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PREFACE

The 31st international conference Ecological Truth & Environmental Research – EcoTER'24 focuses on showing the latest research findings and innovations in the field of ecology, environmental protection and sustainable development. The conference will be held in Sokobanja (Serbia) in hotel Sunce in the period of 18–21 June 2024.

The aim of the conference is to connect the experts in various fields in order to transform attitudes and behaviors in everyday practices, as well as in the industry and economy sector which is essential for achieving the desired changes that our society must undergo.

The 31st international conference Ecological Truth & Environmental Research – EcoTER'24 is organized by the University of Belgrade, Technical Faculty in Bor, and co-organized by the University of Banja Luka, Faculty of Technology; the University of Montenegro, Faculty of Metallurgy and Technology – Podgorica; the University of Zagreb, Faculty of Metallurgy – Sisak; the University of Pristina, Faculty of Technical Sciences – Kosovska Mitrovica and the Society of Young Researchers – Bor.

These Proceedings encompass 119 papers from the authors coming from the universities, research institutes and industries in 15 countries: Brazil, Norway, USA, Spain, Austria, Libya, Italy, Israel, Slovenia, Croatia, Romania, Bulgaria, Montenegro, Bosnia and Herzegovina, North Macedonia, and Serbia. It is a great honor and pleasure to cordially wish a warm welcome to all the participants of the conference.

As a part of this year's conference, the 6th Student Section – EcoTERS'24 will be held. We appreciate the contribution of the students and their mentors who have also participated in the conference and hope that students will continue to explore and to be curious, since education is a never-ending process, and knowledge is continuously growing.

The organization of the EcoTER'24 conference has been financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia.

The support of the Donors and their willingness and ability to cooperate has been of great importance for the success of the EcoTER'24 conference. The organizing committee would like to extend their appreciation and gratitude to the Platinum donors of the conference – Serbia ZiJin Copper doo Bor and HBIS SERBIA, to the Gold donor of the conference – Elixir Group, as well as to the Silver donor of the conference – Serbian Chamber of Engineers.

We would like to express our sincere appreciation to all the authors who have contributed to the Proceedings. We would also like to express our gratitude to the members of the scientific, organizing and honorary committees, reviewers, speakers, chairpersons and all the conference participants for their support of the EcoTER'24. Sincere thanks go to all the people who have contributed to the successful organization of the EcoTER'24.

Prof. Snežana Šerbula,

President of the scientific and organizing committee

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PROSPECTS OF SUSTAINABLE UTILIZATION OF FOOD WASTE

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Abstract

Food waste is a global problem associated with environmental, economic and social impacts. Since the food waste amount to one third of generated municipal solid waste, it represents one of the most unutilized waste streams. Therefore, it is crucial to reduce food waste generation and implement strategies to minimize its impacts on the environment, mostly reflected through greenhouse emissions, water and land use. However, diverse and highly variable nature and composition of food waste is significantly affecting its valorisation and pose main challenge of the food waste management. In order to meet sustainability goals, food waste should be managed in an environmentally and economically viable manner.

Keywords: food waste utilization, valorisation, biogas production, sustainability.

INTRODUCTION

In recent years increasing concern has arisen regarding food waste as one of the global problems which have a huge economic, social and environmental impact.

'Food waste' is generally referred as food losses (i) within the food supply chain, including inedible parts (such as bones, rinds, pits, eggshells etc.) and (ii) after its expiration date [1]. Food waste occurs at all stages of the food supply chain, from the production step to the consumption. However, the largest share of food waste is generated during consumption (i.e. household waste). Only in the European Union (EU) during 2021 household food waste represented 54% of total share, followed by the food processing and manufacturing (21%), while wholesale and retail (7%), restaurants and food services (9%), and primary production (9%) account for the rest of the generated waste [2]. In the EU, nearly 30 million tonnes of inedible parts of food from the production are left per year [3].

