Bio-waste – collection, separation, generated products for second use

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Abstract. In Germany, the recorded quantities of bio-waste have grown continuously after the introduction of a separate organic waste bin. Residual biomass is not a waste – it is a raw material, which forms the basis for various marketable products, such as compost, biogas/biofuels, or biomass coke. This article highlights possible process ways according to the state of the art from bio-waste collection until the generation of products for second use. In addition, possible trends for the development of the bio-waste industry are shown.

1 Introduction

Bio-waste from households includes garden waste such as hedges, grass, and tree-cut as well as food and kitchen waste. In Germany, bio-waste has been collected separately since 1985 and recycled materially or energetically [1]. Since 2015, the EU Waste Framework Directive has been in place, which obligated the member states of the European Union to introduce a separate bio-waste collection. In addition, this is associated with separate treatment for the production of bio-based products. Legal requirements for the recycling processes as well as the strict limiting values for heavy metals and foreign substances in the products must be observed.

With the introduction of the separate bio-waste bin in the 1980s, the amount of bio-waste has now increased to around 15 million tons per year [2]. Depending on the recycling technology used, this collected bio-waste results in secondary products such as compost, biogas, biochar, or even biofuels. This article shows the path from collection to the utilization of secondary products generated from biomass, taking into account current trends.

2 Definition of bio-waste and legal framework

The waste management term for biogenic waste is bio-waste. According to the definition of the EU Directives 2008/98/EC and 2018/851Article 3b Number 4, as well as the German Waste Management Act (Kreislaufwirtschaftsgesetz KrWG) § 3 Paragraph 7, bio-waste comprises

- biodegradable plant waste,
- animal or fungal garden and park waste,
- landscape maintenance waste,
- food and kitchen waste from private households, from the restaurant, canteen and catering industry, from offices and from the wholesale and retail trade, as well as,
- waste from food processing plants comparable to the aforementioned waste,
- waste from other areas of origin of comparable type, nature or material properties.

A large proportion of forestry and agricultural residues, such as slurry and manure, are not included in the bio-waste definition, because they are not disposed of as waste [1]. If the biodegradability of bio-waste is taken as a basis, a distinction is made between "slightly biodegradable herbaceous biomasses", such as kitchen waste, fruit residues, and grasses, and "less degradable woody biomasses", including wood residues and paper [3], whereby the latter is not included in the definition of bio-waste.

In the collection as well as the material and energy recovery of bio-waste, legal framework conditions such as "waste, fertilization, water, and pollution protection law as well as in part also the law of renewable energies" [2] must be complied with.

3 Amount of bio-waste in Germany

In Germany, the amount of separately collected bio-waste has increased over the last 30 years. In 1990, the amount of separately collected bio-waste delivered to recycling plants was about 0.74 million tons. In 2002, this amount was 12.4 million tons and in 2014, 15.45 million tons [3], [1]. In 2018, the amount of separately collected biodegradable waste was about 15.06 million tons [1], slightly lower than in recent years. This was due to the decreasing amounts of garden and park waste but also to the amount of agricultural residues delivered to bio-waste treatment plants [1].

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Which bio-waste can be collected via the organic waste bin depends on the further recycling options and treatment facilities available. Among others, the following biogenic materials are collected: Garden waste (e.g. soil from beds, tree-cut, the bark of trees, flowers, flower soil, trimmings from hedges and shrubs, leaves, needles, plants, parts of plants, brushwood, moss, lawn and grass clippings, weeds, wild weeds, twigs), bread and bakery scraps, eggshells, fruit residues, fruit peels (also from tropical fruits, citrus fruits), as well as raw, cooked, spoiled food residues, etc. [4].

According to waste statistics in Germany, 14.2 million tons of bio-waste were generated in 2017, of which 4.9 million tons were collected via organic waste bins and around 5.4 million tons of garden and park waste was collected [5]. The remaining amount includes market waste and other biodegradable waste from various sources, such as waste from agriculture, horticulture, aquaculture, forestry, hunting and fishing, food preparation, and processing [6].

