CHEMICAL ENGINEERING TRANSACTIONS
VOL. 94, 2022
A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it
Guest Editors: Petar S. Varbanov, Yee Van Fan, Jiří J. Klemeš, Sandro Nižetić
Copyright © 2022, AIDIC Servizi S.r.l.
ISBN 978-88-95608-93-8; **ISSN** 2283-9216
DOI: 10.3303/CET2294177

Potential for Production of Energy and Valuable Products from Food Loss and Waste in Slovenia

Jan Drofenik[a], Danijela Urbancl[a], Bojan Pahor[b,a], Darko Goričanec[a], Zdravko Kravanja[a], Zorka Novak Pintarič[a,*]

[a] University od Maribor, Faculty of Chemistry and Chemical Engineering, Smetanova 17, 2000 Maribor, Slovenia
[b] Saubermacher Slovenija d.o.o., Sp. Porčič 4a, 2230 Lenart, Slovenia
zorka.novak@um.si

Food loss and waste lead to overuse of agricultural land and water and cause large amounts of greenhouse gas emissions. Over the past five years, Slovenia has produced an average food loss and waste of 65 kg/cap/y. Although these cannot be completely eliminated, they can be reduced through appropriate measures, while the rest must be properly treated. In Slovenia, almost half of the food loss and waste is currently processed anaerobically in biogas plants, while the second most common technology is aerobic composting. The latter generates carbon dioxide and will need to be replaced in the future to meet the EU's goal of being carbon neutral by 2050. In this study, the amounts of food loss and waste and their distribution into fractions suitable for different treatment methods were determined. Two treatment technologies were considered to evaluate the potential for producing energy and products from lost and wasted food, namely anaerobic treatment for biogas production and torrefaction for solid biofuel production. Primary production of crop products and cow's milk and slaughterhouse losses were also considered. The results show the proportions of waste by individual food types at all stages of the food chain. Food waste is divided into edible and inedible parts, and conversion factors for biogas or biochar are estimated. On this basis, the energy potential of food waste is estimated to be 431 TJ in the case of biogas production and 417 TJ in the case of biochar. This corresponds to about 1 % of the energy demand of Slovenian households.

1. Introduction

An important area in the food supply chain is food waste. In the European Union, about 20 % of the food produced is thrown away (Sanchez et al., 2020). Estimated levels of food waste range from 158 to 298 kg/cap/y (Corrado and Sala, 2018). A detailed analysis of food waste at the European level along the food supply chain was conducted by Caldeira et al. (2019). Their study showed that fruits and vegetables account for the largest share of food waste, with a similar share in primary production and at the consumer level. The EU is committed to achieving the United Nations goal of halving food waste among traders and consumers and reducing losses in food production and processing (Albizzati et al., 2021).

Research on food waste management and processes for its valorization has increased tremendously in the last decade (Hoehn et al., 2022). Food waste can be processed into biofuels and bioenergy, as well as proteins, enzymes, nutritional supplements, biopolymers, etc. (Tropea, 2022). There are many established and emerging technologies for food waste valorization available (Kassim et al., 2022). However, in order to assess the potential for beneficial utilization of food waste, it is necessary to know its exact composition and how it is divided into edible and inedible parts along the supply chain. Since these data are not yet precisely known for Slovenia, the aim of this study is to obtain the missing data and, on this basis, to develop guidelines for an optimal food waste management policy in Slovenia.

The average citizen in Slovenia consumes about 710 kg/y of food (Zagorc et al., 2020) and throws away about 65 kg/y. Most food waste is generated in households (52 %) and in food services (30 %). The average share of the edible part of food waste is about 40 % (Žitnik et al., 2021). Most food waste is processed in biogas plants (47 %) and 31 % in composting plants. The motivation of this work is to further investigate whether the current level of food waste management in Slovenia can be improved, as there are newer methods processing food