Food waste accounts for a substantial portion of municipal solid waste, representing up to 33% of all waste generated [4]. Around 931 million tonnes of food waste were generated during 2019 globally, 61% of which originated from households, 26% from food service and 13% from retail [5]. However, the degree of food loss and waste fluctuates significantly throughout the regions [6]. In the EU, more than 58 million tonnes of fresh mass of food waste was generated during 2021 (131 kg per inhabitant) [2], which represented an estimated loss of 132 billion euros [7]. At the same time, over 37 million people in the EU cannot afford a quality meal every second day [7], in addition to an almost 770 million of people in the world that were undernourished during 2021 [8]. Therefore, food waste has very important social aspect. Donation of fresh food cannot be commercialised due to logistic or marketing reasons, however it could be facilitated by “food banks” [9].

Other than economical lost, food waste has a huge environmental impact. Food waste is highly biodegradable compared to other types of waste due to high content of degradable nutrients such as proteins, carbohydrates, and lipids which are degraded to methane (CH_4). Methane is gas more detrimental for the environment than carbon dioxide (CO_2). According to the data, about 16% of the total greenhouse gas (GHG) emissions from the EU food system accounts for 254 million tonnes of CO_{2eq}, representing the fifth largest emitter of GHG [7]. Diverting food waste from landfills and converting it into a useful resource, such as biofuels and other by-products, it could reduce its negative impact on the environment and diminish climate change effects [4,10]. Regarding food industries, the beverage industry is major contributor accounting for 26% of all food wastes, followed by the dairy industry (21%), the fruit and vegetable production (14.8%), and the cereal industry (12.8%) [3]. It should be noted that, wasting food puts unnecessary burden on already limited natural resources – land and water use [2,11]. Also labour, effort and investment during producing food are wasted, as well as the resources used in the transport [12]. Moreover, in the last 20 years, primary crop production, vegetable oil and meat production has globally risen for around 52%, 125% and 45%, respectively, and it is estimated that will rise in the future [8].

This paper aims to emphasize the global problem of food waste generation and discuss some value addition processes for sustainable utilization of food waste.

FOOD WASTE

In order to prevent conventional landfilling, several strategies can be employed to diminish the adverse environmental impacts of food waste generation, including source reduction, composting, anaerobic digestion, biogas and energy production. In Figure 1, the proposed food waste hierarchy is given, which consists of descending waste management practices, from more to less preferable and sustainable.

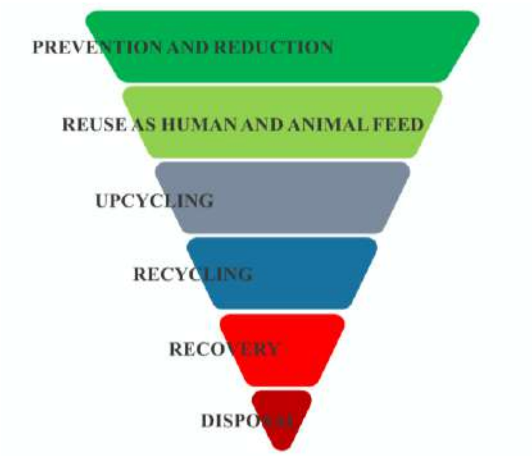

Figure 1 *Food waste hierarchy (adopted from Rakesh and Mahendran [13])*

In the value addition processes (i.e. “upcycling”), wide range of products can be gained by utilizing food waste such as biogases (hydrogen and methane), biodiesel, biopolymers, bioplastics, enzymes, biochar, organic acids, biofertilizers, etc. [4,10,11,13]. Numerous sectors of the food industry generate by-products that can be re-used as animal feed such as sunflower seed expeller, wheat germ from flour milling, sugar beet molasses from sugar production, starch hydrolysates cake from starch production, as well as various by-products from the bakery and pasta industry [14].

