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Waste Collection in Low-density Areas and Air Pollutants Formed in the Process

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Abstract. The particular problems waste collection in low-density areas include the long travel distances required together with the small amount of waste that can be collected during a long journey. The current research investigates the amount of air pollutants (CO_2, CO, HC, NO_x and PM) formed in low-density areas when the current waste collection system is applied, and it proposes options for the minimisation of pollutant emissions. The calculation of air pollutants was carried out according to the amount of burnt fuel. There are no requirements for waste truck emission levels in low-density areas. Emissions could be reduced if there were requirements to use at least EURO III trucks or trucks that comply with higher standards. The optimisation of discharge frequency needs to be dealt with. Emptying containers should be carried out at the same time and in the same collecting area. If different waste types are collected according to the door-to-door system, trucks that can collect different waste types simultaneously should be used. The quantity of emissions could be reduced by replacing the door-to-door system by a waste collection point in a village or a waste station in a municipality centre.

Keywords: waste collection, low-density areas, door-to-door collection, air pollutants.

Conference topic: Environmental protection.

Introduction

Waste collection systems have been implemented throughout the world. In developing countries, this is mostly done by manual labour and, in most cases, the waste is transported to landfills (Amponsah, Salhi 2004: 711–721). In developed countries, a variety of waste streams are collected in order to send materials to processing (Dahlén *et al.* 2007: 1298–1305).

Waste collection and transport is one of the biggest cost items in terms of solid waste management (Greco *et al.* 2014: 364–371; D'Onza *et al.* 2016: 59–65; Johansson 2006: 875–885; Tavares *et al.* 2009: 1176–1185) therefore, it is extremely important to optimise this activity (Vilms *et al.* 2015).

The optimisation of waste transportation that reduces collection costs (Faccio *et al.* 2011: 2391–2405), environmentally friendly fuels that have less impact on the environment (Yang *et al.* 2015: 242–249) and modern solutions (filling-level sensor, global positioning systems) (Anghinolfi *et al.* 2013: 287–296; Faccio *et al.* 2011: 2391–2405; Johansson 2006: 875–885) provide a variety of solutions for waste collection.

The optimisation of a transport schedule is without doubt a topic that must be addressed everywhere. In most cases, the further away from densely populated areas, the more optimal the transport schedules are, particularly for reducing transportation costs. In city areas and suburban districts, there are many waste producers and thus considerably more waste to collect. Therefore, it may be more cost effective to go in the same street several times. In a free market situation, in order to achieve customer satisfaction, the waste transporter is willing to go to the waste producer when the latter so requires, not when it would be most optimal for the waste transporter.

The definition of a low-density area in the context of this article is a small village located in open land with single-family houses and farm houses. Each collection point provides little household waste and the driving distance is significant between collection points (200–1,000m or more).

The main problems with waste collection in low-density areas are the long distances and small quantity of waste collected from the waste producer. Large trucks that collect waste are a burden on roads, and exhaust emissions caused by burnt fuel on long distances pollute the environment. Diesel fuel with a combustion process that causes emissions is widely used in garbage trucks. The environmental impact is a result of both the quantity of the diesel burnt and the required level of purity established by different standards that the exhaust emissions must have. (Larsen *et al.* 2010: 744–754) Fuel consumption and the depending volumes of emissions depend on various factors, such as – collection area, driver, distance, idle run, vehicle weight, etc. (Sandhu *et al.* 2016; Farzaneh *et al.* 2014; Zsigraiova *et al.* 2013: 793–806).

While, for example, noise generated by vehicles is also a problem in big cities (Rey Gozalo *et al.* 2016: 143–147), in rural areas it is not a problem because there are fewer people and the noise generated by trucks is short-lived, lasting only as long as it takes the truck to empty the container.

Currently, household waste in Estonian low-density areas is collected by using the door-to-door collection method. In this system, the waste container is located as close as possible to the waste producer and the producer is obliged to see to it that the container is ready to be emptied at the right time (Dahlén, Lagerkvist 2010: 577–86; González-Torre *et al.* 2003: 129–138).