Around 7.6 million tons of the bio-waste was recycled in composting plants and around 6.6 million tons in fermentation and biogas plants to produce around 3.9 million tons of compost and around 3.4 million tons of fermentation substances [5].

4 Process chain

4.1 Collection of bio-waste

In the recycling and waste management sector, waste disposal service providers collect recyclable materials or waste at the point where they are generated, to make these materials available at the receiving facilities. Furthermore, they transport the fractions leaving these facilities onward for recycling or disposal.

The main purpose is to collect the waste at defined transfer points [7]. These are households (e.g. organic waste bins for bio-waste collection) but also recycling centres, where private individuals can hand in the recyclable biogenic waste generated in households [8]. Ultimately, separate collection of waste for material recycling is essential in terms of compliance with waste stream-specific quality requirements and is now enshrined in law. According to the German Kreislaufwirtschaftsgesetz [9], the waste streams of waste paper, waste glass, plastic waste and bio-waste collected close to households have to be collected separately on a mandatory basis since 2015. Moreover, the German Gewerbeabfallverordnung [10] of August 01, 2017, requires that in addition to the waste fractions paper, cardboard, plastics, glass and metals, wood, textiles and all bio-waste in commercial municipal waste has to be collected separately.

For the assessment of bio-waste, a distinction is made between bring and pick-up collection systems. Whereas in the bring collection systems the waste producer himself is responsible for transporting the waste to a collection point, in the pick-up collection system the waste is collected directly from the point of generation. Bring collection systems are employed in particular when the required transport distance is short, the number of collection points is large, and the amount of waste generated is small. Since the effort falls to the waste producer, the return rates of these systems are comparatively low [8]. In collection systems, a collection vehicle drives to the waste producers' locations one after the other in a regular cycle and picks up the waste there. The collection tours reduce the transport effort compared to the bring system by avoiding empty drive, but this advantage is countered by a high planning effort. Generally, with these systems high return rates can be achieved, since the waste producer is relieved of the transport effort. An example of this is the collection of organic waste close to households.

The collection methods are also differentiated according to the type of waste bins used. Reverse bins are mainly used for the collection of household waste and commercial waste similar to household waste. They are taken from the site to the collection vehicle, emptied there and put back to the site. The waste bins are transported depending on the system, user or personnel of the disposal service provider. In the meantime, there is a wide range of reverse bins on the market with a capacity between 35 to 1100 litres [8]. The operational data evaluation of the German Verband kommunaler Unternehmen (VKU) showed that the average waste bin volume distributed per inhabitant and week throughout Germany is 14 litres [11]. However, the degree of connection to the organic waste bin varies across Germany. Therefore, the statistical value of the container volume provided ranges between 0.5 to 45 litres [11].

Different vehicle variants are available for the collection of waste. The selection of the appropriate vehicle variant depends on the waste fractions and quantities to be disposed of, the container systems used, and the structure of the disposal area. The collected bio-waste is transported by rear, front and side loaders as well as combined front and side loaders, interchangeable containers by roll-off and skip loaders [12–15].

The personnel required depends on the waste provision, the collection method, the waste bin system and the vehicle. Depending on the level of service offered, however, the number of personnel deployed varies. Full service refers to the provision and return transport of the waste bins by an employee of the waste disposal service provider. In the case of partial service, the customer performs these activities. A combination of the two types of service consists, for example, of the provision of the waste bins by an employee of the waste disposal service provider (fetching the waste bins and placing them on the street) and the return transport of the waste bins to the property by the customer.

The operational data evaluation of the VKU showed that in around 74.1 % of all municipal companies considered, staff are deployed in a 5-day week. Meanwhile, working time models such as 4-in-5-day models (3.7 percent of all companies considered) and other working time models are also used in combination. In addition, working hours are increasingly made more flexible due to annual working time accounts [11].

