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Cooking oils and fat waste collection infrastructure planning: a regional-level outline

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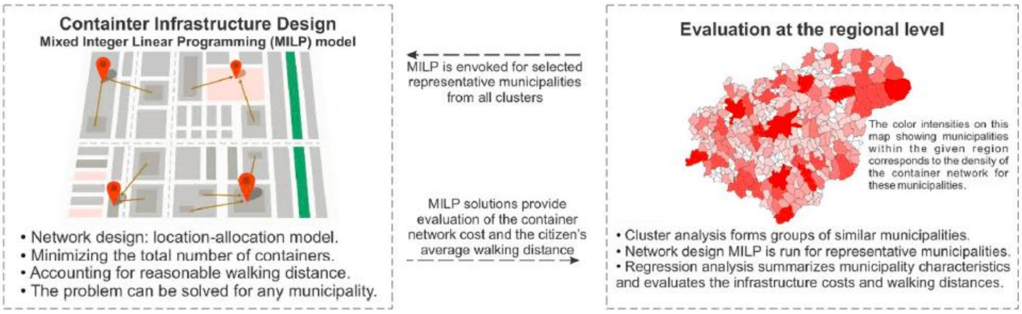
Abstract

Among the current trends in waste management and circular economy is the involvement of new fractions of waste for sorting and collection. One of them is fats and cooking oils, especially those coming from households. Now, the nascent fat waste recycling becomes promoted as regulations and waste recovery targets have been set in the European Union. The traditional manner of discarding household fat waste usually causes sewage problems. However, utilisation of this waste brings the potential for contributing to the energy supply and material recovery. This research presents a mathematical model for the optimal location of fat waste bins and containers in the given municipalities. The container network should comprise as few containers as possible, while the walking distance for the citizens towards the container is as short as possible. The objective of the proposed optimisation model is to minimise the total number of collection points (infrastructure cost). The collection points represent the citizens' addresses in a municipality. The average walking distance towards a container is a novel feature in the model, which is pertinent to waste fractions with low production per person. Cluster analysis describes the variability between municipalities, and further, it is possible to use regression analysis to model the number of containers for any municipality or region. The proposed general decision support tool estimates the total cost and number of bins needed for any region or a country. The region from the Czech Republic, which was used as a study area, revealed the requirement for 609 containers, with only EUR 30,000 of investment cost. There are around 950 inhabitants assigned to a single collection point on average.

Graphic abstract



Keywords: Cooking oil and fat waste, Waste infrastructure planning, Waste bin and container , Network design

Introduction

The segment of cooking oils and fat waste is one of the most challenging areas of current waste management and recycling practices. Such waste, especially that originated from households, is nowadays mostly discarded together with municipal waste or poured into drainage (Zheng et al. 2020) despite it being recognised for the potential of becoming a sustainable source for things like biofuel conversion due to its abundant production worldwide (Goh et al. 2020). Converting waste cooking oils to biodiesel is a multiple-advantage solution that can strengthen energy security, advance a circular economy and minimise waste and environmental pollution (Zhao et al. 2021). While recycling cooking oils and fat has long been mandatory for the food industry in the majority of the European countries, widespread collection systems on a household level, among others, is just being introduced (Foteinis et al. 2020) despite the sizable contribution of households to the total fat waste production (Cho et al. 2015). In Europe, over 60% of the used cooking oil is improperly disposed of, which can cause water drainage clogs, thus increasing the cost of waste water treatment (Bhuiya et al. 2016). Although some research addresses waste cooking oil supply chains (Nugroho and Zhu 2019), still, the literature on the collection infrastructure planning for this category of waste is insufficient, which has led to challenges from both theoretical and practical sides.

Fat waste presents a unique branch within waste management, specifically because of the physical properties of waste (Math et al. 2010). Therefore, planning the collection infrastructure needs special attention. Several countries have recently initiated action to address the recycling of fat waste on the household level. Municipalities collect either strictly cooking oil or all fat waste, which can also contain lard, clarified butter and other types of animal and plant-based fat. One such example is the Czech Republic, where since 2020, the municipalities must enable and facilitate the recycling of the household oils and fats (Fan et al. 2020). Some municipalities already have an existing collection infrastructure of containers and bins for cooking oil and fat waste. Others only have a trial network of a few containers. Yet others may even to date circumvent the regulation by allowing the recycling in collection centres and yards, which are often associated with a large (average) walking distance for the citizens. Such layouts do not motivate people to recycle the cooking oil and fat waste, which proves that walking distances towards the bins significantly impact the quality of separation and this issue must be taken into account (Rousta et al. 2015). The decision-makers (mayors, municipal boards, and authorities) face the problem of choosing the optimal layout for cooking oil and fat waste recycling containers and bins, which would motivate the people to recycle. Sparse collection networks also tend to result in bad recycling behaviour, such as pouring the waste cooking oils into the drainage, which then causes sewerage accidents and further leads to an additional cost (Matusinec et al. 2020). The optimal decision on the collection infrastructure design should typically present a trade-off between the comfort provided to the citizens by minimising the average walking distance (a dense collection network) and minimising the total collection infrastructure costs (Nevrly et al. 2021).

Each particular municipality has its specific features, which ultimately influence the optimal layout of the container network for the fat waste collection. Among these attributes, there are the type of dwellings (e.g. family houses or apartment buildings), the density of buildings or population, the location (city centre or outskirts) and others. The appropriate infrastructure for different areas may differ in the density of waste containers (average walking distance to the nearest collection point) and their type and size (the demand and frequency of waste collection) (Adeleke and Ali 2021).

The collection infrastructure designed for each area has to be feasible in the long run, which can only be done by accounting for concrete needs coming from the physical properties and structure of the cooking oil and fat waste, whose recycling, as mentioned, is quite different from the general waste, glass, plastic and other solid waste. The container capacity is one of the key aspects to address. For example, waste cooking oils from restaurants are collected in containers of a specified size, e.g. 30 L (Ramos et al. 2013). However, collection from households needs special attention since householders bring the cooking oil and fat waste in commonly available (mostly plastic) bottles. Also, the collection frequency should reflect the special physical properties of this type of waste (Stoll and Gupta 1997). The cooking oil and fat waste production amounts are not comparable with other waste fractions. The Czech Statistical Office (2018) reported these amounts are around 27 kg/cap/y given the Czech consumer basket, but the real potential for separate collection is uncertain. The current rates of cooking oil and fat waste recycling are still very low. Production and recycling forecasts are needed in order to address the sustainability of the planned network (Montecinos et al. 2018). Matusinec et al. (2020) report that the production of around 4.5 kt/y of this waste is anticipated by 2025 in the Czech Republic.

This paper aims to propose a general approach to the optimal and sustainable collection infrastructure planning for cooking oil and fat waste. The formulated problem is modelled as a mixed-integer linear program (MILP). The objective function minimises the number of containers and, by extension, the total cost of the collection infrastructure, while a restriction is imposed on the average walking distance to the assigned waste containers. Isolated locations with households (address points) will not affect the overall distribution of collection containers. These locations are usually omitted from the calculation, which is an inappropriate simplification. The solution to the optimisation problem then suggests the optimal layout of the waste container network. Since similar MILPs on optimal waste bins location lead to computationally complex optimisation problems (more details on the computational complexity are provided in the case example), the ultimate goal of this paper is not merely to solve the mathematical program separately for each area, but rather to identify the key properties influencing the optimal solutions for various areas. This approach can be used for planning at the regional or state level. Typical representative candidate municipalities from a sample region have to be selected based on grouping those with similar properties. The optimal layouts (container locations and allocations) are calculated for representative municipalities to transmit information to all municipalities. The total number of containers for the region is then estimated by a regression model with regard to the local conditions and parameters of individual municipalities. It is, therefore, possible to estimate budgets on territorially-larger scales to set up the collection network efficiently.

