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Waste Handling Management in City Centres, Low-Density Areas and Small Islands and its Effect on Formation of Air Emission

MONICA VILMS

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TALLINN UNIVERSITY OF TECHNOLOGY
Department of Civil Engineering and Architecture
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Supervisor: Enn Loigu
Department of Civil Engineering and Architecture
Tallinn University of Technology
Tallinn, Estonia

Co-supervisor: Viktoria Voronova
Department of Civil Engineering and Architecture
Tallinn University of Technology
Tallinn, Estonia

Opponents: Prof Andrius Plepys
The International Institute for Industrial Environmental Economics
Lund University
Lund, Sweden

Prof Ruta Bendere
Department of Environment and Earth Sciences
University of Latvia
Riga, Latvia

Defence of the thesis: 07/09/2018, Tallinn

Declaration:
Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for doctoral or equivalent academic degree.

Monica Vilms

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MONICA VILMS

TTÜ KIRJASTUS

Contents

List of Publications

The thesis is based on four publications which are referred in to the text as Paper I, Paper II, Paper III and Paper IV. All publications are peer reviewed papers published and presented here to fulfil the requirements for the PhD degree of the Tallinn University of Technology.

Paper I: Vilms, M., Voronova, V., Loigu, E., 2015. The Problems of Municipal Waste Collection in City Centers and Air Pollutants Formed in the Process. 15th International Waste Management and Landfill Symposium, Sardinia 2015. Ed. R. Cossu, P. He, P. Kjeldsen, Y. Matsufuji, D. Reinhart, R. Stegmann. Padova, Italy: Cisa Publisher.

Paper II: Vilms, M., Voronova, V., 2016. Non-deposit System Option for Waste Management on Small Islands. Waste Management and Research, 34 (8), 748−754. DOI: https://doi.org/10.1177/0734242X16654752.

Paper III: Vilms, M., Voronova, V., 2017. Waste Collection in Low-density Areas and Air Pollutants Formed in the Process. “Environmental Engineering” 10th International Conference, Vilnius Gediminas Technical University Lithuania, 27–28 April 2017. VGTU Press "Technika", DOI: https://doi.org/10.3846/enviro.2017.058.

Paper IV: Vilms, M., Kalda, O., 2017. Introduction of a New Waste Sorting and Collection System at a University. “Environmental Engineering” 10th International Conference Vilnius Gediminas Technical University Lithuania, 27–28 April 2017. VGTU Press "Technika", DOI: https://doi.org/10.3846/enviro.2017.059.

Author’s Contribution to the Publications

Contribution to the papers in this thesis are:

Paper	Original idea	Study design and methods	Data collection and handling	Contribution to result interpretation and manuscript preparation	Responsible for result interpretation and manuscript preparation
I	MV	MV	MV	MV, EL, VV	MV
II	MV	MV	MV	MV, EL, VV	MV
III	MV	MV	MV	MV, EL, VV	MV
IV	MV	MV	MV, OK	MV, OK	MV, OK

MV – Monica Vilms
EL – Enn Loigu
VV – Viktoria Voronova
OK – Oliver Kalda

The thesis research results were presented by the author at the conferences:

- „15th International Waste Management and Landfill Symposium“, Sardinia 2015;
- “Environmental Engineering” 10th International Conference, Vilnius 2017.

In the year 2017 from April until August the author exchanged knowledge and experiences in the framework of the doctorate studies with researchers, faculty and practitioners at the Florida International University. The foreign studies were supported by the Doctoral Studies and International Programme (DoRa) through the European Social Fund, which is carried out by the Archimedes Foundation.

In the framework of the project Intherwaste, Interregional Environmental Integration of Waste Management in European Heritage Cities the author also participated in the following project seminars:

- 15-16th. November 2017 in Ibiza, Spain, "Integration of Waste Management Solutions into the Urban Décor of Heritage Areas";
- 23rd of March 2017 in Tallinn, Estonia, „Best practices for waste storage“;
- 8-9th. March 2017 in Porto, Portugal, „Waste Deposit in Heritage Areas“;
- 6th of. December 2016 in Tallinn, Estonia, „Problems and bottlenecks of waste management in the Tallinn Old Town“;
- 7th of June 2016 in Tallinn, Estonia, opening seminar for stakeholders „Interregional Environmental Integration of Waste Management in European Heritage Cities.

Introduction

Waste handling has become very important as the population and consumption are growing. Likewise, the growing population and consumption have increased the waste quantities that need to be collected from the waste producers. Currently, waste is considered as a resource, thus massive incineration and landfill should be avoided. The circular economy concept stipulates that waste should be recovered and the materials contained in the waste recycled as much as possible. Effective recovery is possible if waste is collected as sorted as early as possible. Today, waste handling management is a big and complex task, given different kinds of waste and materials contained in it. Different technologies have been created enabling waste handling with recovery of contained materials. Technologically, a specific waste type might be easy to handle, but to collect the waste type from the waste producer in as high quality as possible is more complex. There are very many different parties involved in waste management – the state, local government, private sector, waste producers etc., thus waste management plans that take everyone's expectations and needs into consideration are complex.

