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BIOECONOMY ADAPTATION TO CLIMATE CHANGE: A CASE STUDY OF FOOD WASTE IN SLOVAKIA

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Climate change, periods of droughts or, conversely, increased rainfall significantly affect agronomic patterns and biomass production. In addition, if agriculture and food industry compete with other industries for land and biomass, the priority is given to agro-food use and ensuring food security. This is the main reason why food waste is a promising alternative source of biomass for the industrial segment of the bioeconomy. Moreover, the reuse of food waste leads to circular and sustainable value chains. The aim of this paper is to explore the situation of food waste utilization in Slovakia. We assess the current level of food waste produced by households and its potential as a biomass source. However, to convert food waste into a valid industrial input, it has to be collected separately. The study shows the practice of food waste collection in two Slovak cities, where food waste is used to produce soil substrate and bioelectricity, respectively.

Keywords: food waste, biomass, bioeconomy, sustainability

Introduction

A bioeconomy is a sustainable economy based on biological resources. The EU bioeconomy strategy from 2018 "A sustainable Bioeconomy for Europe – Strengthening the Connection between Economy, Society and the Environment" (EC, 2018) defines the bioeconomy as encompassing all sectors and systems that contain or are based on biological resources (animals, plants, micro-organisms, and biomass including organic waste), their functions and principles. It covers all primary sectors producing biological resources, all economic and industrial sectors using or processing biological resources into goods and services and also land and marine ecosystems and ecosystem services. This definition of the bioeconomy is an extended version of the definition provided by the initial bioeconomy strategy of the EU adopted already in 2012 "Innovating for Sustainable Growth: A Bioeconomy for Europe" where the bioeconomy was characterized as a cross-sectional economic system involving the production of renewable biological resources and the transformation of these resources, including waste streams, into value-added products (EC, 2012).

The need for a bioeconomy has arisen from concerns about the exhaustibility of raw fossil materials and from negative impacts of their use on the natural environment. The EU has formulated five objectives for the bioeconomy: food and nutrition security; sustainable management of natural resources; reduced dependence on non-renewable resources; mitigation of climate change and adaption to climate change; creation of jobs and European competitiveness (EC, 2012; EC, 2018). The EU Bioeconomy Strategy contributes to the European Green Deal, as well as to industrial, circular economy and clean energy innovation strategies. They all underline the importance of a sustainable circular bioeconomy for the achievement of their goals. To develop the bioeconomy in a sustainable manner, the Food and Agriculture Organization of the United Nations (FAO) has identified 10 underlying principles. A sustainable bioeconomy should (FAO, 2021): promote food and nutrition security; ensure that natural resources are conserved, protected and enhanced; lead to a competitive and inclusive economic growth; create healthier, fairer, more sustainable and resilient communities and ecosystems; ensure efficiency in the use of natural resources and biomass; be supported by responsible management and policies; apply innovations, technologies, knowledge; promote sustainable trade and fair market practices; reflect the needs of the society and promote responsible consumption; and boost cooperation between stakeholders.

The availability of biological resources (biomass) is one of the basic prerequisites for the development of a bioeconomy. Biomass can be of domestic origin or imported, and can come from agriculture, forestry, water or waste. Different types of biomass are used in different ways. The production of biomass for non-food purposes should not compete with biomass use for food purposes. Further, biomass production should be ecologically sustainable, both in terms of quantity and environmental impact. An undervalued source of biomass is agricultural and food waste (Lange et al., 2021; Tripathi et al., 2019). The EU aims to increase the share of municipal waste reused or recycled to at least 65% by 2035 and to reduce the share of landfilled waste to a maximum of 10% (EP, 2018). The European Environment Agency reports that biological kitchen waste and garden waste are the largest component of municipal waste in EU countries, building up to 34% (EEA, 2020). The Bio-based Industries Consortium and Zero Waste Europe (BBI and ZWE, 2020) add that on average only 16% of food waste are recovered in the EU, although the potential for transition to a circular bioeconomy would be up to 85% of food waste. Except for food waste from households arising in the consumption phase, biological food waste or by-products are present in the whole food supply chain, starting from agricultural production and harvest, through storage, transportation, processing, retail, up to food use and consumption in industry and the private sector (Blakeney, 2019). Conventional and emerging techniques enable to recover, extract or separate components that can be further valorised e.g. in cosmetics or pharmaceutical industry (Galanakis, 2021). Moreover, nutrients from side streams can be converted and used in the food or feed industry (Smetana et al., 2022).