The remainder of this paper is organised as follows. Section “Literature review” provides a literature review on existing bin location and cooking oil and fat waste management problems. Section “Modelling and decision-making framework” presents the developed mathematical model for the collection networks design. This section then describes the individual characteristic features of municipalities that influence the specifics of the collection network. Given these characteristics, the cluster analysis is used to organise numerous municipalities into a manageable number of groups. In Sect. “Case example”, the suggested methodology is applied to a case example, and then, the regression analysis is used to generalise the obtained results. Finally, Sect. “Conclusions and future research” concludes the paper.

Literature review

Reverse logistics and supply chain are recognised as two environmentally friendly practices that could help in greening conventional supply chains (Kazemi et al. 2019). Reverse logistics can be defined as the process of planning, implementing and controlling backwards flows of raw materials, in-process inventory, packaging and finished goods from a manufacturing, distribution or use point to a point of recovery or proper disposal (Rubio et al. 2008). The reverse supply chain with the main actors involved in fat waste recycling is shown in Fig. 1, where the vertical tiers highlight the essential segments, namely production, discarding and collection, processing, and finally, utilisation (Matusinec et al. 2020). Each particular segment has its problems and logistic challenges specific to each part of this chain (Barbosa-Povoa et al. 2018). The main production of cooking oils and fat waste comes from food producers, households and livestock production (Tsoutsos et al. 2016). It has been revealed that the food industry, restaurants and hotels put together are the biggest source of cooking oils and fat waste; however, they are used to paying the collectors to properly dispose of their waste, including the fat waste (Emara et al. 2018). At the same time, in most households, the cooking oils are currently improperly disposed of, primarily to the sewage system, since the collection infrastructure for them is often nonexistent (Foteinis et al. 2020). However, the research (de Oliveira et al. 2014) shows that the reuse of cooking oil prevents its inappropriate disposal and brings economic yield.

This paper intends to address the first part of the overall reverse supply chain, namely collecting cooking oil and fat waste produced by households, as illustrated in Fig. 1, and, specifically, planning the appropriate collection infrastructure.

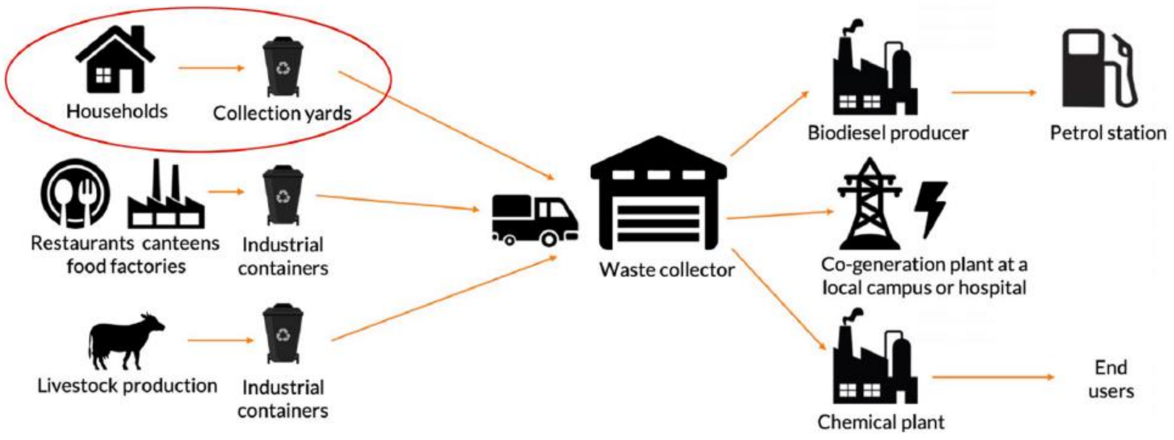


Fig. 1 An example of a typical reverse supply chain covering cooking oils and fats waste management

A literature review in this section focuses on particular parts of the chain. The purpose of this review is to critically evaluate the existing research and reveal a research gap in the area of infrastructure planning for fat waste and cooking oil collection.

Cooking oil and fat waste production

According to the statistics provided by Greenea (2016), the total amount of generated waste cooking oils in the EU was about 1.6 Mt in 2016 (1.9 kg/cap). Out of the total amount, 854 kt came from households and 806 kt came from the industrial sector. The recovery rate was only about 5.6% for household waste and 86% for the business sector (Goh et al. 2020). The available statistical estimations coming from different resources on the waste fat production often vary, e.g. refer to (Mannu et al. 2018). The amount of produced and properly recycled waste differs with regard to socio-economic factors (Martin and de Laet 2018). It has been shown that effective implementation of a collection infrastructure leads to a significant increase in the amount of waste cooking oil collected. Some EU countries, such as Belgium, Sweden, Austria and the Netherlands, have proved that household collection can be highly efficient (Goh et al. 2020). For example, in the case of Austria, the amount of collected waste cooking oils raised from 0.2 to 1 kg/cap/y (Ortner et al. 2016). Other examples of countries that already have an existing cooking oil waste collection policy are China, Japan, the USA and Brazil (Goh et al. 2020; Ruiz et al. 2017). Also, when it comes to the European Union, besides the countries mentioned earlier, the examples are Portugal, Spain, and Croatia (Goh et al. 2020; Ribic et al. 2017).

As a significant portion of the used cooking fats is absorbed and remains in the consumed food, it is further expected that only one-third of the estimated amount would be possible to separate and collect. This paper follows the previous research conducted by Matusinec et al. (2020), where some initial results of selected forecasting methods (Pavlas et al. 2017) are provided. The authors show that a sizable growth in the production and separation of this kind of waste can be anticipated in the near future. The forecasting conducted for the Czech Republic's regions shows that by 2025 the production of at least 4.5 kt/y of this waste is anticipated in the entire country (Matusinec et al. 2020). Compared to Austria (Ortner et al. 2016) with 10.5 kg/cap, it is less than half, so it can be expected that the separate collection amounts will further increase. The suggested forecasting, of course, has certain drawbacks that should further be addressed. More accurate estimates could be produced if more details on the possibilities and capacities for the separation would be accounted for. It may also be possible to address the credibility of the estimates for certain territories by introducing the appropriate weights, as well as addressing the differences between the regions and micro-regions.

Discarding and collection

Fat waste collection networks established in various cities have proved beneficial, and the authorities have eventually sought to expand these networks as the separated and recycled amounts have grown (Ortner et al. 2016). Compared to the collection networks for general waste, glass and plastic, the collection networks for fat waste are quite sparse, which brings challenges to the network design associated with this recycling. Some network layout issues may also arise from insufficient competence of the civil servants responsible for the matters of waste management.

The use of optimisation approaches for planning waste collection infrastructures proves beneficial, as they allow addressing and balancing multiple aspects of the problem context. For instance, the suitable location of waste collection points can significantly affect the waste collection cost and servicing time, as well as the purchase cost of bins (Nevrly et al. 2021). The use of optimisation modelling, however, often leads to computational complexities (Jia et al. 2020). Nevertheless, these complexities may be addressed by means of certain techniques (Alizadeh et al. 2020). Problems combining the decisions on location (where to locate) and allocation (size and number of bins to locate) are often referred to as location-allocation problems. Typical location-allocation models for waste containers turn out to be mixed-integer linear programs (MILP) (Ghiani et al. 2012).

