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# Cooking Oil and Fat Waste Management: A Review of the Current State

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Waste management is a continuously growing area connecting industry and academia nowadays. There are, however, still many issues and sub-areas requiring in-depth analysis and development of new approaches and solutions. One of them is the management of waste cooking oils and fats originated from households. While most of the solid waste is addressed within the circular economy proposal, the fat waste recycling consideration is still in its early stage, as the relevant European Union legislation has only recently been adopted. Disposing of oil and fat waste in a traditional way often leads to sewage problems. However, if utilised, this waste may be a valuable source of energy and material recovery. While maintaining the reverse supply chain viewpoint (from waste producers through the collection to treatment and utilisation), this paper reviews the current state of the waste cooking oils and fats management and identifies the drawbacks in existing collection and handling methods. The review shows that current approaches have shortcoming mainly due to poorly organised collection container networks and provides insights into the importance of effective prognosis of the cooking oil and fat waste whose collection and handling is still in the development. The Czech Republic current state and the future outlook is discussed and commented with regards to the expected growth of production and separation of these wastes. The review stresses the challenges of establishing and coordinating the supply chain segments, which will benefit from applying mathematical modelling to facilitate decision-making.

## 1. Introduction

Cooking oil and other edible oils and fats originated from households are nowadays mostly disposed of together with municipal waste (residuals of grease mixed in the waste) or simply poured into drainage. While the recycling of this waste has been required from food industry companies in most of Europe for a long time, such recycling on a household level is still not a matter even if it presents a significant part of the overall production; e.g., ca. 19 % of the overall production comes from households in South Korea (Cho et al., 2015). In some countries, an initiative towards fat waste recycling is run by the government, as seen, for example, in the Czech Republic, where municipalities are obligated to allow the separate collection of waste cooking oils and fats starting in 2020 (Fan et al., 2020).

Fat waste is a specific branch of waste management. Because of its physical properties and structure, there are special challenges to be addressed (Math et al., 2010). Both vegetable oils and animal fats solidify at low temperatures and melt at high temperatures. At the same time, the former tend to have higher viscosity while the latter may appear in a semi-solid or paste state at room temperature. Handling of this waste is not as straightforward as, for example, glass, paper, or plastic (Stoll and Gupta, 1997).

Fat waste has mostly been disposed-of to sewage (Puspa Asri and Puspita Sari, 2015), which has caused troubles. Fat combined with other solid waste in a sewer leads to clogging the waste system. However, waste cooking oils and fats present a valuable feedstock and commodity which can be utilised for generation of energy

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and even material recovery. This feedstock can, after minor pre-treatment, be utilised at cogeneration plants producing thermal and electric energy or without pre-treatment at agricultural biogas plants (Ortner et al., 2016). Much effort was made to turn waste cooking oils into liquid biofuel for diesel engines – biodiesel (Enweremadu and Mbarawa, 2009). Producing this fuel is possible via the transesterification process (Panadare and Rathod, 2015), which is adopted worldwide, or from hydrotreating (Mayorga et al., 2019). Besides waste-to-energy solutions, cooking oil waste is a valuable feedstock for producing biodegradable polymers, biosurfactants, as well as grease and soap (Panadare and Rathod, 2015). To realise such recycling's full potential, a suitable system for waste cooking oil collection and processing, especially that originated from households, has to be established.

The reverse supply chain of the waste collection may be divided into four segments: production, discarding and collection, processing and utilisation. Households, restaurants, and food producers have been identified as the biggest producers of fat waste (Emara et al., 2018). Note that Math et al. (2010) identifies some other businesses whose fat waste is suitable for biodiesel production. Each particular segment has its problems and logistic challenges specific to each part of this chain, for instance, the appropriate choice of container vehicles is a matter of interest for the waste collector. Because of these differences, it is necessary to approach the problem not only considering the whole chain, but it is essential also to address the individual parts.

## 2. Literature review

Creating a network of fat waste containers on a municipal level is currently a problem, which is yet to be properly solved. For example, nowadays, in the Czech Republic, municipalities mostly use collection yards, that handle the collection of used fats. This approach is not ideal, because the walking distance to these yards is too long. Cities have low expectations regarding the amount of waste that people would recycle (Emara et al., 2018), which leads to low motivation for interest in the subject. On the other hand, it has been shown that cities that, at some point, created a fat waste collection network, are, in most cases, pleased with the result and pursue to extend its network due to the increase of waste produced and collected (Ortner et al., 2016).