The aim of this paper is to explore the situation of biomass availability and utilization of food waste from households in the Slovak bioeconomy. We present the current level of biomass and food waste production and we access food waste management schemes implemented in two Slovak cities where food waste is used as a biomass source for other products.

Material and methods

To illustrate the availability of biomass as a feedstock for the bioeconomy in Slovakia, the study uses statistical data for the last 5 years, from 2016 to 2021.

The amounts of municipal waste, in particular food waste as an additional source of biomass, are evaluated for 2019-2021 (older data not available). Statistical Office of the Slovak Republic is the data source.

Two specific case studies for the biggest Slovak cities, Bratislava and Kosice, complement the information on food waste production and utilisation. Following the recommendations by Tassinari et al. (2021) for case studies research in the bioeconomy, the characteristics of our case studies are:

- Research question: what are practices for food waste collection from households in Slovak cities and how the collected biomass is used?
- Unit of analysis: cities Bratislava and Kosice, Slovakia.
- Sampling strategy: the biggest Slovak cities have been selected because of their potential to provide significant amounts of food waste from households.
- Data collection and analysis: all data and information come from official web sites of the respective city and of its waste collecting and/or processing company; the evidence obtained and a comparative analysis are provided in the Results and discussion section of the paper.

Results and discussion

The entire value chain of bioeconomy products starts with the extraction of resources, i.e. raw material – biomass, then it continues with biomass processing and production of products, and ends with the utilization of final products and the closure of their life cycle. Biomass includes agricultural production, both of plant and animal origin, forestry production, and aquaculture resources and fishing from inland waters and seas. Residues, wastes and by-products resulting from production or consumption may also be an additional source of biomass. Climate change, reflected in changes in average temperatures, precipitation totals, the occurrence of more extreme weather events, significantly influences biomass production and the amount of biomass obtained. The bioeconomy, therefore, aims not only at a transition to bio-based production, but also at making bioeconomy value chains circular and sustainable, meaning that biological resources are conserved, reused andrecovered, and waste streams of biological resources are used as well.

All biomass production takes place on agricultural and forest land, with the exception of aquatic biomass and fishery products. According to the data of the SO SR (for 2022), the total territory of the Slovak Republic has the size of 4,903,394 ha, of which 2,372,341 ha are classified as agricultural land, 2,029,035 ha as forests, 95,349 ha as water surface and the remaining 8.3% are other lands and built-up areas. Arable land accounts for the largest share of agricultural land, 1,404,579 ha, followed by permanent grassland with 849,273 ha. Biological resources produced on land (and in water) can be used for agricultural and food purposes or for other industrial purposes, hence, there is a competition between sectors of the economy for land. However, principles of a sustainable bioeconomy development respect the priority of agri-food use and food security.

Annual biomass production in Slovakia is usually stable, slightly above 19 million tons. In 2021, it reached 19.4 mil. tons, thereof 35.4% were agricultural crops, 38.8% plant residues, fodder crops and freely grazed biomass, 25.7% wood and only 0.04% water biomass. Nevertheless, depending on weather and climatic conditions, biomass production may show variations. During the last 5 years there was a decrease in all sources of biomass produced on soil, including crops, crop residues, and wood. As presented in Table 1, production of crops (excluding fodder crops) decreased by 9%, production of crop residues, fodder crops, forage crops and grazed biomass decreased by 9% and wood production has fallen by 32% from 2016 to 2021. The only increase in the production of biomass was observed for biomass produced from fishing, aquatic plants/animals, hunting and gathering – by 32% or from six to eight thousand tons. That led to an overall decrease in the amount of available biomass by 16%, in absolute terms from 23,078 thousand tons to 19,362 thousand tons of biomass over the analysed period.