Efficient food waste management requires careful consideration of energy consumption, environmental and economic factors. Lifecycle analysis (LCA) as a method for measuring the environmental effects of products throughout its stages from the beginning to its end (including production, consumption, and final disposal), and can be used in order to evaluate the impacts of the food waste technologies in order to minimize its effects and enhance sustainability [1]. Batool *et al*. [1] used the LCA for evaluating today's most used technologies in food waste management to assess its environmental impacts. The results of the LCA showed that among landfilling, composting, anaerobic digestion, incineration, pyrolysis, hydrothermal carbonization, gasification and esterification, landfilling and composting had the highest overall LCA impact value (Figure 2), while anaerobic digestion, gasification and esterification had the lowest. Compared to pyrolysis, incineration and hydrothermal carbonization had higher impact and overall medium LCA impact.

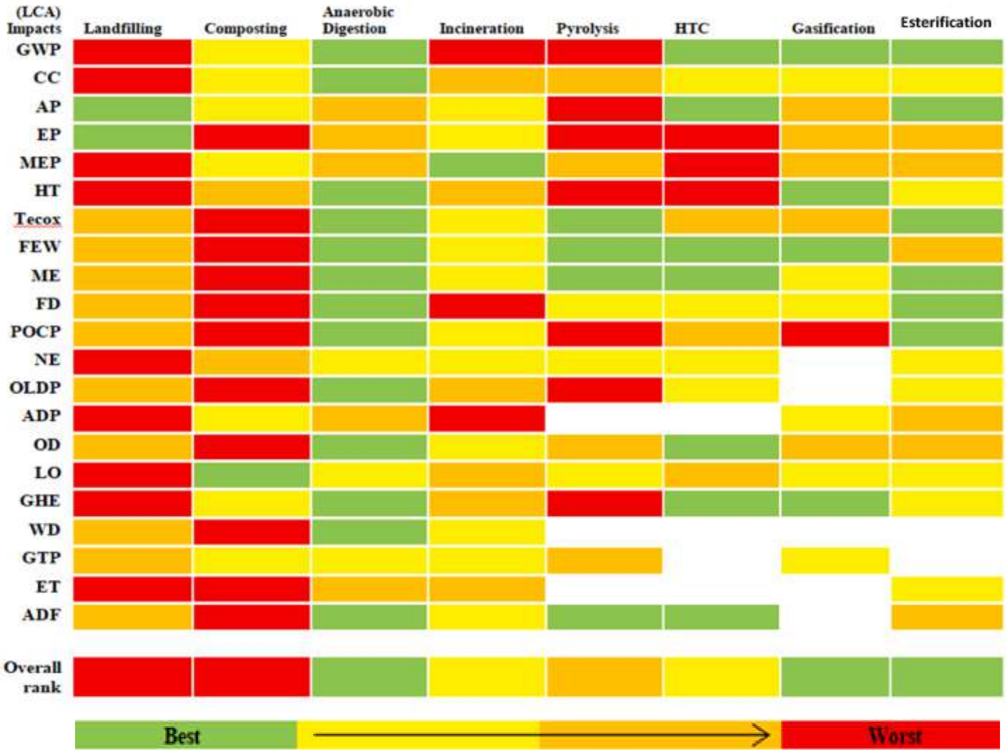

Figure 2 *Life cycle analysis (LCA) environmental impacts comparison of most used technologies in food waste management [1]*

(GWP – global warming potential, CC – climate change, AP – acidification potential, EP – eutrophication potential, MEP – marine eutrophication, HT – human toxicity, Tecox – terrestrial ecotoxicity, FEW – freshwater ecotoxicity, ME – marine ecotoxicity, FD – fossil depletion, POCP – photochemical ozone creation potential, NE – nutrient enrichment, OLDP – ozone layer depletion potential, ADP – abiotic depletion potential, OD – ozone depletion, LO – land occupation, GHE – greenhouse emissions, WD – water depletion, GTP – global temperature potential, ET – ecotoxicity, ADF – abiotic depletion fossil fuel)

Preferred method in the waste management is related to the level of the development of certain country [15]. Similarly, food waste generation in households per capita is found to be high in the developed countries (Table 1).

Table 1 *Average food waste (kg/capita/year) depending on the income of the country [5]*

Income group	Average food waste (kg/capita/year)		
	Household	**Food service**	**Retail**
High-income	79	26	13
Upper middle-income	76	/	/
Lower middle-income	91	/	/

"/" Insufficient data.