Designing these networks is not always ideal if only due to these networks often being significantly sparser than, for example, those for mixed municipal waste or plastic waste. This means that the waste collection network layout is in the competence of civil servants which may result in the non-ideal design of the network. By using optimisation methods, it is possible to construct a better network, that will maximise the amount of disposed-of fat waste and reduce costs of maintenance and handling (Ramos et al., 2013). Consequently, it is crucial for companies processing fat waste to plan the location of their processing capacities (Zhang and Jiang, 2017). Properly selected facility location decreases greenhouse gas emissions and also saves companies money. The complexity of real-life instances of location problems is often increased due to the need for considering uncertainty (Kůdela and Popela, 2015).

Selection of articles used in this literature review was performed by searching for keywords connected to fat waste, cooking oils or waste management. For example, these keywords in ScienceDirect database were “producers of UCO”, ”cooking oil rabble”, ”cooking oil salvage”, “cooking oil collection”, “households oil production”, “households WCO”, “WCO production households”, “WCO production”, “cooking oil production”, “cooking oil production diversification”, “WCO production diversification”, “WCO households”, where WCO and UCO are commonly used abbreviation for waste cooking oils and utilisation of cooking oils. Databases used for the search were ScienceDirect, Scopus and ResearchGate as these databases are proven as quality resources. Some found relevant articles contained citations to other promising manuscripts, that were judged and some of them proven as suitable for this review.

Table 1 summarises relevant research directly or partly focused on fat waste. These articles mostly focus on waste cooking oil; however, some contain grease and other types of fat as well. Five columns in the table correspond to the key activities in the proposed reverse supply chain. Additional criteria representing technical problems in wastewater treatment plants (WTP) and sewerage has been added as they are part of most research in fat waste and may present a secondary objective of research dealing with a waste cooking oil and fat management (Mikulčić et al., 2020). Selected manuscripts do not include quantities of produced fat waste by municipalities, but some do contain data about private sector production. However, as these data do not correspond with focus of the review, they were not taken into account. Total amount of fat waste in the EU can not be determined exactly, but estimation based on the average 8 L of oil per capita on year suggests that this amount is around 4 4 Mt/y (Mannu et al., 2018).

The detailed consideration of the research summarized in Table 1 reveals that the aspect of planning the garbage disposal container network, especially using a prognosis of production, has not been addressed in the literature. The choice of fat waste container design and location through modelling and optimisation would have a significant impact on the efficiency of collection operations. This area has a high potential for further research. The upcoming section provides some insights into the trends and forecasting of cooking oil and fat waste

production and presents some original analysis results of forecasting that will be a subject of further research. It also identifies further potential research directions in the waste management area.

*Table 1: A review of current relevant articles on the topic and assessment of their focus*

| Author | Production | Discarding | Collection | Processing | Utilisation | WTP and sewer problems |
|---|---|---|---|---|---|---|
| Stoll and Gupta (1997) | ✓ | | ✓ | | ✓ | |
| Keener et al. (2008) | ✓ | | | | | ✓ |
| Enweremadu et al. (2009) | | | | | ✓ | |
| Maceiras et al. (2010) | | | | | ✓ | |
| Math et al. (2010) | ✓ | | | | ✓ | |
| Ramos et al. (2013) | ✓ | | ✓ | | | |
| Solymosi et al. (2013) | | | | | ✓ | |
| He et al. (2013) | ✓ | | | | | ✓ |
| Husain et al. (2014) | ✓ | | | | ✓ | ✓ |
| Panadare and Rathod (2015) | | | | | ✓ | ✓ |
| Puspa Asri and Puspita Sari (2015) | | | | ✓ | | ✓ |
| Ortner et al. (2016) | | | | ✓ | ✓ | ✓ |
| Chuah et al. (2016) | | | | | ✓ | |
| Zhang and Jiang (2017) | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Silviana et al. (2017) | | | | | ✓ | |
| Montecinos et al. (2018) | | | ✓ | ✓ | ✓ | |
| Emara et al. (2018) | ✓ | | ✓ | | | |
| Gurd et al. (2018) | | | | | | ✓ |
| Pirooz et al. (2018) | ✓ | | | | | ✓ |
| Rekhate and Prajapati (2019) | ✓ | | | ✓ | ✓ | |
| Lopes et al. (2019) | ✓ | | | | | |
| Mayorga et al. (2019) | | | | | ✓ | |
| Araujo et al. (2019) | | | | | ✓ | ✓ |
| Simasatitkul and Arpornwichanop (2019) | | | | | ✓ | |
| Ahmed and Hossain (2020) | | | | | ✓ | |