In addition to changing climate conditions, also population growth and technological innovations in industrial use of biological resources create pressure on the production of primary raw material. However, expanding productive areas and increasing biomass production in agriculture, forestry and fisheries in a sustainable way are only possible to a limited extent, so additional biomass sources that could serve the production of some products and bioenergy are being sought. Such supplementary sources include food waste. Food waste collection and utilization can reduce the amount of waste landfilled, reduce landfilling costs and – as kitchen waste composting and processing facilities are often located close to regions where waste is produced and collected – reduce transport costs, pollution, and emissions from transport and landfill (Vázquez and Soto, 2017). In recent years, more and more attention has been paid to the production and utilization of food waste. Food is predominantly intended for human consumption. If it is not consumed, then the resources for food production, transport, or disposal were spent inefficiently (Papargyropoulou et al., 2014). Moreover, this inefficiency will lead to negative economic, social and environmental consequences for the sustainability of the whole food sector (Garnett, 2011), increasing global greenhouse gas emissions (Ritchie and Roser, 2021) or contaminating the groundwater (Ren et al., 2018). Thus, the use of food waste does not only represent an additional source of biomass, but also contributes to the application of the circular economy concept in the bioeconomy. To achieve these goals, the society has to undergo a change of attitude towards food waste and to percieve food waste as a source of bioeconomic production rather than a pollution problem (Morone et al., 2017).

Table 1 Biomass production, its composition, and consumption in Slovakia, 2016–2021

	2016	2017	2018	2019	2020	2021
Biomass production in Slovakia (th. tons)	23,078	19,435	20,994	19,806	19,593	19,362
Crops (excluding fodder crops) (th. tons)	7,502	5,833	6,534	6,431	6,955	6,859
Crop residues, fodder crops, grazed biomass (th. tons)	8,245	6,507	7,261	7,259	7,706	7,517
Wood (th. tons)	7,324	7,087	7,192	6,108	4,925	4,979
Fishing, aquatic plants/animals, hunting, gathering (th. tons)	6	7	7	8	7	8
Domestic biomass consumption (th. tons)	19,376	16,225	18,633	18,000	17,314	17,168

Source: SO SR

Note: domestic biomass consumption takes into account foreign trade

Table 2 Amount of municipal waste and some of its components in Slovakia, 2019–2021

	2019	2020	2021
Total municipal waste (th. tons)	2,369.7	2,611.6	2,702.2
Mixed municipal waste (th. tons)	1,166.4	1,190.1	1,128.5
Biodegradable kitchen and restaurant waste (th. tons)	4.16	16.27	35.92
Edible oil and fat (th. tons)	0.43	3.86	1.76

Source: SO SR

The main driving force supporting the collection of food waste and its utilization in Slovakia is the public policy defined by the Waste Act (NR SR, 2015). The Act obliges municipalities to ensure the collection of biodegradable kitchen waste from households from 1st January 2021. There was an exception for cities Bratislava and Kosice because they have a facility for energy recovery of waste; for them the obligation was postponed to 1st January 2023. The aim of a separate collection of kitchen food waste is to reduce its share in mixed municipal waste and to enable its subsequent usage.

Data on the amount of waste (see Table 2) indicate that the introduction of the obligation to collect biodegradable kitchen waste increased the volume of collected kitchen (and restaurant) waste more than 8-fold between 2019 and 2021, from 4.16 thousand tons to 35.92 thousand tons. Edible oils and fats are also collected separately; 1.76 thousand tons were collected in 2021.