The issue of integrating various decisions within an existing collection network is often addressed, while the problem context implies that the network is being expanded. Hem-melmayr et al. (2014) integrate the routing of waste collection vehicles and the allocation of waste bins to the sites. The authors solve the routing part with a metaheuristic algorithm (for computational reasons) and the bin allocation part as a MILP. It should be highlighted that the location problem is solved on the strategic decision-making level, while the collection routes are planned on the tactical or operational levels (Prodhon and Prins 2014). The waste collection routing problem has been applied in the cooking oil collection problem (Ramos et al. 2013). However, the location decisions are omitted in that research, as the authors address the waste collection from an existing network of restaurants, schools and canteens. As research (Gultekin et al. 2020) shows, it is reasonable to balance the issue of container placement on the municipal level and the issue of collection vehicle routing. However, given the specific nature of the recycled waste considered in this research, the focus of the container network planning is on the walking distance as this consideration can result in larger amounts of the recycled waste. Similarly, other research articles investigate other factors that should motivate people to recycle such as promotion and education about pro-environmental behaviour (Janmaimool 2017). Other mechanisms that should motivate people to both reduce the waste production and increase recycling, respectively, are the pay as you throw system, which is designed to motivate the population to reduce the production of mixed municipal waste (Nevrly et al. 2021). These strategies are becoming widely applied in solid waste management systems, especially in the USA and in the EU (Elia et al. 2015).

Promoting waste separation, especially in developing countries, necessarily requires building new infrastructure. Thus, for the research presented here, the work done by Rousta et al. (2015) appears of particular importance. The authors study the impact of walking distance to the nearest waste container on the willingness to recycle. This aspect is extremely important for the cooking oil and fats collection infrastructure planning. The researchers Nevrly et al. (2021) extend existing waste container location models by adding an objective capturing the walking distance to their MILP. It is possible to maximise the volumes of the recycled fat waste and at the same time reduce collection and handling costs by means of optimisation modelling when the collection network is designed (Ramos et al. 2013). Also, given the supply chain presented in Fig. 1, it is apparent that the appropriate layout of the collection network is an important issue for waste-processing companies when they design and establish their facilities and plan their processing capacities (Zhang and Jiang 2017).

Planning at the regional (or even state) level is problematic because the territorial division contains a huge number of municipalities (e.g. the Zlfn Region comprised 307 municipalities in 2020). A comprehensive view precludes addressing all municipalities independently. It is advisable to find general dependencies and create a mathematical model based on them. It would be possible to aggregate values for the whole monitored area.

Processing and utilisation

As mentioned earlier, the traditional way of discarding the fat waste for quite a while has been to pour it into the drainage (Asri et al. 2015). This approach often results in clogging the sewage (Husain et al. 2014). On the other hand, if utilised properly, this waste can be quite valuable in terms of power generation (Matusinec et al. 2020). Even if the production of this waste seems to be negligible, due to its chemical properties it may present a significant source for valorisation from the overall circular economy perspective, as discussed in (Giuliano et al. 2019). When properly recycled, this waste can be processed for use in resins for paints and varnishes, detergents, soaps, fabric softeners, soaps, pet feed, glycerin, lubricants for engines and biodiesel (de Oliveira et al. 2014). Among the waste-to-energy applications, one may think of the use of oil and fat waste as a fuel for combined heat and power plants after undergoing some preliminary processing as more sources are continually being sought for meeting the growing planetary demands (Arodudu et al. 2020). This waste is as fuel without additional processing at some facilities such as farm biogas plants (Ortner et al. 2016). The use of edible vegetable oils and animal fats for biodiesel production has traditionally been of high concern (Girotto et al. 2015). There have been certain technological developments aiming to facilitate biodiesel production from the fat waste (Sodhi et al. 2017) as this type of fuel is naturally derived from vegetable oil and animal fat hydrocarbons (Enweremadu and Mbarawa 2009). The two technologies, namely transesterification (Panadare and Rathod 2015) and hydrotreatment (Mayorga et al. 2019), are recognised for their capability for processing fat waste into biofuels. However, in these processes, waste cooking oil quality plays an important role (Chuah et al. 2017). The authors (Math et al. 2010) recall various processes and industry branches for whom the biodiesel production from the generated fat waste is relevant and appropriate. When it comes to material recovery, fat waste may be used for chemical manufacturing of polymers, surfactants, grease, and soap, among other things (Panadare and Rathod 2015). Waste cooking oil, which contains light oil components, has been proposed as a sustainable product for improving aged asphalt recycling (Zahoor et al. 2021). Last but not least, the optimal biorefinery location and operation is also a subject of studies like (Galanopoulos et al. 2020), which proposes a methodology of combining a supply chain network MILP model with a process plant simulation model developed for the optimisation of a biorefinery system in a defined area, followed by a final evaluation of economic and environmental indicators.

To sum up, there are many potential benefits that can come from recycling household cooking oil and fat waste and that have not been harvested to the fullest extent. Ultimately, to realise this potential, an appropriate waste collection and processing network needs to be designed and implemented. Therefore, this paper focuses on developing a relevant optimisation model for fat and cooking oil waste collection infrastructure planning. The authors further attempt to tackle the economic issues related to the strategic decisions on such infrastructure planning.

Modelling and decision-making framework

With respect to the computational complexity of the optimisation problem of waste containers location and address-to-collection point allocation, it is reasonable to have a high-quality primary estimation of the municipality collection infrastructure in its first phase (Sect. "Decision-making model for the collection network design"). Specifically, it concerns the estimation of the number of containers, their size/capacity and utilisation, and it is reasonable to develop a general decision-making model that will be able to estimate these parameters with sufficient accuracy for the selected municipalities. The selection of representative municipalities for further analysis on the larger scale is then described Sect. "Cluster analysis".

Decision-making model for the collection network design

The goal of the proposed mathematical model is to find the optimal placement of cooking oil and fat waste containers in the given municipalities. The notation of used symbols is in Table 1. The network of containers should consist of as few containers as possible, while the walking distance of citizen towards the container is as short as possible.

The proposed optimisation model includes two criteria. The first is modelled as the objective function, which minimises the total number of collection points (1)-(2). Every citizen of the municipality (respective address) is assigned to the nearest collection point to determine the total number of containers, the container size and the walking distance towards an assigned collection point.

$\min z_1$ (1)

The second criterion is implemented in the form of constraints, which limit the average walking distance within the municipality (3)-(4). As mentioned, if the walking distance is too long, the motivation for recycling decreases. Shortening these distances should result in larger amounts of recycled fat waste. Once the optimal number of collection points is first found, the best possible average walking distance is searched with the fixed locations of bins. This constraint (4) can be relaxed by setting the limit very high. The model incorporates several other constraints to ensure reasonable results. The capacity of the collection network must cover the total production of fat waste which is represented by constraints (5). Constraints (6) serve to distribute the waste collection evenly between collection points. Constraints (7) represent a calculation of the collection load for each point. Finally, constraints (8)—(10) describe the variable domains.

$$z_1 = \sum_{a \in A} \delta_a \tag{2}$$

$$z_2 = \frac{\sum_{a \in A} p_a \sum_{j \in J} x_j d_j M_{out(j,a)}}{\sum_{a \in A} p_a} \tag{3}$$

$$z_2 \leq w_{max} \tag{4}$$

$$q_a \leq \delta_a c_a \quad \forall a \in A, \tag{5}$$

$$y_a + \sum_{j \in J} x_j M_{out(j,a)} = 1 \quad \forall a \in A, \tag{6}$$

$$q_a = p_a y_a + \sum_{j \in J} \sum_{b \in A} p_b x_j M_{out(j,b)} (-M_{in(j,a)}) \quad \forall a \in A, \tag{7}$$

$$x_j \geq 0 \quad \forall j \in J, \tag{8}$$

$$y_a, q_a \geq 0 \quad \forall a \in A, \tag{9}$$

$$\delta_a \in \{0,1\} \quad \forall a \in A. \tag{10}$$

Cluster analysis

Particular municipalities may differ significantly from each other. This heterogeneity is then reflected in the varying needs in terms of collection infrastructure from the viewpoint of the necessary services that collect the waste produced by the citizens. The goal is to ensure the proper waste separation as a basis to meet the obligations related to the Circular Economy Package. It is necessary to equip the municipality infrastructure with the needed number of collection bins and containers given the number of collected waste fractions and the respective amounts. It is necessary to ensure the availability of collection points and the relatively small walking distance to them (Nevrly et al. 2021) to make the waste separation effective for the citizens. It is also necessary to reasonably allocate the collection capacities so that the infrastructure reflects the character of a given municipality. The following text is dedicated to the approach of cluster analysis, which is used to select representative municipalities for calculations.