The separate collection of waste is important also because of the European Union targets established for the year 2020. The current most widespread door-to-door collection method will not permit reaching the targets in Estonia. The given system needs to be supplemented by other methods through which waste producers can deliver waste. Waste producers will deliver their sorted waste if the process is made as simple and convenient as possible. The door-to-door collection system seem inefficient when comparing the waste amount to the transportation costs in low density areas. In densely populated areas, the door-to-door collection system may be justified as the waste quantity collected per kilometre travelled is larger. Separate waste stream collection using the door-to-door system increases traffic density which causes various nuisances – noise, congestion, exhaust emissions etc. Densely populated areas have different characteristics, for example in Tallinn's old town waste producers are companies as well as private persons. The containers used in the old town are small compared to the large containers used in areas of prefabricated concrete apartment buildings. Densely populated areas may have areas with single family dwellings which each have their own 240 l container which are emptied by the waste truck driving up to it, stopping and accelerating. The waste truck accelerates and brakes frequently if the distances between the numerous emptying points are small which increases the air pollution quantity. Sorted wasted collection using the door-to-door collection system implies many waste vehicles perform similar activities in the same region.

The main problems analysed in the current thesis in the researched areas are:

- Tallinn's old town and similar, densely populated city centres where the problem is waste collection without increasing traffic density, causing odours, noise or exhaust emissions as well as avoiding disturbing residents and tourists in the collection area. At the same time, waste should be collected by waste type and delivered to the waste transporter;
- The problem on small islands with seasonal tourism is an exponential increase in waste creation and low responsibility among tourists about the waste reaching the mainland for handling;

- Low density areas where a small amount of waste is collected relative to the kilometres travelled and time spent. The waste vehicle burdens village roads and access to containers may be hindered depending on weather conditions.

The aim of the thesis is:

- To become acquainted with solutions in different areas – low density, small islands and Tallinn's old town as an example of a densely populated area;
- To offer waste collection methods that cause less air pollution;
- To find more suitable waste collection methods for the analysed areas.

The following stages were completed in order to achieve the aims of the thesis:

- Description and analysis of existing solutions;
    - Densely populated areas (Paper I)
    - Small islands (Paper II)
    - Low-density areas (Paper III)
    - In organisations (Paper IV)
- Data collection from waste management companies;
- Analysis of data received, existing air pollution quantity calculations (Paper I and Paper III);
- Comparison of air pollution quantity (Paper I and Paper III) between the existing and recommended waste transport solutions;
- Legislation overview;
- Offering/finding possibilities for waste taxation (Paper II);
- Transportation caused air pollution's effects on people/the environment.

1 Background

The waste act (Jäätmeseadus 2017) regulates waste management in Estonia according to which local governments must organise waste management within their administrative territory. The local government is obligated to collect sorted waste which enables recovery to the largest extent possible. The local government must make a waste management plan with aims for the upcoming years which establish the development and organisation of waste management. The waste management plan may be devised for several entities within the municipality. The waste management plan describes the waste transport within the administrative territory and the sorting development with deadlines per concrete waste type. In addition to the waste management plan the local government must devise waste management regulations which stipulate the waste handling process, waste transport areas as well as sorting and collection point requirements. The waste management regulations provide instructions for the municipality's residents concerning waste delivery and exact waste treatment requirements such as container size, colour, emptying frequency etc. The local government must continually monitor the fulfilment of the waste management regulations. The waste management plan references the packaging act (Pakendiseadus 2017) obligations which regulate the collection and recycling of packaging waste. The local government institution establishes packaging and packaging waste collection methods in its administrative territory and stipulates these as part of the waste management regulations. The largest waste amount by volume is packaging waste, therefore the separate collection obligation and the collection functioning is extremely important.

The local government receives financing for waste management through the Environmental Charges Act which stipulates pollution charges proceeds for municipal waste landfill (Keskkonnaministeerium 2014b). Most municipal waste is no longer taken to landfill sites, thuslocal governments must find additional funding, for example by applying to the Estonian Environmental Research Centre.

The main aim of waste handling is to recover and recycle as much waste as possible. The recovery and recycling principle is also followed by the European Union circular economy package. The circular economy principle is depicted in diagram 1. For the year 2020 recovery targets have been established for increasing the level of collection by type and obligations placed on municipalities. Since the year 2015 waste collection by type must be organised for paper, cardboard, metal, plastic and glass. The state waste management plan stipulates that a waste station network for recoverable waste must be established, so that citizens have comfortable opportunities for delivering their waste (Keskkonnaministeerium 2014b). Given that pollution charges do not provide sufficient financing for waste handling, consideration should be given for establishing a state waste tax. The tax proceeds can be used for developing waste handling and citizen use of the waste station network. Currently there are situations where the inhabitant of one municipality cannot take their waste to the waste station on the territory of another municipality even if the latter is closer and the waste transport to that station logistically more convenient. After the Estonian administrative reform, the problem still persists.