In 2018, the VKU member companies used the partial service for the collection of bio-waste in around 53.8% of cases, while the full service was used in 12.5% and the combined service in 33.8% of all cases [11]. The staffing of the vehicles with drivers and loaders shows a slightly higher vehicle staffing for the collection of bio-waste bins up to 360 litres in the full service with an average of 1.9 loaders than for residual waste [11]. For bio-waste collection in full service, a loader performs about 325 lifting operations per day for organic waste bins up to 360 L, while in partial service it can reach up to 547 lifting operations for containers up to 360 L, state 2018 [11].

In addition to the factors already mentioned, the emptying intervals of the waste bins are taken into account when planning collection processes. These range from several times a week to weekly, to fortnightly or four-weekly emptying. The length of the intervals depends on the type of waste to be collected. For example, in metropolitan areas, waste bins for organic waste are emptied weekly to fortnightly. Rural regions have a 14-day collection rhythm for the organic waste bin [11].

4.2 Typical treatment of bio-waste

In biological waste treatment, various microorganisms degrade organic substances. A distinction is made between degradation with air-supply (aerobic process steps like composting) and degradation under exclusion of air (anaerobic process steps like fermentation or biogas production). Both processes serve for the inertisation of waste and the reduction of waste volumes. The products resulting from biological waste utilization are, on the one hand, biogas, which is used in the plant or in combined heat and power plants (CHPs) to generate electricity and heat, and, on the other hand, a solid fraction with a greatly reduced biological reactivity [8].

Composting plants are classified according to their waste inputs:

In bio-waste plants, especially kitchen waste, balcony and garden waste that are collected separately in bio-waste bins, as well as green waste, canteen waste and suitable waste from trade and food industries are processed. In green waste composting, only green waste, such as cutting of trees, shrubs and grass, as well as foliage, is treated. In addition, there are plants in which only sewage sludge with added structural material is converted into compost. As a combination of this, structurally rich green waste can also be mixed with low-structural bio-waste and fermentation residues. Structural materials are wood-like components of bio-waste [8].

For the exploitation of biogenic waste, 213 bio-waste composting plants for mixed bio-waste, 631 green waste composting plants, 49 combined composting and fermentation plants, 76 sewage sludge composting plants and 25 other biological plants (including production plants for the treatment of waste) were operated in 2017 [6].

In waste treatment, fermentation plants are used for the biochemical conversion of bio-waste as well as food and grease residues. After mashing, the organic substances are decomposed by anaerobic bacteria to carbon dioxide and methane (under exclusion of oxygen). The biogas is captured and, with its high methane content (50-80 percent), used in combined heat and power plants to generate electricity and heat. Digestion residues are used as fertilizer, but they can also be processed into compost after being dewatered by means of a centrifuge or press. For the recycling of biogenic waste in 2017, there were 248 biogas and fermentation plants, 49 combined composting and fermentation plants, 76 sewage sludge-composting plants, and 25 other biological plants (including production plants where waste is treated [6].

Mechanical-biological waste treatment (MBT) is used to pre-treat municipal waste prior to landfilling. Through various treatment steps and a subsequent biological treatment, a low-reaction waste can be produced, which may be deposited according to the requirement of the German Deponierungsverordnung. In addition to pre-treatment prior to landfilling, MBT can also be used for pre-treatment of waste prior to thermal treatment, whereby the waste is dry-stabilized [8]. In the first step of biological or mechanical-biological waste recycling, the residual waste is mechanically pre-treated. In this process, the fractions with a high calorific value, such as plastics for energy recovery and metals for material recycling, are sorted out.

In addition to MBT, mechanical-biological stabilization plants (MBS) are in operation. In these plants, the biogenic components remain in the high-calorific stabilate. In addition, other recyclable fractions are recovered. In a first step, the residual waste is conditioned, i.e. shredded, for subsequent drying. Drying reduces the moisture content of the residual waste in a targeted manner. Finally, dry mechanical processing is carried out, in which the residual waste is divided into various waste fractions of different quality with high-calorific value. Metals, contaminants and inert materials are also separated in this process stage. In this process, only small quantities, e.g. the inert materials, are deposited in landfills [8]. In Germany, the total capacity of the 52 mechanical-biological waste treatment plants was about 3823.0 million tons of bio-waste in 2017 [6].