The door-to-door collection method has the advantage of collecting waste from each household. Thus, the material that the holder of waste sorts can be collected neatly and with little effort. However, the waste producer should have separate collecting bins for paper, bio-waste and household waste for the collection of clean sorted materials. There should be two or more cars going in each region to collect all the waste that has been collected by type. This in turn means twice or more times the load on both the environment and other aspects (road congestion, noise, fuel consumption, truck depreciation, etc.). The time spent by the worker on one ton of waste collected in low-density areas is higher than in densely populated areas because the distances are long and the quantity of waste collected from the waste producer is smaller.

There is also insufficient awareness among people about how to sort waste and why it should be done. In order to improve the results of waste sorting, it is necessary to increase people's environmental consciousness in this area. The practice of burning household waste in bonfires is widely used all over the world (Watson 2012) and unfortunately it also takes place in many low-density areas of Estonia with the purpose of getting rid of waste by way of burning it. Everything is burnt (for example, it is very common to burn old oils and various types of plastic packaging), despite the fact that the burned material may harm the environment and cause pollution. A test of burning household waste was performed in order to measure pollutant concentrations and emissions. The results showed high concentrations of carcinogenic (PCDD/F, PAH) compounds, which led to the conclusion that burning waste in open fires must be avoided because a significant amount of compounds that are directly harmful to human health is emitted into the ambient air (Maasikmets *et al.* 2016: 438–446).

The current research investigates the amount of air pollutants (CO_2, CO, HC, NO_x and PM) formed in low-density areas when the current waste collection system (door-to-door) is applied, and it proposes options for the minimisation of pollutant emissions.

Methodology

The survey was conducted in ten villages of different sizes in different regions of Estonia. The number of people of the surveyed villages was between 3 and 111. The frequency of visits of the garbage truck to the village, the length of the route in the village and the fuel consumption on the village territory were surveyed. On the basis of the obtained data, the average lengths of the route of the truck and the annual fuel consumption per village were received.

Air pollution emissions are calculated according to the amount of burnt fuel.

To calculate air pollutants, the amount of energy released in the process of burning diesel fuel is determined.

$$E(kWh) = Q\frac{kWh}{kg} \cdot N(kg), \tag{1}$$

where: Q – calorific value of diesel fuel; N – the amount of consumed fuel; E – energy.

Proceeding from the initial data, the quantity of used fuel in litres is known; equation 2 is used to determine the mass quantity of the consumed fuel.

$$\rho = \frac{m}{V} \tag{2}$$

where: ρ – fuel density; V – volume; m – molar mass.

EU Emission standards for trucks and buses (DieselNet 2016) present chemical exhaust emissions for diesel engines (CO, HC, NO_x, Particles). Having determined the energy by using equation (1), we can calculate the emission amounts formed in the process of burning the given amount of diesel fuel, according to the target in the emission standards (equation 3).

$$E_a(g) = E(kWh) \cdot E_t \frac{g}{kWh}, \tag{3}$$

where: E_a – emission amount; E – energy; E_t – emission target.

The average formula of diesel fuel $C_{12}H_{23}$ is used to determine the amount of generated CO_2.

The reaction developing in the process of burning diesel is expressed in equation 4.

$$C_{12}H_{23} + 17.75O_2 = 12CO_2 + 11.5H_2O; \tag{4}$$

$$nd = \frac{m}{M} = 4.91 mol; \quad (5)$$

$$m = nd \cdot (n \cdot M(CO_2)), \quad (6)$$

where: nd – moles of diesel fuel; M – molar mass; n – moles; m – mass.

According to equation 6, burning 1 litre diesel fuel, 2,593 kg CO_2 will be produced.

$$2.593 kgCO_2 = 4.91 mol \cdot 12 mol \cdot 44 \frac{g}{mol}.$$

Discussions

The separate collection of waste is an obligation required by legislation (Riigiteataja 2016). All waste producers must collect waste separately, regardless of whether they live in an urban area or in a low-density area.

With regard to the European Commission's initiative on Europe's transition to a circular economy (European Commission 2016), the targets for municipal waste recycling are 60% by 2025 and 65% by 2030, which is an especially big challenge for Eastern Europe. The biggest problem in Estonia is achieving the target for plastic material, which is 55% for 2025. Currently, the achieved target is approximately 29% (Keskkonnaministeerium 2016). In connection with an increase in recycling targets, waste collection and sorting, particularly in low-density areas, require optimisation and upgrading, and in the near future.