Paper Received: 26 April 2022; Revised: 31 May 2022; Accepted: 09 June 2022
Please cite this article as: Drofenik J., Urbancl D., Pahor B., Goričanec D., Kravanja Z., Pintarič Z.N., 2022, Potential for Production of Energy and Valuable Products from Food Loss and Waste in Slovenia, Chemical Engineering Transactions, 94, 1063-1068 DOI:10.3303/CET2294177

waste into solid and liquid fuels and into various chemicals (Isah et al., 2020). Torrefaction, which converts biomass into high-value solid biofuel, is also a promising technology (Lin et al., 2021).
This work is an extension of our previous work (Drofenik et al. 2021), in which different scenarios of changes in agricultural policies and eating habits and their impact on food self-sufficiency in Slovenia were studied. The main objective of the current paper is to analyze food loss and waste within different parts of the food chain, assess its edible and inedible parts, and evaluate its energy valorization potential by the total conversion to a) biogas or b) biochar.

2. Methods

The following stages of the food supply chain in Slovenia were considered in the analysis of food loss and waste: a) primary production of food and feed before and during harvest/slaughter, b) food production and processing after harvest, c) food distribution and trade, and d) consumption stage (food services and households). In the last two stages of the food supply chain, where food waste and discarded food occur, data on the percentage of edible food were also collected (Žitnik et al., 2021). For food losses during production and processing, it was estimated that another 50 % of food is still edible (Stenmarck et al., 2016).

2.1 Distribution of food losses and food waste in Slovenia

The boundaries of the investigation were set for the Republic of Slovenia. Food of plant origin (cereals, vegetables, potatoes, fruits) and food of animal origin (various types of meat, milk, eggs) were considered. These types of foods caused about 125 kt of food loss and waste, which is almost 90 % of the total food loss and waste. This study did not consider food loss and waste from fish, sugar beets, and oil crops. The main part of the study focused on the generation of food waste in the food chain, starting at the stage of primary production with cereals after harvest, animals after slaughter, as well as milk and eggs drawn from animals. In Slovenia, food losses and waste were not yet subdivided by type of food. Caldeira et al. (2019) disaggregated food losses and waste generated at different stages of the food chain in the EU in 2011 by type of food. Based on this research and data on food loss and waste and food production and consumption, the amounts of food lost and wasted in Slovenia were broken down by type of food for four stages of the food supply chain.

2.2 Energy production from food losses and food waste in Slovenia

Based on the distribution of waste by food type, the next step was to evaluate the potential for converting waste into products and energy. In this study, two technologies were considered: anaerobic digestion of waste to biogas and torrefaction to solid fuels. In the latter, food waste is exposed to a moderate temperature between 200 °C and 300 °C in the absence of oxygen, increasing the density of the product and its calorific value. Torrefaction is considered a pretreatment method for improving the physical, chemical, and biochemical properties of raw biomass feedstocks for subsequent use in co-firing and gasification processes. When raw biomass is torrefied, solid material with high energy density is obtained that is compact, grindable, and has low H/C and low O/C ratios. In addition, hydroxyl groups (- OH) are removed during the process, resulting in the production of hydrophobic materials.
It was assumed that the inorganic part of food waste is not suitable for biogas production or biochar. In particular, these are the bones, which constitute most of the inedible part of the meat, and the eggshell, which constitutes the inedible part of eggs. In addition, liquid wastes such as milk, egg and wine wastes are not suitable for the torrefaction process. It was hypothesized that the edible parts of the waste are more suitable for conversion to biogas and the non-edible parts are more suitable for biochar. The reason for this is that the edible part of food waste contains a lower percentage of cellulose, which is more difficult to break down in the process of anaerobic digestion. The non-edible part, e.g., the peels, is richer in lignocellulosic materials, which are more suitable for the charring process during torrefaction (Brachi et al., 2018).

3. Results

The results of the study are presented in Section 3.1, which contains the distribution of food waste by type for all stages of the Slovenian food supply chain, and in Section 3.2, which shows an assessment of the total energy potential of food waste in Slovenia in the case of conversion to biogas and biochar.