A report by the Association of Waste Industry (AWI, 2022) states that in 2016-2019, garden and kitchen bio-waste accounted for 44% of mixed municipal waste on average. In 2020, up to 62% of bio-waste in Slovakia ended up in a landfill or in a facility for energy recovery. This shows untapped potential of biological waste as a source of biomass for processing industries (Figure 1).

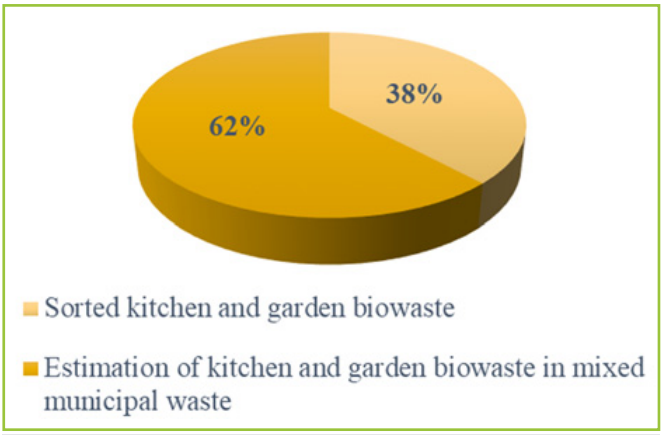

Figure 1 Potential of food bio-waste in Slovakia, 2020
Source: AWI, 2022

BBI and ZWE (2020) estimate that annually 84.40 kg of kitchen waste per inhabitant are produced in Slovakia and only 7.89 kg per inhabitant are separated and collected. The total production of biological kitchen waste then amounts to 460 thousand tons per year, thereof 43 thousand tons are collected, but the potential could be up to 391 thousand tons. The difference, 348 thousand tons, is a possible additional source of biomass that could be used for example for the production of compost, biogas or bioenergy, or bioenergy, or for the extraction of compounds.

Case studies: kitchen waste collection from households and its utilization in Bratislava and Kosice

Urban areas are the main source of biomass from kitchen waste as they concentrate more people who have limited possibilities of own composting of biological waste. Hence, the collection of biological waste like kitchen and food waste provides biomass for further material or energy recovery. This study focuses on two biggest Slovak cities, Bratislava and Kosice. Bratislava is the country's capital with a population of 476 thousand inhabitants, located in south-western part of Slovakia; Kosice has a permanently living population of 229 thousand people and is the centre of the eastern part.

In 2021, Bratislava produced 3.4 thousand tons of biological kitchen and canteen waste, for Kosice the quantity was 0.8 thousand tons. Kitchen and canteen waste represented 1.27% and 0.82%, respectively, of total municipal waste. We assume that a portion of kitchen and food waste is not separated from other waste and is, therefore, recorded as mixed municipal waste, hence the abovementioned percentage can be underreported.

For Bratislava it was mandatory to introduce a system of kitchen waste collection from households from January 2023, but already in October 2021 this collection has started in the first of the 17 city districts with a gradual involvement of the remaining districts. From the launch of the first phase until the end of January 2023, more than 5,000 tons of kitchen bio-waste have been collected. About 140 thousand households participate in the collection scheme (City of Bratislava, n.d.; Olo, n.d.). The management of kitchen waste collection in Bratislava is slightly different for family houses and for apartment buildings. All households received a small basket for food waste together with a set of compostable bags (150 pcs for 12 months), which they can use directly at home. Family houses store closed bags with food waste in a larger 20-litre container, which they also received from the city council, until kitchen waste is removed by a waste company. For apartment buildings, a common container with a volume of 120 litres or 240 litres, usually located at the place for municipal waste, is available for cumulating bags. Containers for biological kitchen waste are distinguished by brown colour and labelled by a pictogram. The frequency of kitchen waste removal is once a week, in warmer months of March-November twice a week. The collected kitchen waste is processed into a certified compost, or so called soil substrate effeco, and green energy. The processing facility is located approximately 70 km away but Bratislava has started the preparation for building its own plant. The magistrate of Bratislava estimates the production of biological kitchen waste up to 120 kg per inhabitant. If all this waste were collected and used for the production of compost, it would be possible to obtain 16 thousand tons of compost per year, which could enrich 534 ha of soil (City of Bratislava, n.d.). Organic soil compost is a fertilizer based on renewable carbon and as such is decreases the amounts of waste, substitutes chemical fertilizers from fossil resources, provides nutrients and improves water retention capacity of soil, prevents its degradation and increases its productive capacity (effeco.eu, n.d.). Costs to the city to collect and transport biological kitchen waste are planned in Bratislava's budget for 2023 in the sum of 4.6 mil. €. Inhabitants