A survey carried out by the Stockholm Environment Institute Tallinn Centre (SEI Tallinn 2013) showed that the average amount of household waste generated per person in Estonia is 216 kg. A garbage truck can hold an average of 10–12 tons of waste. If on an average there are 50 inhabitants in a low-density village (Beltadze 2012), then the amount of mixed household waste collected from one village is 216 * 50 = 10.8 tons/year. Proceeding from the aforementioned calculation, it would be sufficient if one garbage truck visited the village once a year on average. However, the long term storage of mixed household waste gives rise to other problems, which are mostly caused by the degradation of bio-waste (odour, rodents, bacteria, fermentation).

If people sorted their waste properly then the amount of household waste would be relatively small. Currently, it is compulsory to collect waste separately and the local governments or producer responsibility organisations have had to create possibilities for the disposal of separately collected waste. The places meant for delivery are mostly created in the centres of urban communities or near shops – in places where people often go.

If the current door-to-door collection system was also used for collecting waste separately, the waste transporter would have to make several collection rounds. Each additional waste collection round increases the volume of air emissions. By using a multichamber truck, it would be possible to slightly reduce the volume of air emissions.

If a person living in a low-density area sorted the generated waste, the quantities of different types of waste per capita would be as shown in Table 1. The most abundant type of waste would be bio-waste. There is enough space in the vicinity of a low-density area and all the generated bio-waste should be composted there so that the waste transporter or the holder of waste would not have to collect it. Other types of waste presented in Table 1 should already now be collected separately in accordance with the legislation in force (Riigiteataja 2016) and delivered to the waste transporter through the waste collection points created for that purpose, which are mostly located in the centres of local governments or near shops.

Table 1. Waste composition of mixed household waste and the volume in litres according to the density of the type of waste (*SEI Tallinn 2013; SEI Tallinn 2008)

Type of waste	Quantity in mixed household waste kg/pers./yr*	Percent of mixed household waste*	Volume (litres)	Average density, kg/m3
Household waste	46	24	240	200
Bio-waste	69	31	210	330
Paper/cardboard	29	13	480	60
Packaging	65	29	430	150
Other (electrical and electronic, hazardous,	7	3		

If we assume that people sort the waste in accordance with the regulations, then the amount of household waste collected with the door-to-door system would be much smaller than it is now; thereby, the occurrence of air emissions would also be less. Mostly, the density of household waste varies between 87 and 348 kg/m3 (Eek 2007; Bilitewski

et al. 1997; Wrap, Futures 2010). In a low-density area, the most common container size is 240 litres. If we consider that the average density of household waste is 200 kg/m^3, then a person should empty a household waste container once a year. As an average family consists of 2.4 people (Statistikaamet 2016), then the amount of household waste is actually higher, and a 240-litre container should be emptied three times a year. If a waste collection point were set up in a village centre, one could calculate the necessary periodicity of emptying the containers in the village centre on the basis of the density data in Table 1. If 50 people live in the village and there is a waste collection point, then approximately 12,000 litres of household waste should be collected a year. The number of emptying times of the container depends on the size of the container – 4,500 l, 2,500 l, 1,500 l, 800 l would accordingly need emptying 3, 5, 8 or 15 times a year.

Larsen *et al.* 2009 in his article studied the diesel consumption in waste collection both in urban and rural areas and found that the fuel consumption ranges from 1.6 to 10.1 l diesel tonne-1 of waste and was highest for collection in areas with a low population density.

In low-density areas, most people have cars that they can use for transporting the waste to the nearest settlement or a village centre with a collection point (bring-system). In this case, a big garbage truck does not have to drive to each waste producer and it would significantly help save the costs of the waste transporter in relation to the door-do-door collection system.

The bring-system is commonly used. The system operates with different collection tanks (bins, containers, barrels, wheeled containers, roll-off containers, compactor containers, etc.) and for different types of waste (Bilitewski *et al.* 1997; Bilitewski *et al.* 2010; McLeod, Cherrett 2011). There may also be smaller waste drop-off sites or even a complete recycling centre. The efficacy of drop-off sites and kerbside bins in waste collection has been reflected in several surveys (Gallardo *et al.* 2012: 1623–1633; Teixeira *et al.* 2014: 1584–1594). Unfortunately, most of the surveys are limited to the urban environment.