5 Future development

5.1 Pre-treatment for improved biogas generation

In the field of biogas technology, research on new feed materials and the optimization of the related processes is required. E.g., lignocellulose materials are playing an ever-increasing role in the production of bioenergy, as their formation is not in competition with agricultural production areas. An energy and ecologically sensible approach to the extraction of biogas is the fermentation of straw, which is mainly composed of cellulose, hemicellulose and lignin. However, due to the natural protection mechanisms of the straw against microbial attacks, straw is considered a difficult-to-degrade substrate in the biogas process. Therefore, fermentation of straw requires a substrate pre-treatment in order to access as much of the material as possible for the biogas process.

On lab scale, TH Köln investigated mechanical, biological and combined biological-thermal pre-treatment methods of wheat straw for the optimized use of lignocellulose in biogas production [16]. Figure 1 gives an impression on the performance of the chosen pre-treatment technologies.

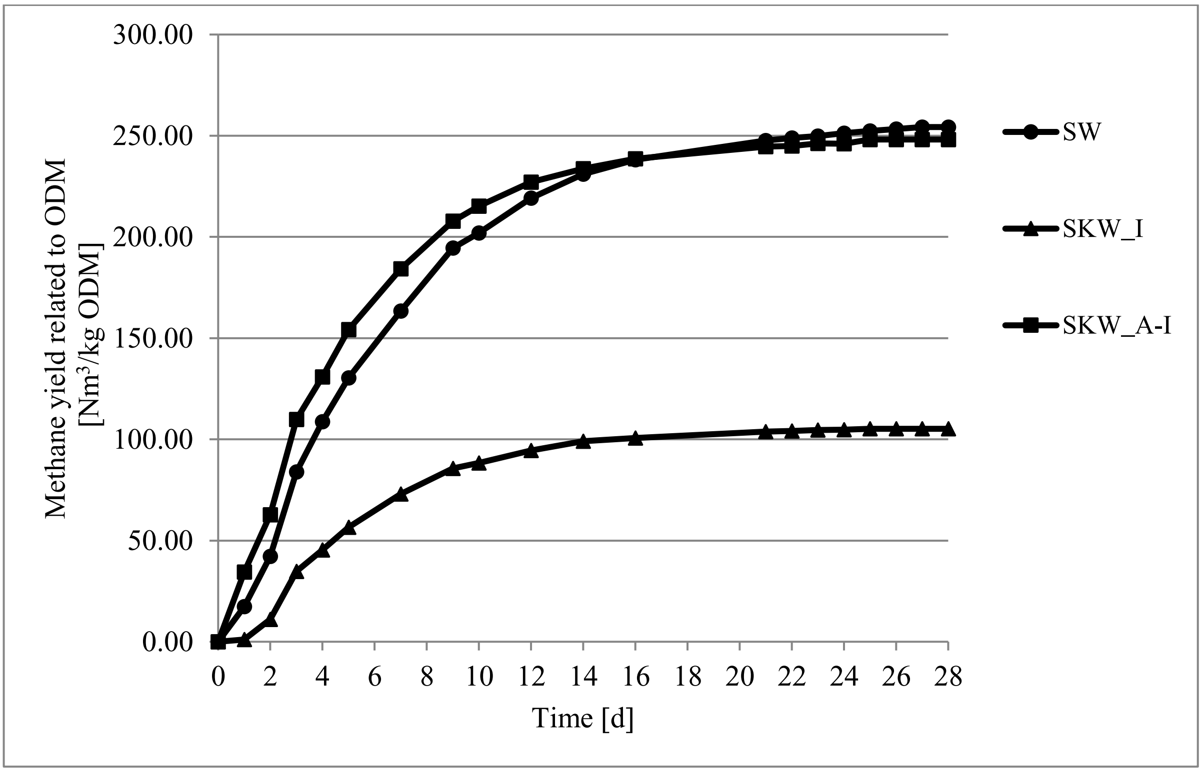

Fig. 1. Methane yield during batch wise fermentation of straw containing samples at 39 °C related to the respective organic dry matter (ODM). SW: milled straw with addition of water; SKW: milled straw with addition of compost and water; A: autoclaving for 20 min. at 121 °C; I: incubation for 14 days at 25 °C.

