of similar products from conventional materials. This was due to induced environmental impact during pre-treatment of bottom ash, as well as additional consumption of cement during the production process when minerals obtained from ash were utilized. The situation would change if more minerals were utilized. Moreover, if the impact of the recycling of non-ferrous and ferrous metals were included, the results can be expected to have a lower environmental impact.

8.6 Comparison of waste incineration versus gasification

In the study by Arena et al. (2015), incineration of residual MSW in a moving grate combustor was compared with its gasification in a vertical shaft gasifier. The results indicated that waste incineration has lower emissions than gasification across many impact categories, including the impact on climate change. The higher impact from gasification was due to the use of metallurgical coke in the process to enable high temperatures in the molten section of the gasifier.

8.7 Pyrolysis of waste plastics

In the study by Perugini et al. (2005), pyrolysis of waste plastics had a lower impact on climate change compared to its incineration or landfilling. Mechanical recycling of polyethylene and low-temperature pyrolysis of polyolefins released 4.2 times fewer greenhouse gases than incineration with energy recovery and 3.1 times less compared to landfilling. The largest avoided impact originated from avoided production of polyethylene and polypropylene.

8.8 Nitrogen recovery from sewage sludge

Sustainability of energy recovery from sewage sludge during its digestion or incineration might be further reduced by seizing the potential of nitrogen recovery during its drying (Deviatkin, 2017). A reduction of the impact on climate change of 30% could be achieved when nitrogen is recovered during thermal drying of sewage sludge when compared to its incineration without nitrogen recovery and production of nitrogen fertilizers via an energy-intensive Haber-Bosch process.

9 Summary

Energy recovery from various waste streams might represent sustainable waste management options. Despite the significant emissions originating either directly during the waste-to-energy processes, e.g. incineration, or during incineration of products obtained therein, such as syngas, pyrolysis oil, or biogas, energy recovery from waste usually contributes to the reduction of environmental impact through avoided conventional disposal of waste, which is oftentimes landfilling in developing countries or in countries with economies in transition, and due to expected avoided production of electricity, heat, fuels and chemicals, which could be produced from waste.

Availability and composition of waste strongly affect the sustainability of energy recovery from waste. Furthermore, sustainability of energy recovery is determined by the right choice of the treatment method, e.g. anaerobic digestion of biowaste versus its incineration, or pyrolysis of plastic waste versus its incineration in countries with the low carbon intensity of electricity grid mixes. Finally, the operating environment determines the sustainability of the energy recovery options within a range of other waste management methods. Therefore, attention should be given not only to the energy recovery methods but also to the environmental impact of the conventional disposal methods of specific waste and to the types of replaced products.

Cross references

References

Anuar Sharuddin, S.D., Abnisa, F., Wan Daud, W.M.A., Aroua, M.K., 2016. A review on pyrolysis of plastic wastes. Energy Convers. Manag. 115, 308–326. https://doi.org/10.1016/J.ENCONMAN.2016.02.037

Arena, U., 2012. Process and technological aspects of municipal solid waste gasification. A review. Waste Manag. 32, 625–639. https://doi.org/10.1016/j.wasman.2011.09.025

Arena, U., Ardolino, F., Di Gregorio, F., 2015. A life cycle assessment of environmental performances of two combustion- and gasification-based waste-to-energy technologies. Waste Manag. 41, 60–74. https://doi.org/10.1016/J.WASMAN.2015.03.041

Berglund, M., Börjesson, P., 2006. Assessment of energy performance in the life-cycle of biogas production. Biomass and Bioenergy 30, 254–266. https://doi.org/10.1016/J.BIOMBIOE.2005.11.011

Chen, D., Yin, L., Wang, H., He, P., 2014. Pyrolysis technologies for municipal solid waste: A review. Waste Manag. 34, 2466–2486. https://doi.org/10.1016/J.WASMAN.2014.08.004

Deviatkin, I., 2017. The role of waste pretreatment on the environmental sustainability of waste management. Lappeenranta University of Technology, Lappeenranta.

Deviatkin, I., Havukainen, J., Horttanainen, M., 2017a. Comparative life cycle assessment of thermal residue recycling on a regional scale: A case study of South-East Finland. J. Clean. Prod. 149, 275–289. https://doi.org/10.1016/j.jclepro.2017.02.087

Deviatkin, I., Sormunen, A., Rantsi, R., Havukainen, J., Horttanainen, M., 2017b. LCA of MSWI BA treatment with an davanced treatment technology and consequent recycling of the mineral fractions obtained, in: Sixteenth International Waste Management and Landfill Symposium. Cagliari, Italy.

European Commission, 2017. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - The role of waste-to-energy in the circular economy package.

Havukainen, J., Zhan, M., Dong, J., Liikanen, M., Deviatkin, I., Li, X., Horttanainen, M., 2017. Environmental impact assessment of municipal solid waste management incorporating mechanical treatment of waste and incineration in Hangzhou, China. J. Clean. Prod. 141, 453–461. https://doi.org/10.1016/j.jclepro.2016.09.146

Hupponen, M., Grönman, K., Horttanainen, M., 2015. How should greenhouse gas emissions be taken into account in the decision making of municipal solid waste management procurements? A case study of the South Karelia region, Finland. Waste Manag. 42, 196–207. https://doi.org/10.1016/j.wasman.2015.03.040

Inguanzo, M., Domínguez, A., Menéndez, J.., Blanco, C.., Pis, J.., 2002. On the pyrolysis of sewage sludge: the influence of pyrolysis conditions on solid, liquid and gas fractions. J. Anal. Appl. Pyrolysis 63, 209–222. https://doi.org/10.1016/S0165-2370(01)00155-3

Liikanen, M., Havukainen, J., Hupponen, M., Horttanainen, M., 2017. Influence of different factors in the life cycle assessment of mixed municipal solid waste management systems – A comparison of case studies in Finland and China. J. Clean. Prod. https://doi.org/10.1016/j.jclepro.2017.04.023

Liikanen, M., Havukainen, J., Viana, E., Horttanainen, M., 2018. Steps towards more environmentally sustainable municipal solid waste management – A life cycle assessment study of São Paulo, Brazil. J. Clean. Prod. 196, 150–162. https://doi.org/10.1016/J.JCLEPRO.2018.06.005

Martínez, J.D., Puy, N., Murillo, R., García, T., Navarro, M.V., Mastral, A.M., 2013. Waste tyre pyrolysis – A review. Renew. Sustain. Energy Rev. 23, 179–213. https://doi.org/10.1016/J.RSER.2013.02.038

Perugini, F., Mastellone, M.L., Arena, U., 2005. A life cycle assessment of mechanical and feedstock recycling options for management of plastic packaging wastes. Environ. Prog. 24, 137–154. https://doi.org/10.1002/ep.10078

Williams, P.T., 2013. Pyrolysis of waste tyres: A review. Waste Manag. 33, 1714–1728. https://doi.org/10.1016/J.WASMAN.2013.05.003

World Energy Council, 2016. World Energy Resources. Waste to Energy.