3.1 Distribution of food losses and food waste in Slovenia

From 2014 to 2019, Slovenia produced about 4,200 kt of food and feed of plant origin annually, most of which (about 3/4) was green fodder and grass for animal feed. About 600 kt of food of plant origin and 800 kt of food of animal origin were produced for human consumption. About 125 kt of food waste was generated, of which the majority (90 kt or 72 %) was plant food waste. Since the ratio between consumed food of plant origin and consumed food of animal origin is much more balanced than that of food waste, i.e. 57.8 % of all food consumed in Slovenia is of plant origin, it can be concluded that more food loss and waste is generated from the mass unit of consumed food of plant origin than from those of animal origin. Figure 1 shows the supply chain for food of plant origin. The green boxes in Figure 1 show the amounts of plant-origin food lost and wasted at each stage of the food supply chain and the percentage of edible food at each stage. Overall, 41.7 % of lost and wasted food was still edible at the time of disposal. Approximately 15 % of all plant foods produced are lost and wasted. It should be noted that almost 100 kt of food intended for human consumption was lost during production at the primary stage, i.e., before and during harvest. These losses are caused by weather conditions, fluctuations in purchase prices, inappropriate cultivation and harvesting methods that may result in lower yields or damage to the food, etc. These losses were not analyzed further in this research.