Enhancement of methane production was not detected when wheat straw was incubated with compost (SKW_I). This behavior can be explained by the high lignin content of the compost, which cannot be decomposed anaerobically. However, thermal treatment by autoclavation of this mixed material led to higher methane yield.

5.2 Fuels generated from bio-waste

In road transport, biogenic fuels such as biodiesel, vegetable oil and bioethanol have been used since 1995 [17]. For example, 56.3 million tons of fuel were used in Germany in 2019; in terms of energy content, diesel accounted for 63.6%, gasoline for 30.7%, and biogenic fuels for 4.9% [18]. Biogenic fuels manufactured in 2019 include biodiesel with about 2.3 million tons, bioethanol with about 1.2 million tons, bio-methane with 49,000 tons and vegetable oil fuel – also referred to as HVO ("Hydrogenated Vegetable Oil"/Hydrated Vegetable Oil) – with 27,000 tons [18].

Biofuels are divided into first and second-generation fuels. For the production of first generation biofuels, crop based feedstock, such as oil, sugar and starch, are used. For the production of second-generation biofuels, almost the entire plant is used to produce fuel [19].

Biogenic waste can also be processed into fuels, for example, wood residues and biodegradable garden and park waste can be used to produce bioethanol, as this is usually obtained from the starch and sugar content of plants and plant residues [20].

In theory, biomass-to-liquid (BtL) fuels can be produced from heterogeneous residual and waste materials [20], but in practice, residual materials from agriculture and forestry, such as straw and forest residues, have been used so far [21].

Biogas can be obtained from the fermentation of biomass, especially bio-waste [22]. In the dry fermentation process, resulting methane can be processed into gas-to-liquid (GtL) fuel or biogas after appropriate treatment [23]. For example, the Berliner Stadtreinigung collects about 60,000 t of bio-waste per year, from which their biogas plant produces 3.6 million m³ of bio-methane. They use the biogas, among other things, to fuel their 160 gas-powered waste collection vehicles, which cover 2.5 million km annually. This saves over 2 million litres of conventional diesel every year [23].

In addition, fuels can be generated from plastic waste; for example, the ReOil process can currently process about 1 litre of oil from 1 kg of waste plastic [24]. Ecological as well as economic advantages of the processes and their large-scale implementation, including the pre- and post-processing steps, need further investigation [25].

5.3 Generation of bio-char

The use of plant residues and other biomass allows complementing or even completely replacing fossil resources.

Thermochemical treatment (pyrolysis) can be used to generate bio cokes from biogenic residues. These bio cokes can be used directly – or after further treatment by activation and functionalization – as adsorber materials or soil conditioners.

Generally, bio coke denotes biomass whose carbon content has been increased by thermal treatment excluding oxygen [26, 27].

For activation, physical processes with oxidizing gases (e.g. steam, CO_2) are used, while the chemical activation uses various, usually dehydrating chemicals (alkali hydroxides, acid, and chlorides). Pyrolysis coal or pyrolysis coke are coals produced using pyrolysis processes [27]. Bio-char from hydrothermal carbonation processes is often referred to as HTC coal [28, 29].