Selecting merely a few representative municipalities in a given region has to be made due to the considerable computational difficulty in decision-making on the required number of containers and the collection network layout. The cluster analysis is applied to select the representatives. The results for the selected municipalities are further be used to compile a regression model that defines the expected number of containers in any municipality in a given region. The municipalities in the area are grouped into several clusters based on the following factors to determine the reasonable number of fat waste collection containers:

- population,
- the population density in a built-up area,
- the population density in the whole area of a municipality,
- the average population per address point,
- share of occupied dwellings in family houses from the total,
- commuting to work into the municipality,
- commuting for work outside the municipality
- total number of collective accommodation establishments,
- number of unoccupied dwellings used for recreation,
- central heating connection,
- production of separately collected plastic waste,
- production of separately collected paper waste,
- production of separately collected glass waste,
- production of separately collected bio-waste,
- production of mixed municipal waste.

These factors have been selected as essential by the authors based on their experience and several studies in the field of waste management. A comprehensive review of the modelling of waste generation has been the source for the most influential factors (Beigl et al. 2008). The sociodemographic parameters specific to the Czech Republic (Rybova et al. 2018) are also adopted here. David et al. (2020) link the income, household size and environmental concern with the waste quantity produced. Household type and size are identified as influential in the demand for waste collecting services (Ghorbani et al. 2007). The study (Triguero et al. 2016) analyses the willingness to accept different waste management policies on the country level in the EU. Some socio-demographic characteristics and rural/urban living have an impact on the perception of individuals and their participation in recycling; however, these things differ in different countries. Bach et al. (2004) are looking for the relationship between the demographic parameters and the amount of collected waste paper. The significant impact is revealed for such indicators as the number of overnight stays per person, income indices, the employment structure and the household structure of municipalities. The mentioned studies consider various parameters and factors, but they are not always entirely revealed to the reader.

In the following analysis, the correctness of the factor will be verified, and the significant ones will be used for regression analysis. The selection of significant factors is one of the outputs of this study. Individual factors have to be normalised for the cluster analysis, and some have to be transformed given the nature of the data distribution. A two-phase clustering procedure has been used to ultimately form the clusters. In the first phase, the municipalities, which in some respects show an extreme character, are removed. Further groups are created based

on the cumulative population in municipalities, while the list of municipalities is ordered by population size. Subsequently, an iterative k-means algorithm is applied to form the required number of clusters. The sum of absolute deviations between the individual factors has been used as the distance metric between data for each pair of municipalities.

Case example

The Czech Republic has been selected for some case examples for this research. The country comprises over 6,000 municipalities, which involve large cities as well as very small villages of hundreds and even tens of inhabitants. The Czech Republic is contextually suitable for the studied problem, given its current state of waste management (not suitable cooking waste infrastructure). Within the European Union, it belongs to a group of countries that have already developed a collection network for recycling municipal solid waste while still setting up the collection of some new waste fractions. For these reasons, further significant modernisation of the existing waste management infrastructures towards a substantially more effective circular economy is highly expected. The Czech Republic consists of 14 regions. A comprehensive solution for the whole country would demand high-quality stratification and many calculations for the representative municipalities. The authors suggest choosing a reasonable regional perspective. With regard to the similarity of regions, the results should be applicable to other regions. The Zlfn Region is selected for the case example in this research.

First, cluster analysis has been used to group similar municipalities. Clustering has been run in two steps, with extreme values being removed first—these were small municipalities that have low waste production but could affect the results. Afterwards, the municipalities have been divided according to the number of inhabitants so that three groups would be created. Waste quantity is the most influential factor from the collection infrastructure point of view. The selected number of clusters corresponds to the variability of the factors in the region. These three groups have been further divided into a total of eight clusters. This approach creates a grouping of the municipalities in the region, which differ significantly in terms of the selected factors. From each cluster, two representatives which best describe the cluster are then selected (in terms of the minimum total distance from all other municipalities in the cluster). The selected municipalities and other parameters are provided further in the next section.

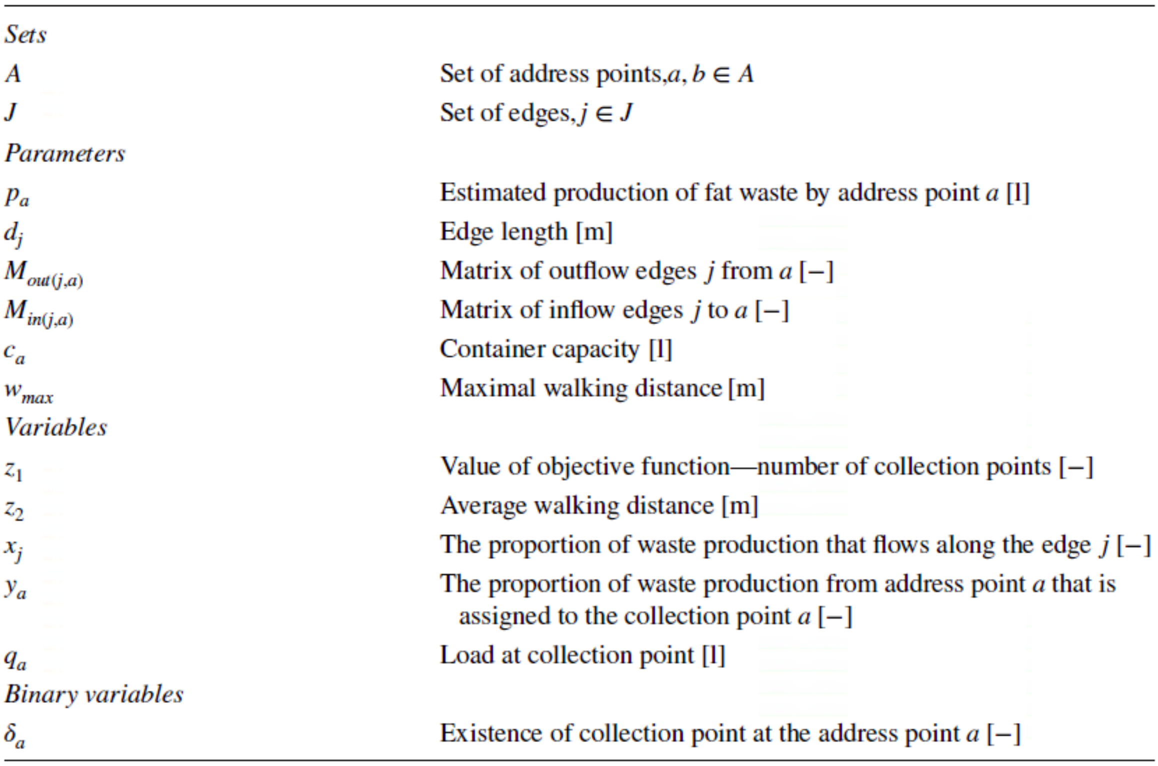
Container allocation model

As part of data pre-processing, one of the tasks has been to select the potential container locations. Also, to reduce the computational complexity of the examples, the total number of potential locations needs to be somewhat limited. Compared to the total number of address points, only 20% of these nodes entered the model as potential collection points. The collection points have been randomly selected, which does not guarantee the achievement of a global optimum. However, the testing has shown merely a few % error rate. This issue is one of the problematic areas of the presented research, and so, more attention should be paid to it in further research. The authors propose a further division of a municipality into separate sub-areas with minimal impact on the overall quality of the solution.