In the case of the described bring-system, people bring their waste to the drop-off site in their private car (Dahlén, Lagerkvist 2010: 577–86), and, in this survey, this is considered an accompanying action to some other main activity; for example, a person goes shopping and can also visit a drop-off site on the way. It is assumed in the survey that no fuel consumption arises for the waste drop-off.

In the case of the surveyed villages, the location of a suitable central waste collection point was on average 2.5 km away from the village border and in the range of 0.5 to 3.6 km, depending on the shape and size of the village.

Table 2 shows the comparison of the volumes of air emissions arising from two different collection methods (door-to-door and drop-off site in a village), and in the case of a Euro III and Euro V compliant vehicle. The quantities of CO_2 emissions per one collection round in the case of a drop-off site would be lower by half than it is currently in force for the door-to-door collection method. By comparing the emission volumes caused by the door-to-door and a Euro III compliant vehicle, one can see that the relative importance of CO, HC, NO_x and particulates is smaller by half. In the case of a Euro V compliant vehicle, the emissions at emptying at a central drop-off site of the village would be even smaller. According to the obtained results, the creation of a drop-off site would be justified.

According to the population census, there are 4,438 villages in Estonia (Beltadze 2012), the average length of a collection round of one village is 9.4 km, and a garbage truck visits a village 13 times a year on average. It would take about 207,900 litres of diesel fuel to collect waste from all of the villages, which means that as a result of burning in a Euro III compliant vehicle, 540 t of CO_2, 4.2 t of CO, 1.3 t of HC, 10 t of NO_x and 0.2 t of particulates will be emitted into the environment.

Table 2. Emission levels of one collection round in a village in the case of different collection systems and vehicle standards

	EURO III		EURO V	
Pollutants	Door-to-door	Collection point in village	Door-to-door	Collection point in village
CO_2, kg	9.4	5.0	9.0	5.0
CO, g	73.5	39.1	52.5	27.9
HC, g	23.1	12.3	16.1	8.6
NO_x, g	175.1	93.1	70.0	37.3
Particulates, g	3.5	1.9	0.7	0.4

In low-density areas in Finland, drop-off sites are used for the collection of sorted waste. The collection site is usually located next to local shops or in rural areas at road junctions. There is also an annual waste tax in Finland, which gives people the right to use the service (Pieber 2004). In addition to the amount of pollutants emitted into the environment, each waste collection method has its pros and cons, which are listed in more detail in the Table 3. If one could choose between different methods of collection, many of them could help reduce the volume of air emissions caused by garbage trucks. In addition, such solutions where people have to take their own waste somewhere further from home also reduces other aspects – heavy trucks do not burden/destroy roads in low-density areas, there is less noise, accessibility is no problem in severe weather conditions, etc.

The positive and negative sides can be different, depending on whose point of view. The door-to-door system is very convenient for people, but people need to take other sorted waste elsewhere with their cars for disposal since this system is mostly used for collecting household waste from low-density areas. From the company's point of view, the door-to-door collection method helps earn more by charging for emptying each container, but the work of the driver is more time-consuming. In the case of a collection point or collection centre, the garbage truck could go and empty a larger amount at a time.