5.4 Modification and milling of bio-char

The adsorption capacity of carbon surfaces for certain pollutants can be increased by surface expansion of the outer surface (e.g. by grinding) and inner surface (modification) [30]. Adsorption experiments were performed by the authors using biochar produced from Brazilian sugar cane bagasse that was gained by pyrolysis. The ash content of the biochar was about 32%. For functionalization of the biochar, 10 g of the material was functionalized for 2 hours using sodium hydroxide (200 mL, c = 5 mol/L) at 90 °C. After modification, precise amounts of biochar were stirred in a methylene blue solution (100 mL, β = 27 mg/L mass concentration) at 20 °C for 72 hours to reach equilibrium. Here, methylene blue served as a lead substance representative of organic pollutants. After equilibrium was achieved, a chemical analysis of the supernatant liquid was performed to estimate the adsorption capacity (Figure 2).

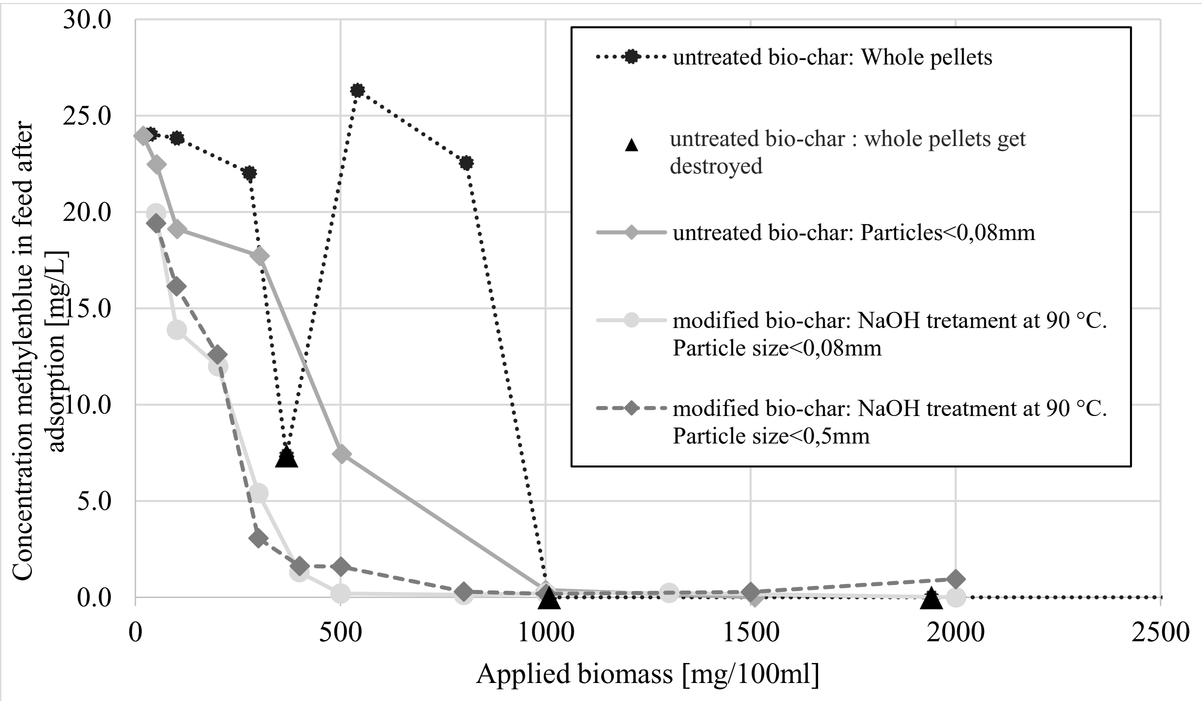

Fig. 2. Breakthrough curve of methylene blue of modified and untreated biochar with different particle sizes

Figure 2 shows that an increase in surface areas through grinding and modification of the surface had a positive effect on the adsorption capacity. In this case, the influence of grinding on the created surface is greater than the modification with sodium hydroxide. As a side effect of grinding, a higher homogeneity of the biochar was achieved.

6 Conclusions

Bio-waste utilisation to a large extend depends on a proper collection and the separation of undesired substances. The resulting plant residues and other biomass can complement or even completely replace fossil resources. They serve as sources for the generation of gaseous, liquid and solid products for second use, e.g. biogas, biofuels or bio-char.

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