In the Czech Republic, the most used types of recycling street containers have a volume of either 120 L or 240 L. The smaller volume of 120 L can be more suitable for less inhabited areas; on the other hand, for locations that are densely inhabited, the volume of 240 L can be more efficient for cooking oil and fat waste collection. Due to the more common use of 240 L containers, the model has been run using only them. However, where the utilisation is lower than 50%, these containers can be replaced by smaller containers of 120 L volume. As fat waste is not discarded as frequently as other types of waste, the longer maximal walking distance should be allowed compared to, for example, the distance towards plastic waste containers (Matusinec et al. 2020).

The proposed model has been implemented in the GAMS software (but any mathematical programming environment can be used), where it has been solved for each municipality using the CPLEX solver.

Table 1 Notation of the model



Sets	
A	Set of address points, $a, b \in A$
J	Set of edges, $j \in J$
Parameters	
p_a	Estimated production of fat waste by address point a [l]
d_j	Edge length [m]
$M_{out(j,a)}$	Matrix of outflow edges j from a [−]
$M_{in(j,a)}$	Matrix of inflow edges j to a [−]
c_a	Container capacity [l]
w_{max}	Maximal walking distance [m]
Variables	
z_1	Value of objective function—number of collection points [−]
z_2	Average walking distance [m]
x_j	The proportion of waste production that flows along the edge j [−]
y_a	The proportion of waste production from address point a that is assigned to the collection point a [−]
q_a	Load at collection point [l]
Binary variables	
δ_a	Existence of collection point at the address point a [−]

The maximum number of containers has been set extremely high, and the maximum walking distance has been set to 500 m, while the container capacity has been counted as 240 L. The computational results for the selected representative municipalities are reported in Table 2. The computational time depends mainly on the specific character of the municipality, where the proximity of alternative solutions prolongs finding the optimum. The number of address points (population size) also plays an important role. However, the required time cannot be well estimated before the calculation.

Due to the pre-processing of the number of address points described earlier, the location of containers in the Brumov-Bylnice municipality has been calculated only for the larger part of the city. This municipality consists of four units, namely parts of Brumov, Bylnice, Svaty Stepan and Sidonie. For the former two, the application of the modelling approach is possible with the mentioned pre-processing. However, it was not possible for the remaining two smaller parts of the municipality. To address this issue, one container had to be manually added to each Svaty Stepan and Sidonie. Container locations are visualised using the container coordinates for two examples, a small-size municipality (Fig. 2) and a middle-size municipality (Fig. 3). Among the marked pinpoints in Fig. 3 (the chosen container locations), one may observe that some containers are close to each other. It is attributed to the dense construction of a block of flats in certain areas of the considered municipality. For this situation, it could be appropriate to allocate only one larger container to serve this entire area.

Table 2 Numerical results for the 16 representative municipalities selected from the Zlin region

Municipality	Number of containers	Average walking distance [m]	Population	Population density [per km^2]	Computational time [s]
Bánov	2	434	2106	132	1.08
Brumov-Bylnice	4+2	482	5528	98	3.28
Bystřice pod Lopeníkem	2	413	806	59	8.02
Hluk	4	421	4372	155	46.13
Holešov	7	297	11,579	341	33.45
Jablůnka	2	373	2056	251	1.03
Kelč	2	384	2706	97	0.66
Koryčany	2	362	2751	67	1.16
Kroměříž	20	345	28,620	561	1,236.73
Ludkovice	1	491	716	60	0.22
Napajedla	6	300	7171	362	38.16
Osvětimany	1	482	882	45	0.30
Rožnov pod Radhoštěm	13	401	16,398	415	1,103.67
Uherské Hradiště	11	340	25,247	1188	22.08
Valašské Klobouky	4	334	4946	184	24.36
Vlčnov	3	470	2999	141	36.03

Fig. 2 Visualisation of container infrastructure (small-size municipality: Jablunka)

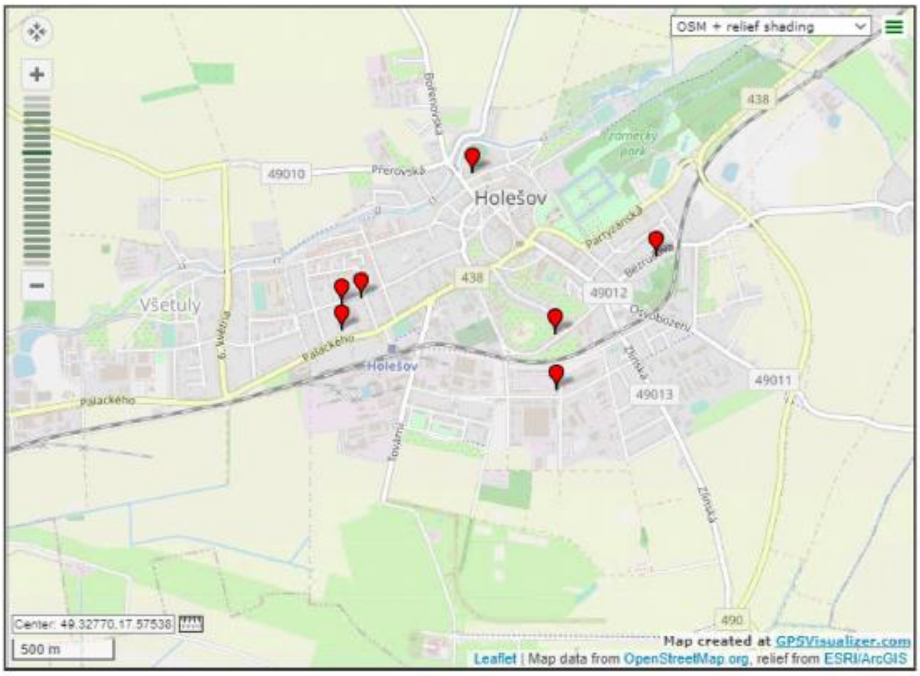


Fig. 3 Visualisation of container infrastructure (middle-size municipality: Holesov)

Regression model

The regression analysis aims to explain the required number of fat waste collection containers and the average walking distance from address points to collection points given certain characteristic attributes of the municipalities. The regression model processes the optimisation results (MILP model). This approach is an acceptable generalisation of the network planning model's results so that the optimisation would not need to be run for all the municipalities as there are about 300 municipalities in the Zlfn Region. The regression analysis has used the same factors as the cluster analysis in Sect. "Literature review". The criteria have been defined by a mathematical model in Sect. "Modelling and decision-making framework". Based on the Spearman rank-order correlation coefficient, six significant factors have been selected for the final regression model: population (x_1); population density in the built-up areas (x_2); average population per address point (x_3); the number of unoccupied dwellings used for recreation (x_4); the number of commuters outside the municipality (work, school) (x_5); and a square of the previous variable (it is normalised per thousand of the population) ($x_6 = x_5^2$).