It is obvious that a focus area for food waste prevention programmes must be household waste. For example, a 4-person household could save on average about 400 €/year if food waste is reduced in line with various proposals [2]. The Food and Agriculture Organization (FAO) of the United Nations is strongly dedicated to raise public awareness of this global problem by publishing guides explaining how to reduce environmental footprint from household food waste in simple and effective way [12,16]. The "motivation-opportunity-ability" framework has recently been promoted as a theoretical tool for reduction of household food waste by using tools such as stickers, leaflets, measuring cups, recipe cards etc. [17]. By analysing several household food management behaviours, van Herpen *et al*. [18] has provided initial evidence that self-reported survey measurements can be used to assess the effects of household food waste interventions and to effectively decrease the amount of food waste.

Comprehensive understanding of the factors contributing to food waste in various facilities such as healthcare, is crucial to develop effective strategies to minimize waste generation in complex surroundings [19]. Arriz-Jorquiera *et al*. [19] proposed mathematical framework for reducing food waste by approximately 22.5% in a 1000-bed hospital in Florida (USA) which could lead to weekly reduction of more than 113 kg of food waste.

Prevention of food waste generation under legislative framework

The European Commission (EC) has established an action plan to reduce food waste as integral part of the Circular Economy [14]. Generally, the legislative proposals on waste in the Circular Economy include long-term targets to reduce landfilling of waste while increasing reuse and recycling of key waste streams, such as municipal and packaging waste [9]. The EU's Horizon research programme (2021–2027), will target actions in six clusters under 'Global challenges and European industrial competitiveness', in which one cluster represent food, bioeconomy, natural resources, agriculture and environment [20]. The EU and its Member States are also committed to achieving the global Sustainable Development Goal (SDG) of the United Nations, to reduce food waste per capita at the retail and consumer level by 2030, and to reduce food losses along the food production and supply chains within SDG Target 12.3. The focus is on two indexes: *the Food Loss Index* (measures losses for key commodities in a country across the supply chain, up to and not including retail), and *the Food Waste Index* (measures food and inedible parts wasted at the retail and consumer levels in food retail, households and food service sector) [5]. The EC also supports awareness rising at national, regional and local levels and the dissemination of good practices in food waste prevention which are urgently needed in order to reach sustainability targets [9].

Value addition processes for biogas production

Food waste as a stream of municipal solid waste is particularly hard to quantify because absence of harmonised and reliable method, which makes more difficult to assess its scale, origins, and trends of this kind of waste over time [9].

Prior to the production of valuable products, pretreatments of waste food are needed due to variable composition influenced by factors such as seasonal effect, cooking methods, consumption patterns and geographical variations. The percentage of biodegradable substances in food waste vary in the terms of carbohydrate (6–54%), protein (2.4–28%) and lipid (1.5–30%) contents. Kitchen waste, fruit and vegetable waste were found to contain the highest content of water, amounting to 60–90% [11]. According to Kannah *et al*. [10], food waste contains 39–65*wt*.% of carbon and 5.8–7.5*wt*.% of hydrogen, and regarding component analysis, it contains 35.1–67*wt*.% of carbohydrates. In addition, the food waste from beverage, dairy, fruit/vegetable, and cereal industries are rich in protein, fat, carbohydrates, which provides good possibility for production of fermentative products [3].

The pretreatment of food waste includes physical, chemical and biological methods, which can be used to enhance the hydrolysis rate of food digestion. The physical pretreatment methods, such as freezing, sonication, microwave and hydrothermal/thermal treatments, can disrupt the matrix structure of food waste resulting in enhancement of liquefaction of bio-substances, similar to chemical methods including ozonation, acid and alkaline reactions, which are used for disintegration. During biological methods, proteins, macromolecular starches, lipids, long chain fatty acids and free amino acids are converted by hydrolytic enzymes (protease, amylase, and lipase) into glucose and free ammoniacal nitrogen. This disintegration is favourable for biomethane production, and it does not cause secondary pollution of the environment [11].