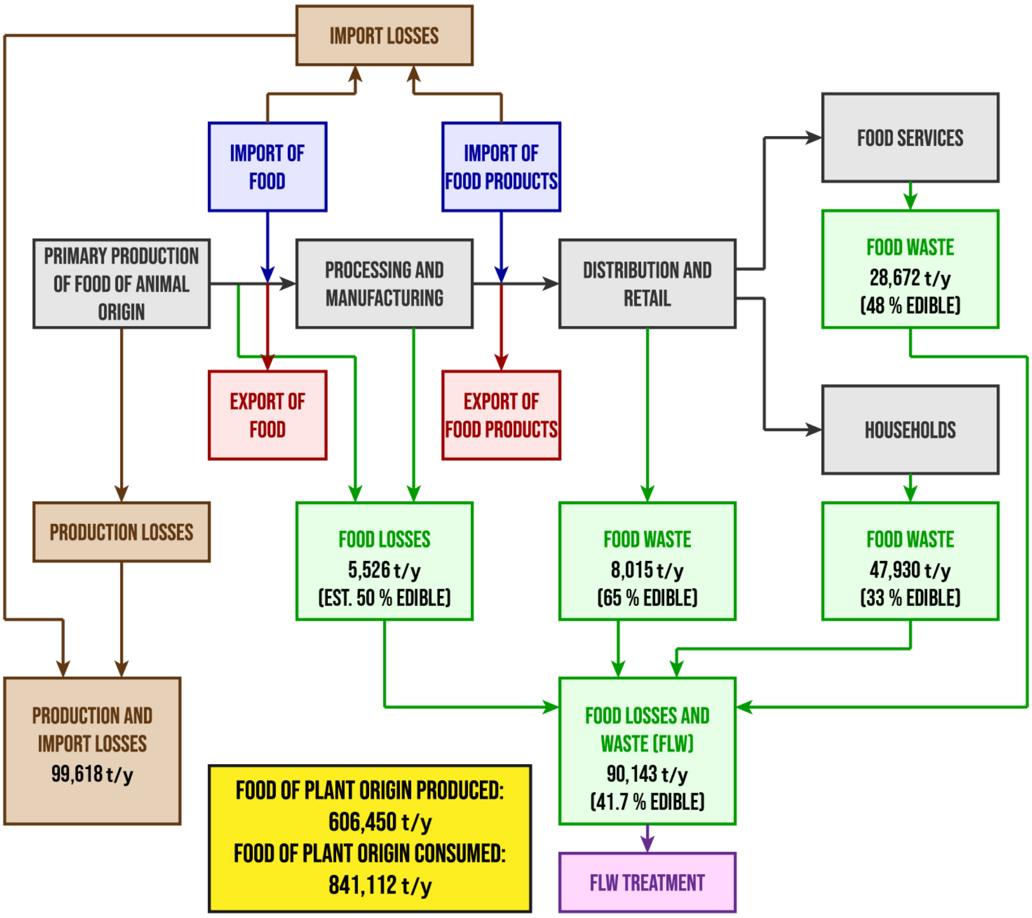

Figure 1: The supply chain for food of plant origin

In the supply chain for food of animal origin, there is an additional stage compared to the supply chain for plant food, namely the production of animal feed and its conversion into food of animal origin. Figure 2 shows the supply chain for food of animal origin. In this chain, there are large losses in the pre-harvest stage that have no direct economic or environmental impact, as these losses are, for example, unharvested grass or fodder left in the field. Also in Figure 2, the green boxes show the amounts of food lost and wasted at each stage of the animal food supply chain. It is interesting to note that in this supply chain, only about 5 % of all food of animal origin produced ends up in the "lost and wasted food" category. On the other hand, only 22 % of the mass of all feed is converted into food of animal origin. This indicates a low efficiency in the conversion of plant feeds into meat. If we consider that the production of animal feed takes up a large part of arable land and that the production of food of animal origin causes a large part of greenhouse gas emissions, a major problem in this supply chain becomes clear.
Quantification of food losses by individual parts of the food chain was followed by analysis of quantities by individual types of food waste. Data from the article by Caldeira et al. (2019) served as the basis. Table 1 shows the percentage distribution of food loss and waste at the different stages of the food chain by type of food. It was found that the largest percentage of food waste is waste from vegetables, potatoes, wheat, and products

made from them, each of which is around 20 %. For all three types of food, most food waste is generated at the consumption level, i.e., households, restaurants and food services.
Primary production/processing and retail/distribution account for a smaller share of food loss. The total shares of the individual parts of the food chain listed in the last row of Table 1 agree well with the data of the Statistical Office of the Republic of Slovenia, according to which 52 % of food waste occurs in households, 30 % in restaurants and food services, 11 % in distribution and retail, and 7 % in food production (Žitnik et al., 2021).

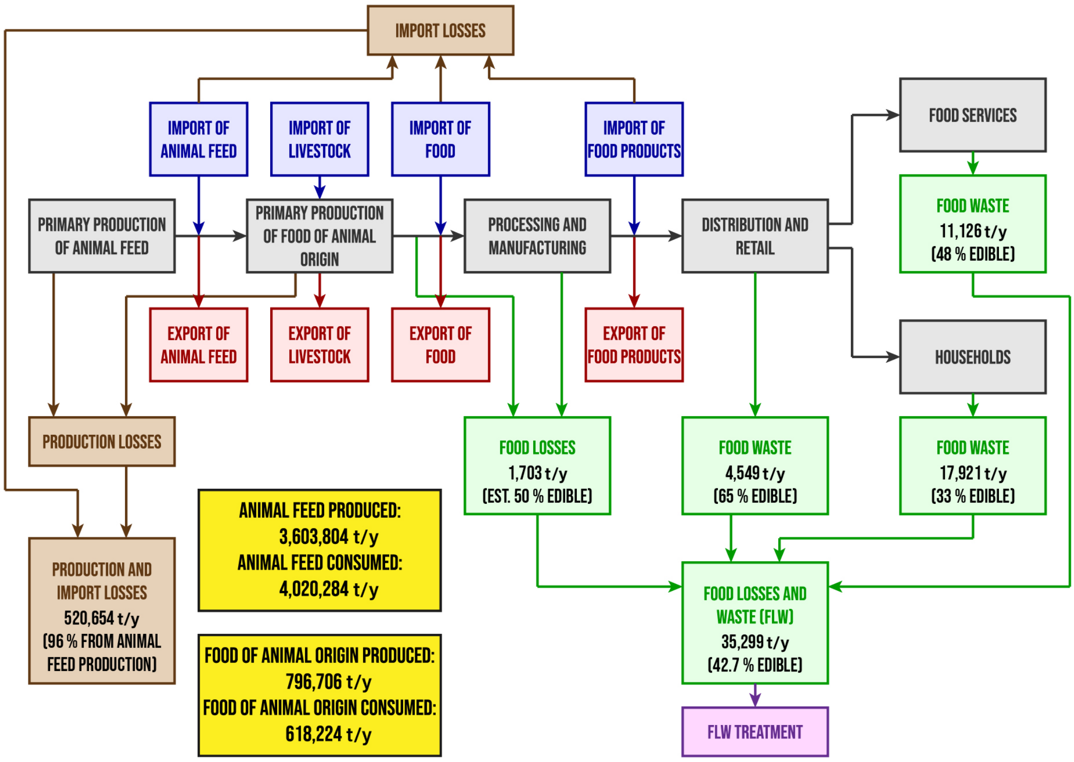

Figure 2: The supply chain for food of animal origin

Table 1: Distribution of food losses and waste by type of food and stages of the supply chain (linked to total amount of 125 kt)