## 3. Trends and future directions

Data like total fat waste production and further processing capabilities are necessary for the correct design of the whole recycling network. However, especially in some EU countries, recycling this type of waste has only drawn attention recently, and so the quality and quantity of the existing data are insufficient. To produce an appropriate forecast, it should be noted, it is not simply enough to study the recent-years trends but also account for various factors of socio-economic and demographic nature, which may prove to be a difficult task. One possible direction is a reverse identification from manufacturers and customers, which may provide a baseline for the total amount entering the market. Based on the estimated amount of household fat and oil consumption as well as growing habits and willingness of citizens to separate, the achievable potential could be evaluated. Existing and new approaches that would partly solve this problem need to be improved for the elimination of the related identified issues.

### 3.1 Trends in cooking oil and fat waste production

In the case of the Czech Republic, the separation of edible fats and oils has undergone a system change in recent years. When interfering with the collection of new waste fraction, it is desirable to adapt the existing infrastructure in order to make the change possible. It is necessary to estimate the expected future waste production in order to make the change sustainable in the long term. It is evident that at present, the fats and oils separation is at the beginning of growth, as Figure 1a shows. The approach that is presented in the study Smejkalová et al. (2019) and particularly deals with a bio-waste is used to forecast the production of fats and oils production. The methodology uses the idea of credibility theory and is able to respond to sudden changes

in production. The following conditions must be met to use this forecasting approach: some territories have already responded to the change and information on the separation potential is available. Figure 1a) shows that production has begun to increase significantly in some micro-regions and substantial differences between micro-regions arise. This approach was applied at the level of micro-regions and subsequently also regions in the Czech Republic. The method by Smejkalová et al. (2019) was newly supplemented by data reconciliation for maintaining links in the hierarchical structure of territories presented by Pavlas et al. (2017) since the separation of the fat waste is at its beginning evident trends in aggregated territories are a necessary contribution from the micro-regional forecasting point of view.

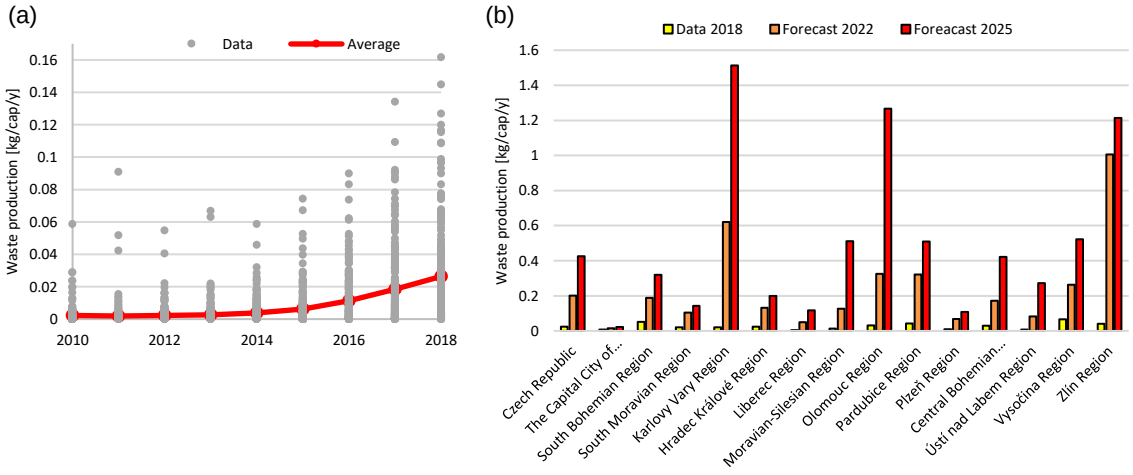


*Figure 1: Data and forecast on the production of edible fats and oils at the level of the Czech micro-regions (a) Historical data on micro-regional level (b) Forecast for years 2022 and 2025: state and regional level*

The separation potential for edible fats and oils was set at 3 kg/cap/y according to the consumer basket of the Czech Republic for the year 2018 (Czech Statistical Office, 2018). It is assumed that about only third is suitable for separation, because of evaporation and remaining contents in the food. The initial results of the combination of approaches presented in previous papers are shown here. Based on the results, a significant increase in the production of separated fats and oils can be expected in the coming years. Figure 1b) shows the production of this waste in 2018, the last year with available data. The forecasts in the years 2022 and 2025 are drawn at the level of regions of the Czech Republic. By 2025 the production of more than 4.5 kt/y of edible fats and oils can be expected in the Czech Republic. Further development of the approach should focus on the more precise estimation of the separation potential. There is also a research gap in the determination of weights for the credibility of particular territories regarding the forecasting quality. It would be beneficial to take into account the difference in the development of regions and micro-regions.