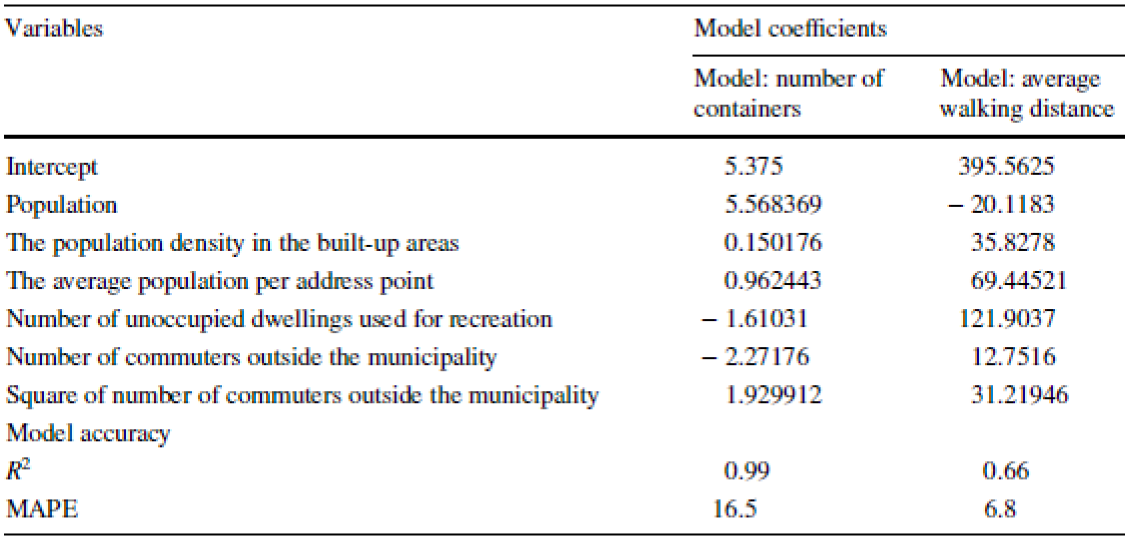
With respect to the properties of the data, the z-trans-form (in terms of regression analysis transformation) has been performed, and subsequently, the data have been processed using the Principal Component Analysis due to the issue of multicollinearity. Ultimately, the resulting model is based on a classical linear regression. A model based on gamma regression was also tested; however, it was not selected for further analysis due to certain diagnostic problems. The feature selection has been applied by backward elimination of insignificant predictors. That is, the complete model with the entire array of predictor variables is first considered, and then, insignificant predictors are gradually removed. Other methods of feature selection and addressing the predictor importance (such as LASSO regression) have also been tested, but their results were unsatisfactory from a diagnostic viewpoint. The final results of the analysis have then been transformed back into basic variable form. The form of the regression equation ultimately produced is given in (12).

$$y = x_1 + x_2 + x_3 + \frac{1}{x_4} + \frac{1}{x_5} + \frac{1}{x_6} \quad (12)$$

Here, the dependent variable y denotes is the estimated value for the two models: the number of containers and the average walking distance. The parameters of the two models are shown in Table 3.

The population of the Zlin Region is approximately 583 thousand. When the regression model for the number of containers is applied for the whole region, it results in 609 containers in total. However, the regression analysis results had to be adapted in terms of some negative values, which have to be set to zero. Additional adjustments have been made to round the value to integers. On average, there are about 957 inhabitants per collection container. The average walking distance usually ranges from 300 to 400 m for municipalities in the region. The purchase price of one 240 L container is around EUR 50 (Czech Republic), so the total investment in infrastructure in the region is approximately EUR 30,000.

Table 3 Results of regression analysis



Variables	Model coefficients	
	Model: number of containers	Model: average walking distance
Intercept	5.375	395.5625
Population	5.568369	– 20.1183
The population density in the built-up areas	0.150176	35.8278
The average population per address point	0.962443	69.44521
Number of unoccupied dwellings used for recreation	– 1.61031	121.9037
Number of commuters outside the municipality	– 2.27176	12.7516
Square of number of commuters outside the municipality	1.929912	31.21946
Model accuracy		
R^2	0.99	0.66
MAPE	16.5	6.8

The MAPE of a given model for the number of containers is significantly increased for smaller municipalities, where a few pieces of containers represent a significant error

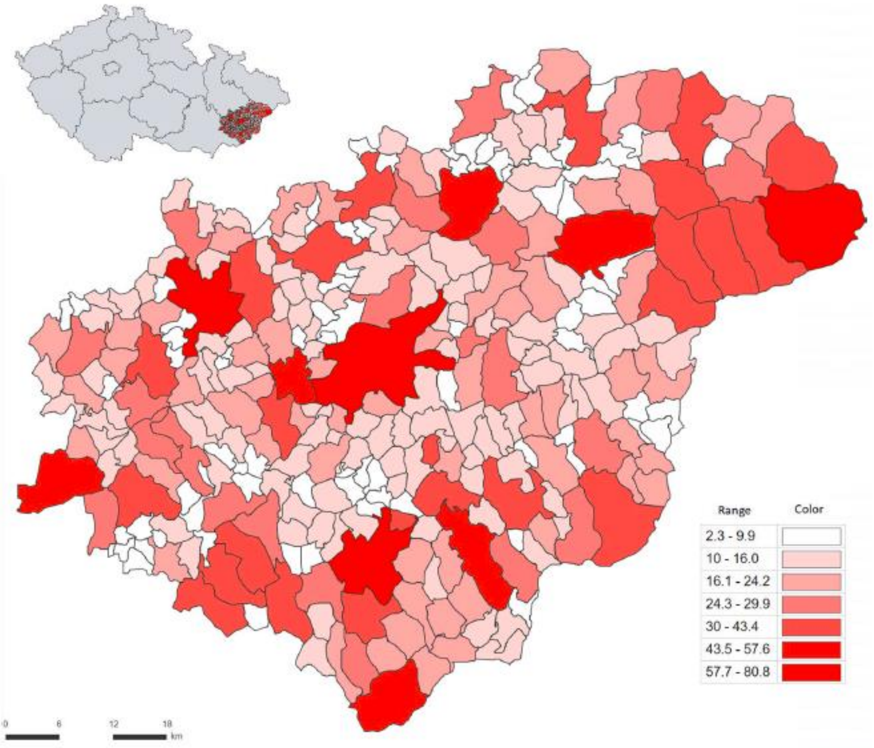


Fig. 4 Map of the estimated number of containers for the whole region

However, the operational costs related to the regular collection from allocated containers are expected to exceed the mentioned purchase costs significantly. A significant shift in separation is expected in the coming years, so there will come a time to reasonably allocate additional containers to other places within the studied areas. The map in Fig. 4 shows the estimated number of containers and the frequency of collection operations for all the municipalities within the region.

Conclusions and future research

This paper has aimed to create a general modelling framework for describing the necessary collection infrastructure in various municipalities. The authors follow up on their previous research, especially (Matusinec et al. 2020), where the authors provide a literature review and identify a research gap, and (Nevrly et al. 2021), where the authors develop and apply a model with similar objectives (e.g. regarding the minimisation of the number of collection points and walking distance).

The design of collection points has been approached in a novel way by taking into account the average walking distance instead of simply enforcing a constraint on individual address points. The infrastructure will not be adapted inappropriately due to isolated living areas with low density population (insufficient waste produced for a separate container resulting in longer walking distance). As this is a conceptual change, it is appropriate to plan centrally from the perspective of the region or state. The approach shows how to determine an estimate on territorially larger scales with the help of regression analysis in combination with cluster analysis. Cluster analysis has been used to describe the variability in socio-economic features of the municipalities. The computational example has been run for a selected region of the Czech Republic—the Zlfn Region. Within each cluster, representatives have been selected. This approach has enabled the following theoretical and methodological viewpoints on the produced results:

The utilisation of a regression model created from the selected factors (independent variables) and the results for representative municipalities (dependent variable).

Use of municipality similarities within the same clusters, or, alternatively, a combination of the results for representatives from the neighbouring clusters, if the municipality of interest is not in the middle of the cluster (e.g. a weighted average according to distance from a centroid of a particular cluster).