Food	Production and processing	Retail and distribution	Restaurants and food services	Households	All together
Beef	0.29 %	0.65 %	1.29 %	1.84 %	4.08 %
Pork	0.20 %	1.26 %	2.49 %	3.55 %	7.49 %
Poultry	0.46 %	0.99 %	1.96 %	2.80 %	6.21 %
Lamb	0.01 %	0.03 %	0.06 %	0.09 %	0.19 %
Dairy	0.36 %	0.52 %	2.05 %	4.76 %	7.69 %
Eggs	0.03 %	0.17 %	1.02 %	1.25 %	2.48 %
Wheat	0.69 %	2.63 %	6.72 %	8.12 %	18.16 %
Corn	0.13 %	0.29 %	0.73 %	0.89 %	2.03 %
Barley	0.01 %	0.02 %	0.05 %	0.07 %	0.15 %
Potato	2.02 %	1.38 %	5.12 %	9.75 %	18.27 %
Vegetables	0.86 %	1.55 %	7.51 %	13.83 %	23.75 %
Fruit	0.38 %	0.47 %	2.46 %	5.00 %	8.30 %
Wine	0.32 %	0.05 %	0.27 %	0.56 %	1.20 %
All together	5.8 %	10.0 %	31.7 %	52.5 %	100 %

3.2 Energy production from food losses and food waste in Slovenia

After the quantities for each type of food waste were estimated based on Table 1, the division into edible and non-edible parts was made. For each part of each food type, data on the specific production of biogas by anaerobic digestion (Weinrich et al., 2018) and on the specific production of biochar by torrefaction (Huang et al., 2020) were obtained. Subsequently, two scenarios were analyzed to evaluate the energy potential of food waste in Slovenia by converting all food waste into a) biogas and b) biochar.

It was determined that biogas processing of the lost and wasted food considered in this research would represent an annual energy potential of 430.6 TJ, of which 193.2 TJ (45 %) comes from inedible parts. The process of torrefaction of all the lost and wasted food considered represents a slightly lower energy potential, 417.0 TJ, but the contribution of inedible food is slightly higher, 198.9 TJ (48 %). This is because the inedible part is mainly waste parts of vegetables and peels, e.g., potatoes and fruits. Peels contain a higher proportion of cellulosic materials than the edible part, so the torrefaction yield is somewhat higher.

Figures 3 and 4 show the energy potential of food waste by processing it into biogas (Figure 3) and biochar with torrefaction (Figure 4). The vast majority of biogas is supplied by food waste from wheat, followed by pork and potatoes. In the conversion to biochar, fruit and potato waste contribute a significant share in addition to wheat food waste.