Micro-region Uherský Brod has been selected for the comparison and test computations. Its population is about 53,000 cap, and it consists of 30 municipalities with various size. The generation of fats and oils is expected to reach 13.1 t by 2022 and 90.4 t by 2025, which is a huge increase within just five years from 2020. The grid of containers has been deployed through a simple model of mathematical programming, where the total number of collection points was minimized. The capacity for the collection point is set to 120 L, and the collection by vehicles is assumed to be performed once every two weeks. The collection frequency can be increased if the available vehicle fleet would allow higher utilization. The maximum load for the collection points is assumed at 30 kg. The computation was performed with the relative optimality gap equal to 5 %. The total number of address points is about 16,000, which were paired with over 300 candidate locations for collection point. The model suggested the minimum number of collection containers to 28 for 2022 and 128 for 2025. The growth is very significant due to not available space in already allocated containers. The average walking distance then changes from 827 m to 687 m. The average walking distance is still very high compared to collection points for commonly separately collected waste fractions which are below 100 m in the Czech Republic. However, for such a commodity with low total production, it would not be profitable and neither efficient to increase the density of the container network.

### 3.2 Future research directions

There are still many problems specific to fat-waste that should be addressed in a comprehensive way. The overall lack of data on the production amounts from households was discussed above. Container location and volume choice, collection vehicle routes, and other aspects can lead to increasing the collection of the

residentially-produced fat. As mentioned, the location and volume of containers is a significant part of the issue. Another challenge is presented by the routing of collection vehicles, which represents a major part of the whole fat and cooking oil waste management. The frequency of collection does not only relate to the volume of waste in the container, but it has to reflect the weather conditions as well. Not efficient collection management may result in solidification of content and unpleasant odours. The container content should also be protected from extreme temperatures. Due to the specificity of this commodity, vehicles with properties that meet features of such waste may be required. Due to the possibility of using warehouses for fat waste storage, the collection task can also be formulated as a location-routing problem where, in addition to route planning, the location of a warehouse facility is proposed. A further extension may include the subsequent transport to the processing facility. In combination with intermediate facilities, a network flow problem may be incorporated.

## 4. Conclusions

Fat waste has much potential in the upcoming years as it has unique properties that allow us to produce biodiesel, thermal and electric energy, as well as materials like biodegradable polymers. Thanks to rising attention from public and government initiatives, the amount of collected fat waste originated from households is growing. It creates collection problems that can be solved with optimisation methods. This type of waste has special requirements for handling and collection, and it needs to be researched to find suitable solutions to this problem. Current solutions for the collection of other waste types are not always suitable for fat waste, which has its specific challenges. This paper contains division and characterisation of current research in waste management and other related work focused on fat waste. Areas that offer considerable research gap in creating new methods and approaches have been mentioned. Original and promising results based on forecasting were presented, and related future research directions were identified. The short comparison of container allocation was performed for the municipality Uherský Brod with about 53,000 cap. It has been found that the fat and oil container grid will have to grow significantly in the upcoming years, the sufficient amounts equal to 28 containers for 2022 and 128 containers for 2025. This result corresponds to 414 cap on average assigned to one collection container.

In further research work, the authors will focus on these areas, which will be based on a forecast of fat waste production and estimates of its composition, designing of collection sites infrastructure, and the problem of complex waste treatment chain linked to the ultimate processing of fat waste. The results of such research will help to achieve economic and ecological benefits such as fewer clogging incidents and local biofuel consumption growth. Municipalities can benefit from cost savings on sewerage repairs, WTP on fat waste handling and local businesses can benefit from biodiesel usage and its byproducts. Thanks to lowering sewerage accidents, traffic will not be stopped, and there will be fewer complications connected to these accidents such as unpleasant odours or temporary unavailability of water.

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