The mentioned possibilities may be complemented with the use of different weights based on the character of a given cluster and the accuracy of the regression model. The resulting regression model describes 99% variability, so it is safe to assume that the cluster analysis has indeed been performed properly for the relevant factors. The attributes used in the cluster analysis, which then go unused in the regression analysis, have no negative impact on the results in any way. The most important factors in the developed model are population, population density in the built-up areas, the average population per address point, the number of unoccupied dwellings used for recreation and the number of commuters outside the municipality. The estimates for all the municipalities within the region suggest allocating 609 containers with 950 inhabitants per container on average. It is appropriate to plan a separate collection infrastructure to use the identified potential of cooking oil and fat to reduce environmental impact and use it efficiently for energy production. Years following the considered year will lead to other changes in the overall separation of cooking oils and fat. It could further serve as an explanatory variable in the adjusted regression analysis.

The study shows a general approach for planning the regional and state policies related to waste collection infrastructure. By means of cluster analysis, it is possible to use the approach for large areas and at the same time to ensure the description of high data variability in a reasonable computational time. The general nature of the approach enables other waste fractions to be planned similarly, which may be especially useful for new waste fractions such as textiles that are to be recycled in the EU from 2025.

While accounting for the properties of any given category of waste (especially concerning the production quantity), the decision-making on the locations for collection containers tends to focus on the specific context of that particular waste fraction. Therefore, one suggestion for further research could be to simultaneously address the collection of multiple waste types to avoid situations when the citizens must recycle different waste fractions at different locations.

References

Adeleke OJ, Ali MM (2021) An efficient model for locating solid waste collection sites in urban residential areas. Int J Prod Res 59(3):798-812. https://doi.org/10.1080/00207543.2019.1709670

Alizadeh R, Allen JK, Mistree F (2020) Managing computational complexity using surrogate models: a critical review. Res Eng Des 31:275-298. https://doi.org/10.1089/ees.2018.0366

Arodudu O, Holmatov B, Voinov A (2020) Ecological impacts and limits of biomass use: a critical review. Clean Technol Environ Policy 22:1591-1611. https://doi.org/10.1007/s10098-020-01911-1

Asri NP, Sari DAP, Poedjojono B, Suprapto S (2015) Pre-treatment of waste frying oils for biodiesel production. Mod Appl Sci 9(7):99-106. https://doi.org/10.5539/mas.v9n7p99

Bach H, Mild A, Natter M, Weber A (2004) Combining socio-demographic and logistic factors to explain the generation and collection of waste paper. Resour Conserv Recycl 41(1):65-73. https://doi.org/10.1016/j.resconrec.2003.08.004

Barbosa-Povoa AP, da Silva C, Carvalho A (2018) Opportunities and challenges in sustainable supply chain: an operations research perspective. Eur J Oper Res 268(2):399-431. https://doi.org/10.1016/j.ejor.2017.10.036

Beigl P, Lebersorger S, Salhofer S (2008) Modelling municipal solid waste generation: a review. Waste Manag 28(1):200-214. https:// doi. org/10.1016/j. was man.2006. 12.011

Bhuiya MMK, Rasul MG, Khan MMK, Ashwath N, Azad AK (2016) Prospects of 2nd generation biodiesel as a sustainable fuel—part: 1 selection of feedstocks, oil extraction techniques and conversion technologies. Renew Sustain Energy Rev 55:1109-1128. https:// doi.org/10.1016/j.rser.2015.04.163

Cho S, Kim J, Park H-C, Heo E (2015) Incentives for waste cooking oil collection in South Korea: A contingent valuation approach. Res Conserv Recycl 99:63-71

Chuah LF, Klemes JJ, Yusup S, Bokhari A, Akbar MM (2017) Influence of fatty acids in waste cooking oil for cleaner biodiesel. Clean Technol Environ Policy 19:859-868. https://doi.org/10. 1007/s 10098-016-1274-0

Czech Statistical Office, Consumer basket 2018 <www.czso.cz/csu/ czso/spotrebni_kos_archiv> Accessed 27 Jan 2021

David VE Jr, Wenchao J, Mmereki D (2020) Household solid waste management in Monrovia, Liberia: Influencing factors, characteristics, and management solutions. J Solid Waste Technol Manag 46(1):77-86. https://doi.org/10.5276/JSWTM/2020.77

de Oliveira RB, Ruiz S, da Silva MLGD, Struffaldi A, Bocatto E (2014) Environmental sustainability and reverse logistics: an analysis of the recycling networks of cooking oil waste in Sao Paulo, Brazil. In: 2014 Proceedings of PICMET ’14: infrastructure and service integration, pp 2756-2763.

Elia V, Gnoni MG, Tornese F (2015) Designing Pay-As-You-Throw schemes in municipal waste management services: a holistic approach. Waste Manag 44:188-195. https://doi.org/10.1016/). wasman.2015.07.040

Emara IA, Gadalla MA, Ashour FH (2018) Supply chain design network model for biofuels and chemicals from waste cooking oil. Chem Eng Trans 70:433-438. https://doi.org/10.3303/CET18 70073

Enweremadu CC, Mbarawa MM (2009) Technical aspects of production and analysis of biodiesel from used cooking oil—a review. Renew Sustain Energy Rev 13(9):2205-2224. https://doi.org/10.1016/j.rser.2009.06.007

Foteinis S, Chatzisymeon E, Litinas A, Tsoutsos T (2020) Used-cooking-oil biodiesel: life cycle assessment and comparison with first-and third-generation biofuel. Renew Energy 153:588-600. https:// doi.org/10.1016/j.renene.2020.02.022

Fan YV, Klemes JJ, Walmsley TG, Bertok B (2020) Implementing circular economy in municipal solid waste treatment system using P-graph. Sci Total Environ 701:134652. https://doi.org/10.1016/]. scitotenv.2019.134652

Galanopoulos C, Giuliano A, Barletta D, Zondervan E (2020) An integrated methodology for the economic and environmental assessment of a biorefinery supply chain. Chem Eng Res Des 160:199-215. https://doi.org/10.1016/jxherd.2020.05.016

Ghiani G, Lagana D, Manni E, Toraldo M (2012) Capacitated location of collection sites in an urban waste management system. Waste Manag 32(7):1291-1296. https://doi.org/10.1016/jrwasman.2012.02.009

Ghorbani M, Liaghati H, Mahmoudi H (2007) Household waste management in Mashad: characteristics and factors influencing on demand for collecting services. Pak J Biol Sci 10(21):3952-3955. https://doi.org/10.3923/pjbs.2007.3952.3955

Girotto F, Alibardi L, Cossu R (2015) Food waste generation and industrial uses: a review. Waste Manag 45:32-41. https://doi.org/10. 1016/j. wasman.2015.06.008

Giuliano A, De Bari I, Motola V, Pierro N, Giocoli A, Barletta D (2019) Techno-environmental assessment of two biorefinery systems to valorize the residual lignocellulosic biomass of the Basilicata region. Math Model Eng Probl 6(3):317-323. https:// doi.org/10.18280/mmep.060301

Goh BHH, Chong CT, Ge Y, Ong HC, Ng J-H, Tian B, Ashokkumar V, Lim S, Seljak T, Jozsa V (2020) Progress in utilisation of waste cooking oil for sustainable biodiesel and biojet fuel production. Energy Convers Manag 223:113296. https://doi.org/10.1016/j. enconman.2020.113296

Greenea (2016) Analysis of the current development of household UCO collection systems in the EU. https://theicct.org/sites/ default/files/publications/Greenea%20Report%20Household%20UCO%20Collection%20in%20the%20EU_ICCT_20160629. pdf. Accessed 27 Jan 2021

Gultekin C, Olmez AB, Balcik B, Ekici A, Ozener OO (2020) A decomposition-based heuristic for a waste cooking oil collection problem. In: Derbel H et al (eds) Green transportation and new advances in vehicle routing problems. Springer, Switzerland, pp 159-176. https://doi.org/10.1007/978-3-030-45312-1_6