	Bratislava			Košice		
Basic statistics						
Area	367.6 km^2			243.7 km^2		
Population	475,503			229,040		
Waste production						
(th. tons)	2019	2020	2021	2019	2020	2021
Total municipal waste	212.2	261.6	270.3	94.2	106.5	101.5
❐ mixed municipal waste	113.0	127.6	118.3	49.1	49.9	51.7
❐ kitchen and canteen waste	1.008	5.086	3.444	N/A	0.196	0.832
❐ edible oil and fat	0.083	0.876	0.420	0.002	0.055	0.056
Scheme for kitchen waste collection						
Incentive for kitchen waste collection	legislation			legislation		
Starting date	1st Jan 2023			1st Jan 2023		
Pilot phase before implementation	yes			yes		
Information campaign before implementation	yes			yes		
Containers for kitchen waste	yes brown colour and pictogram			yes brown colour and pictogram		
Volume of containers	family houses: 20 l apartment buildings: 120 or 240 l			family houses: 30 l apartment buildings: 240 l		
Frequency of waste collection	Jan–Feb: 1× per week Mar–Nov: 2× per week Dec: 1× per week			family houses: 1× per week apartment buildings: 2× per week		
Costs induced by the scheme	for households: no for municipality: yes			for households: no for municipality: yes		
Main product from kitchen waste/other products	certified compost, bioenergy			bioelectricity from biogas, digestate		
Problems in kitchen waste collection	concerns related to smell, leakage of waste components, pests, open container lids, insufficient separation of food packaging and other undesired waste					

Figure 2 Comparison of kitchen waste collection schemes from households in Bratislava and Košice
Data sources: SO SR, City of Bratislava, City of Kosice, Olo, Kosit

pay a general fee for waste collection and disposal, mandatory collection of kitchen waste does not mean any additional, specific fees for them (City of Bratislava, n.d.). Concerns of residents in connection to the collection of biodegradable kitchen waste are related to bad smell, possible leakage of liquid components, the presence of pests or the lack of containers for food waste. A test of samples of the collected kitchen waste showed good discipline of residents and high purity of bio-waste (97.5%), impurities were mainly caused by plastics that do not belong into kitchen waste (with the exception of compostable bags). The scheme of separated kitchen waste collection led to a reduction in the amount of kitchen waste in mixed municipal waste, although it was still present (Olo, n.d.).