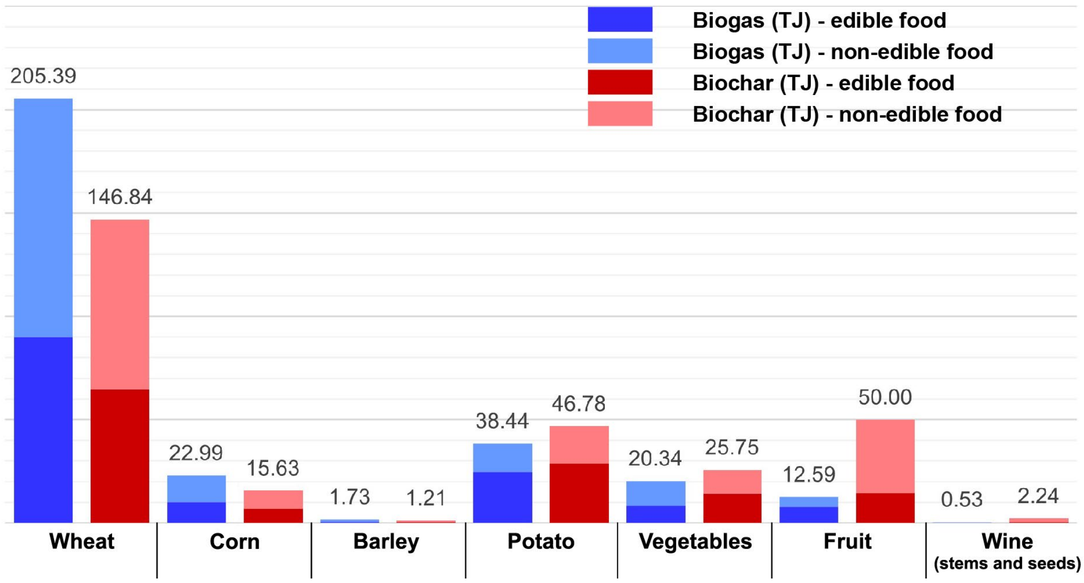

Figure 3: Potential of energy recovered from lost and wasted food of plant origin in TJ

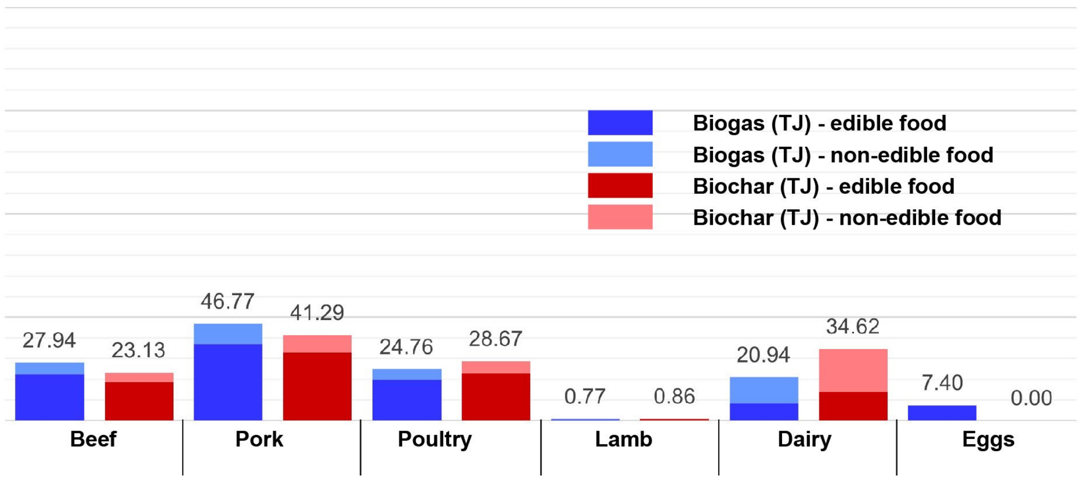

Figure 4: Potential of energy recovered from lost and wasted food of animal origin in TJ

4. Conclusions

This paper presents for the first time the breakdown of food waste in Slovenia by type of food and by individual segments of the supply chain. It was found that vegetables, wheat and potatoes account for the largest share of food waste in the entire food supply chain. The largest share of food waste of this type is generated by food consumption. The high proportion of wheat in food waste suggests that people purchase bread and products

made from wheat irrationally. More rational purchasing of vegetables could also lead to less waste. The key to sustainable agricultural development in the future is to minimize or avoid the generation of edible food waste and to use only the inedible parts of food waste for energy production.
A rough estimation of the energy potential of food waste in Slovenia gave a result of 417 TJ when treating food waste by torrefaction and 431 TJ when converting it into biogas. This corresponds to about 1 % of energy consumption in Slovenian households. The average annual energy consumption in Slovenia is 0.052 TJ per household, which means that food waste contains an energy potential for about 8,000 households, i.e. for 2 average Slovenian municipalities. Nevertheless, the top priority must be to eliminate the edible part of food waste. From the remaining non-edible part, almost enough energy could be obtained for the households of an average Slovenian municipality.