Table 3. Advantages and disadvantages of different collection methods

Collection method	Advantages	Disadvantages
Door-to-door collection	* comfortable for the waste producers as the waste collection takes place at each household * the content of containers can be checked * possibility to choose the size of the waste container * mandatory container will help prevent illegal waste disposal (e.g. littering of forests)	* large number of small volume waste bins to empty * vehicle must stop at each house * waste container must be accessible for the waste transporter * the amount of secondary raw materials sorted out by one producer is small * higher air pollution, noise and traffic load cause by vehicles
Waste collection centre - an area surrounded by a fence and controlled by a warden where people can take their previously at home sorted waste themselves (Kriipsalu *et al.* 2016)	* guarded area * waste can be delivered when sorted * further handling easier * most of the waste can be delivered for free * one place for many types of waste * allows the local government to fulfil its obligation proceeding from the Waste Act to organise waste sorting and separate collection * large service area * trained staff * permanent place	* open at certain times * the sorted waste is brought to the waste plant by the waste producer with their own transport * congestion of transport at the waste collection centres increases * waste dumped illegally behind the fence * may disturb the surroundings * accompanying maintenance costs * bigger investment * need for larger territory
Drop-off site (bring site) – an unfenced area with containers of different types of waste and where people can bring household waste and sorted waste to be recycled or processed in other ways (Kriipsalu *et al.* 2016)	* always open * in an accessible place * allows separate collection of waste * waste disposal can be combined with other planned trips * no accompanying costs for the waste producer	* the waste is transported by the waste producer with their own means of transportation * no surveillance * the waste producer's awareness of sorting may be insufficient * awareness raising

In order to increase the likelihood of waste disposal, the central waste collection point of the village should be created on people's path of travel in such a way that it would be easily accessible for most of them (people's direction of movement either towards the workplace or village centre must be taken into account). Martin et al. 2006: 357–395 describes in his survey that the collection point and its containers must be accessible and convenient to use. Clear guidelines for waste producers contribute to waste sorting, and the location must be accessible by car. At the collection point it is possible to determine the basic mistakes made by the waste producers when sorting the waste. Knowing the basic mistakes helps organise directed awareness raising campaigns.

The current air emissions volumes of the door-to-door collection method could be reduced if people took recyclable waste material to the collection points created for that purpose; in this way, the amount of waste in the household waste container would be reduced. Raising people's awareness and applying various economic measures would contribute to this. Existence of an economic mechanism would certainly improve waste management. Currently, there is much packaging waste in people's containers, despite the fact that there is a system that allows people to collect it separately and deliver it free of charge. Since the price of emptying a waste container is very cheap (mostly up to 5 euros for a 240 l container), people lack the motivation to collect waste separately. The emptying charge for a household waste container should definitely be higher than the emptying charge for a sorted waste container.

One possible economic mechanism would be to establish a waste tax in a local government or in the country, which would apply to all territories. In this case, the drop-off site containers should have chips in order to avoid a situation where wrong people use the containers.

The use of a variety of Wireless Sensor Networks (Ramson, Moni 2016) in the containers will help reduce the emptying periodicity and the volume of generated emissions. The systems are able to show the current filling ratio of a container, and this allows the waste collector to prepare more effective emptying logistics so that all the trips to the containers would be justified.

Conclusions

The results show that the air emissions generated are the highest in the case of door-to-door collection method, in comparison with a collection centre located on the territory of a local government and a collection point in a village.

The volume of emissions could be reduced by optimising the collection schedule. Often, the trucks end up in a situation where the containers in the same village are emptied at different times. In most cases, the reasons for this are the different sizes of containers that become full at different times in different families. The solution to this would be that if the waste transporter – in knowing the quantity of waste generated by a family – suggested a container of different size for the grounds so that emptying could take place less often or more often, so that all of the containers in the same village could be emptied at the same time.

If only EURO III compliant trucks are allowed for waste collection in some densely populated areas, then in low-density areas there is no such restriction and cars of all kinds may drive there. Thus, by imposing a requirement whereby only vehicles that meet the requirements of at least the EURO III or higher standards may drive in the countryside, the volume of emissions could be reduced.

If the requirements to collect two or more types of waste from people with the door-to-door system were followed, it would mean two cars driving the same route; therefore, the quantities of emissions would be double.

When it comes to emissions, abandoning the door-to-door collection system and having people take their own waste to a collection point in a village centre or a collection centre on the territory of the local government would largely reduce emissions. Since it is obligatory to separately collect different types of waste and people drive around anyway, then they can combine waste disposal with some other trip and the volume of generated emissions would be zero.

The volume of emissions could be reduced if people's awareness of sorting was better and if the sorting was supported by the economic mechanism. If people sorted their waste properly by putting biodegradable material into the compost and taking paper, cardboard and packaging to a designated collection point, then the truck would need to visit the village less often, even in the case of the door-to-door collection method.

Disclosure statement

Authors declare that they dont have any competing financial, professional, or personal interests from other parties.

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