The city of Kosice fulfilled its obligation to introduce a scheme for biodegradable kitchen waste collection from January 2023 across its all 22 city districts. Preparation and gradual introduction of the collection mechanism took place since July 2021. Experience from the pilot phase of bio-waste collection suggested that small containers designated for the kitchen and biodegradable bags may have disadvantages in the process of large-scale implementation. People expressed dissatisfaction with the size, style and design of the small containers. Compostable bags intended for primary collection in the kitchen were evaluated as unnecessary because of getting torn quite often or because of getting wet when stored in the kitchen. So currently, small kitchen containers are not distributed by the city authorities and households arrange them themselves if needed, and waste is placed into bigger accumulation containers just free, not being tied in any (compostable) bag. Family houses received only a 30-litre brown container and a set of 25 protective bags free of charge. They put their kitchen waste into the 30-litre container and prepare these containers for waste removal according to a predefined schedule. Residents of apartment buildings dump the containers/baskets they use for kitchen bio-waste into a common 240-liter brown collection container where a protective bag is inserted after each emptying by the waste company (container protecting bags are the only bags used, no smaller bags for food waste are allowed). Kitchen waste is removed once a week from family houses and twice a week from apartment buildings. From the city's perspective collection of kitchen waste leads to high costs – Kosice estimates 2.7 mil. € in 2023. These costs have to be covered from a general fee charged for waste management from inhabitants (no specific fee for kitchen waste collection has been introduced) (City of Kosice, n.d.; Kosit, n.d.). In the first 10 days of 2023, 12.5 tons of kitchen bio-waste were collected in Kosice (SBA, 2023). The collected waste is taken to a biogas station located approximately 10 km from the city and serving Kosice and other close-by municipalities, where the obtained biogas is further used to produce electricity, and the remaining end product, digestate, is used as an organic fertilizer. The station has an installed capacity of 0.998 MW with an expected annual green electricity production of 7,792 MWh (Energie-portal, 2017). Environmental benefits of electricity production from kitchen waste include the reduction of waste, smaller demand for fossil fuels, less emissions of greenhouse gases, elimination of soil or water pollution. Obstacles for a more successful implementation of the kitchen waste collection scheme include negative attitudes of some residents, concerns about the smell from kitchen waste and throwing food with packaging into kitchen waste containers (Kosit, n.d.).

In general, a problem of collecting biological kitchen waste in Slovakia is the management and organization of its separate collection. For municipalities it is costly (claimed average costs for one ton of kitchen bio-waste are 342 €, with a variation between 36 € to 1,338 € per ton, while average costs for one ton of mixed municipal waste are 68 €). Moreover, municipalities must collect the waste with a sufficient frequency in order to make kitchen waste collection comfortable for households, avoiding bad odours or pests. A second problem are insufficient and unevenly distributed authorized capacities for processing of biodegradable kitchen waste. In some cases, food waste is collected, then it is composted, but it is not processed into any certified end product. For this low-quality compost there is no demand, so it can happen that in the end it is landfilled. Another issue in food waste collection is the interest and discipline of inhabitants, who put in items that do not belong into separated biological kitchen waste (AWI, 2022).

Conclusions

Climate change and extreme weather conditions together with growing population and technological innovations affect not only

agricultural production used for food processing, but also available quantities of crops, animal products and residues used as a biomass source for further processing in a bioeconomy. In the period from 2016 to 2021 Slovakia faced a decrease in the production of all sources of biomass (except for aquatic biomass). Production of crops, of crop residues, fodder crops and grazed biomass and of wood decreased. This led to an overall decrease in biomass quantities by 16%. Increasing biomass production in agriculture, forestry and fishing through an extensive management in a sustainable way is only possible to a limited extent. Therefore, food waste seems to be a promising source of biomass. Food waste is not only an additional source of biomass, it also contributes to the application of circular economy concepts in the bioeconomy and has positive environmental, social and economic impacts.

As our article shows, there is still potential for using food waste as a source of biomass in Slovakia. Various problems prevent the utilization of this potential. One of the problems is the organization of biological kitchen waste collection from households. It is a costly process for municipalities, which needs to be done with a sufficient frequency. A second problem is the discipline and interest of residents to participate in a responsible food waste separation, although results from two cities, Bratislava and Kosice show that the collection scheme has been implemented quite successfully. In some regions the chain of waste collection encounters a problem of capacities for the processing of biodegradable kitchen waste. The cities of Bratislava and Kosice do not face insufficient capacities with authorisation for kitchen waste processing, however Bratislava plans to build its own plant to reduce the transportation distance. Increasing the comfort of collection for citizens, in the form of providing collection containers, together with increased awareness, guaranteed waste processing and implementation of new biotechnologies are possible ways to achieve a higher utilization of food waste. On the other hand, policy makers should also pay attention to regulations, permissions, authorisation and control of food waste processing to ensure good quality of the resulting product (e.g. compost) such that it can be used and returned to the circle of nutrients, energy and carbon.

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