Acknowledgements

Funding from the Ministry of Agriculture, Forestry and Food, and the Slovenian Research Agency (project V2-2009, program P2-0414 and project J7-1816) is acknowledged.

References

Albizzati P.F., Tonini D., Astrup T.F., 2021. A Quantitative Sustainability Assessment of Food Waste Management in the European Union. Environmental Science & Technology, 55 (23), 16099-16109.
Brachi P., Miccio F., Ruoppolo G., Stanzione F., Miccio M., 2018. Pressurized Steam Torrefaction of Wet Agro-industrial Residues. Chemical Engineering Transactions, 65, 49-54.
Caldeira C., De Laurentiis V., Corrado S., van Holsteijn F., Sala S., 2019. Quantification of Food Waste per Product Group Along the Food Supply Chain in the European Union: a Mass Flow Analysis. Resources, Conservation and Recycling, 149, 479-488.
Corrado S., Sala S., 2018. Food Waste Accounting Along Global and European Food Supply Chains: State of the Art and Outlook. Waste Management, 79, 120-131.
Drofenik J., Pahor B., Kravanja Z., Pintarič Z.N., 2021. Scenario Analysis of Changes in the Food Supply Chain. Chemical Engineering Transactions, 88, 721-726.
Hoehn D., Margallo M., Laso J., Ferdnandez-Rios A., Ruiz-Salmon I., Aldaco R., 2022. Energy Systems in the Food Supply Chain and in the Food Loss and Waste Valorization Processes: A Systematic Review. Energies, 15(6), 2234.
Huang J., Qiao Y., Wang Z., Liu H., Wang B., Yu Y., 2020. Valorization of Food Waste via Torrefaction: Effect of Food Waste Type on the Characteristics of Torrefaction Products. Energy & Fuels, 34(5), 6041-6051.
Isah S., Ozbay G., 2020. Valorization of Food Loss and Wastes: Feedstocks for Biofuels and Valuable Chemicals. Frontiers in Sustainable Food Systems, 4, 82.
Kassim F.O., Thomas P.C.L., Afolabi O.O.D., 2021. Integrated Conversion Technologies for Susatinable Agri-food Waste Valorization: A Critical Review. Biomass and Bioenergy, 156, 106314.
Lin Y. L., Zheng N. Y., Hsu C. H., 2021. Torrefaction of Fruit Peel Waste to Produce Environmentally Friendly Biofuel. Journal of Cleaner Production, 284, 124676.
Sanchez J., Caldeira C., De Laurentiis V., Sala S., Avraamides M., 2020. Brief on food waste in the European Union. <https://www.researchgate.net/publication/343879091_Brief_on_food_waste_in_the_European_Union>, accessed 14.04.2022.
Stenmarck Å., Jensen C., Quested T., Moates G., 2016. Estimates of European Food Waste Levels, Reducing Food Waste Through Social Innovation, Fusions. <https://www.eu-fusions.org/phocadownload/Publications/Estimates%20of%20European%20food%20waste%20levels.pdf>, accessed 01.04.2022.
Tropea A., 2022. Food Waste Valorization. Fermentation, 8(4), 168.
Weinrich S., Schäfer F., Bochmann G., Liebetrau J., 2018. Value of Batch Tests for Biogas Potential Analysis; Method Comparison and Challenges of Substrate and Efficiency Evaluation of Biogas Plants. In: Murphy, J.D., IEA Bioenergy Task 37, 10. <https://www.ieabioenergy.com/wp-content/uploads/2018/11/Batch_tests_web_END.pdf>, accessed 15.04.2022.
Zagorc B., Moljk B., Brečko J., Hiti A., Bele S., 2020. Report on the state of agriculture, food industry, forestry and fisheries in 2019 - an overview by agricultural markets. <www.kis.si/f/docs/Porocila_o_stanju_v_kmetijstvu_OEK/ZP_2019_splosno__priloge_net.pdf>, accessed 15.07.2021 (in Slovenian).
Žitnik M., Petric P., Kalin K., Hotić M., 2021. In 2020, almost 2 % more food waste generated than a year earlier. <https://www.stat.si/StatWeb/en/News/Index/9865>, accessed 19.03.2022.