Hemmelmayr V, Doerner KF, Hartl RF, Vigo D (2014) Models and algorithms for the integrated planning of bin allocation and vehicle routing in solid waste management. Transp Sci 48(1):103-120. https://doi.org/10.1287/trsc.2013.0459

Husain IAF, Alkhatib MF, Jammi MS, Mirghani MES, Zainudin ZB, Hoda A (2014) Problems, control, and treatment of fat, oil, and grease (FOG): a review. J Oleo Sci 63(8):747-752. https://doi.org/10.5650/jos.ess13182

Janmaimool P (2017) Application of protection motivation theory to investigate sustainable waste management behaviors. Sustainability 9(7):1079. https://doi.org/10.3390/su9071079

Jia L, Alizadeh R, Hao J, Wang G, Allen JK, Mistree F (2020) A rulebased method for automated surrogate model selection. Adv Eng Inform 45:101123. https://doi.org/10.1016/j.aei.2020.101123

Kazemi N, Modak NM, Govindan K (2019) A review of reverse logistics and closed loop supply chain management studies published in IJPR: a bibliometric and content analysis. Int J Prod Res 57(15–16):4937–4960. https://doi.org/10.1080/00207543.2018.1471244

Mannu A, Petretto G, Garroni S, Sireus V, Vlahopoulou G, Mulas G(2018) Bentonite as a refning agent in waste cooking oils recycling: fash point, density and color evaluation. Nat Prod Commun 13:613–616. https://doi.org/10.1177/1934578X1801300523

Martín RI, de Laet M (2018) Geographies of fat waste. Or, how kitchen fats make citizens. Sociol Rev 66(3):700–717. https://doi.org/10.1177/0038026117726731

Math MC, Kumar SP, Chetty SV (2010) Technologies for biodiesel production from used cooking oil—a review. Energy Sustain Dev 14(4):339–345. https://doi.org/10.1016/j.esd.2010.08.001

Matušinec J, Hrabec D, Šomplák R, Nevrlý V, Pecha J, Smejkalová V, Redutskiy Y (2020) Cooking oil and fat waste management: a review of the current state. Chem Eng Trans 81:763–768. https://doi.org/10.3303/CET2081128

Mayorga M, Cadavid J, Martinez J, Rodriguez L, Trujillo CA, Lopez M, Bonilla J, Lopez C (2019) Evaluation of zeolite-based catalyst supports for the production of biokerosene by hydrotreating of oils. Chem Eng Trans 74:13–18. https://doi.org/10.3303/CET1974003

Montecinos J, Ouhimmou M, Chauhan S, Paquet M (2018) Forecasting multiple waste collecting sites for the agro-food industry. J Clean Prod 187:932–939. https://doi.org/10.1016/j.jclepro.2018.03.127

Nevrlý V, Šomplák R, Smejkalová V, Lipovský T, Jadrný J (2021) Location of municipal waste containers: trade-of between criteria. J Clean Prod 278:123445. https://doi.org/10.1016/j.jclepro.2020.123445

Nugroho YK, Zhu L (2019) Platforms planning and process optimisation for biofuels supply chain. Renew Energy 140:563–579. https://doi.org/10.1016/j.renene.2019.03.072

Ortner ME, Müller W, Schneider I, Bockreis A (2016) Environmental assessment of three diferent utilisation paths of waste cooking oil from households. Resour Conserv Recycl 106:59–67. https://doi. org/10.1016/j.resconrec.2015.11.007

Panadare DC, Rathod VK (2015) Applications of waste cooking oil other than biodiesel: a review. Iran J Chem Eng 12(3):55–76

Pavlas M, Šomplák R, Smejkalová V, Nevrlý V, Zavíralová L, Kůdela J, Popela P (2017) Spatially distributed production data for supply chain models—forecasting with hazardous waste. J Clean Prod 161:1317–1328. https://doi.org/10.1016/j.jclepro.2017.06.107

Prodhon C, Prins C (2014) A survey of recent research on locationrouting problems. Eur J Oper Res 238(1):1–17. https://doi.org/10. 1016/j.ejor.2014.01.005

Ramos TRP, Gomes MI, Barbosa-Póvoa AP (2013) Planning waste cooking oil collection systems. Waste Manag 33(8):1691–1703.https://doi.org/10.1016/j.wasman.2013.04.005

Ribic B, Voca N, Ilakovac B (2017) Concept of sustainable waste management in the City of Zagreb: towards the implementation of circular economy approach. J Air Waste Manag Assoc 67(2):241–259. https://doi.org/10.1080/10962247.2016.1229700

Rousta K, Bolton K, Lundin M, Dahlén L (2015) Quantitative assessment of distance to collection point and improved sorting information on source separation of household waste. Waste Manag 40:22–30. https://doi.org/10.1016/j.wasman.2015.03.005

Rubio S, Chamorro A, Miranda FJ (2008) Characteristics of the research on reverse logistics (1995–2005). Int J Prod Res 46(4):1099–1120. https://doi.org/10.1080/00207540600943977

Ruiz MS, de Oliveira RB, Strufaldi A, da Silva MLGD (2017) Cooking oil waste recycling experiences worldwide: a preliminary analysis of the emerging networks in the São Paulo Metropolitan Region, Brazil. Int J Energy Technol Policy 13(3):189–206. https://doi.org/10.1504/IJETP.2017.084490

Rybová K, Slavík J, Burcin B, Soukopová J, Kučera T, Černíková A (2018) Socio-demographic determinants of municipal waste generation: case study of the Czech Republic. J Mater Cycles Waste Manag 20(3):1884–1891. https://doi.org/10.1007/s10163-018-0734-5

Sodhi AK, Tripathi S, Kundu K (2017) Biodiesel production using waste cooking oil: a waste to energy conversion strategy. Clean Technol Environ Policy 19:1799–1807. https://doi.org/10.1007/s10098-017-1357-6

Stoll U, Gupta H (1997) Management strategies for oil and grease residues. Waste Manag Res 15(1):23–32. https://doi.org/10.1006/wmre.1996.0062

Triguero A, Álvarez-Aledo C, Cuerva MC (2016) Factors infuencing willingness to accept diferent waste management policies: empirical evidence from the European Union. J Clean Prod 138:38–46. https://doi.org/10.1016/j.jclepro.2016.05.119

Tsoutsos TD, Tournaki S, Paraíba O, Kaminaris SD (2016) The used cooking oil-to-biodiesel chain in Europe assessment of best practices and environmental performance. Renew Sustain Energy Rev 54:74–83. https://doi.org/10.1016/j.rser.2015.09.039

Zahoor M, Nizamuddin S, Madapusi S, Giustozzi F (2021) Sustainable asphalt rejuvenation using waste cooking oil: a comprehensive review. J Clean Prod 278:123304. https://doi.org/10.1016/j.jclepro.2020.123304

Zhang Y, Jiang Y (2017) Robust optimisation on sustainable biodiesel supply chain produced from waste cooking oil under price uncertainty. Waste Manag 60:329–339. https://doi.org/10.1016/j.wasman.2016.11.004

Zhao Y, Wang C, Zhang L, Chang Y, Hao Y (2021) Converting waste cooking oil to biodiesel in China: environmental impacts and economic feasibility. Renew Sustain Energy Rev 140:110661. https://doi.org/10.1016/j.rser.2020.110661

Zheng T, Wang B, Rajaeifar A, Heidrich O, Zheng J, Liang Y, Zhang H (2020) How government policies can make waste cooking oilto-biodiesel supply chains more efcient and sustainable. J Clean Prod 263:121494. https://doi.org/10.1016/j.jclepro.2020.121494