Hydrogen is considered as one of the most promising clean and renewable fuels. Currently, prevalent processes for hydrogen production are unsustainable due to their dependence on fossil fuels or non-renewable energy sources [21]. Food waste can be converted to hydrogen through gasification of biomass *via* partial oxidation under high temperatures with suitable catalyst. However, the economic feasibility of this promising method needs further investigation [22]. The cost of hydrogen production from food waste is in the wide range, from 2.05 $/kg up to 13.55 $/kg [21]. Hossain *et al*. [21] showed that hydrogen fuel generated from food waste in Bangladesh during the course of 2023 was 0.46 million tons. The benefits from hydrogen production from food waste are numerous, apart from solving the problem of landfill sites, hydrogen used for energy production could have positive impact on the environment by reducing CO_2 emitted from fossil fuels, thus diminishing global warming potential, since a significantly smaller mass of hydrogen can displace much larger mass of fossil fuels, thus emphasizing it economic justification. The quantity of 0.46 million tons of hydrogen can substitute 1.9 million tons of coal, or 1.3 million tons of diesel or 1.19 million tons of natural gas. The quantity of saved diesel fuel could cut CO_2 emissions by 3.85 million tons [21,22].

Valorisation of food waste to biomethane is promising solution, which align with the growing global focus on sustainability, renewable energy, and waste reduction. Biomethane recovery from the organic biomass is the most successful by the anaerobic digestion. Process based on microorganisms or bacteria digestion can be operated at temperatures within mesophilic (at 37 °C) and thermophilic (at 55 °C) conditions. The recovered biogas comprises of 50–75% of biomethane and 25–50% of carbon dioxide [10], as well as hydrogen sulfide, ammonia gas, siloxanes, water vapour, and other volatile organic compounds. Therefore, biomethane need to be purified to a level above 95% [11]. According to data from the study by Ahire *et al*. [4], the highest quality biomethane was observed for fruit pulp, whereas the lowest quality was observed for vegetable waste. As previously said, anaerobic digestion is one of the technologies with the lowest LCA impact value [1].

CONCLUSION

The main challenge of food waste management is highly variable and diverse nature and composition of food waste, which could be solved by central separation or by separation at the source. The improvements of the determination of feedstock composition are needed for efficient food valorisation. In the future, innovations in pretreatment methods would result in higher efficiency of the various bio-products from the food waste (e.g. food waste could be sustainable source of hydrogen-based energy). Probably the most cost-effective design regarding household food waste, as the dominant portion of the municipal waste, is to prioritize food waste reduction at the source. Multidisciplinary approach to this complex problem is surely needed, as well as greater engagement of all structures in resolving inappropriate disposal of food waste and cutting food losses.

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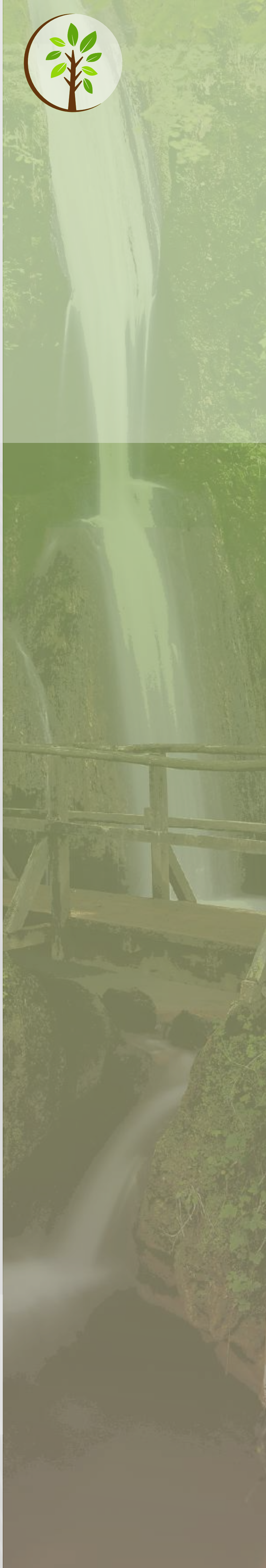

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