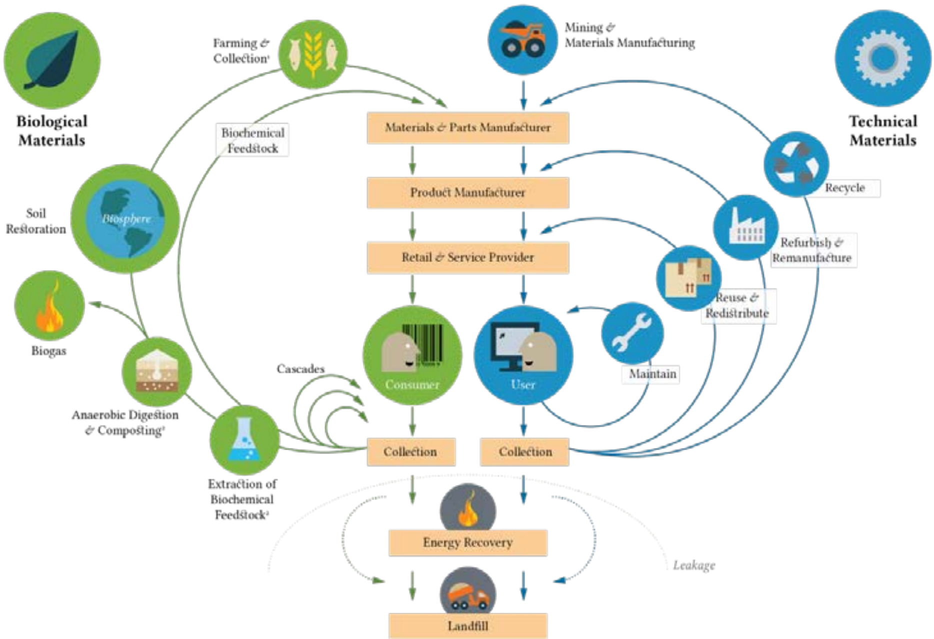

Diagram 1. Depiction of the Circural Economy (Ellen MacArthur Foundation 2016)

Since the year 2004 when the corresponding waste act was established in Estonia local governments are obligated to organise municipal waste collection on their own administrative territory. The obligation exists for all municipalities where the minimal number of inhabitants is 1 500 persons (Möller 2009).

The European Union member states, especially the Nordic countries use the organised waste transport model in waste handling extensively. The organised waste transport utilised in Estonia uses similar principles as in many other European Union member states. (Avfall Sverige 2014; Götze et al. 2016; Nelles, Grünes, and Morscheck 2016; De Jaeger and Rogge 2014; Keskkonnaministeerium 2014a; Pérez et al. 2017)

The local government has the possibility to organise waste transport solely on its own territory or to cooperate with neighbouring rural municipalities. Organised waste transport aims to incorporate all waste producers into the waste handling process.

Waste producers are obligated to participate in waste transport if organised waste transport has been established. As participation is compulsory, a waste producer must pay for waste transport even in the case of empty runs. Paying for empty runs motivates waste producers to collect waste into containers or bags instead of burning it in the oven/stove or disposing of it into nature.

The local government has a better overview of the municipal waste collection system and the opportunity to control costs through the organised waste transport tender. Organised waste transport has made it possible to have most of the waste producers participating in collection systems (SA Säästva Eesti Instituut 2014).

In areas without organised waste transport, a so-called free market situation exists where all waste transporters may participate. The residents are free to choose which service provider they want to use for emptying their containers.

The Government of the Republic Estonia has started a waste transportation organisation reform which stipulates that the citizen has the obligation to join a waste transport system but has the right to choose an appropriate service provider. The new waste transport model would be based on the local government's registration documentation. The system would permit several registered waste management companies to collect waste in the same area under free market conditions. (SA Säästva Eesti Instituut 2014)

The local government would maintain the right to stipulate general waste transport conditions and register companies conforming to the conditions. The reform would eliminate the local government's possibility to control waste transport and the waste producers will have to pay more. The collection and transport logistical costs would increase under the model of several waste transport companies as the total travelled distance per waste ton would increase. (SA Keskkonnaõiguse Keskus 2015)

The possible increased competition would also increase noise, traffic density and air pollution caused by the waste truck.

The municipal waste removal fuel costs in different areas have been analysed by A. Larsen et al. 2009 and Christensen 2010. The finding results are displayed in Table 1.

Table 1. Fuel costs per municipal waste ton depending on removal location (A. W. Larsen et al. 2009; Christensen 2010)

Pick-up location	Fuel cost per ton, l (Christensen)	Fuel cost per ton, l (Larsen)
Apartment building outside city centre	1.7	1.7
City centre	3.0	3.0
Single family houses in urban areas	3.6	3.4
Village centre	5.7	4 (Small towns)
Low-density areas	6.3	7.5

The fuel cost per ton is very small in areas with apartment blocks as many waste producers live together and larger containers are used, which when emptied, fill the waste vehicle quicker than when the vehicle collects waste from smaller containers.

The A. Larsen et al. 2009 research concluded that emptying drop-off site containers in all areas (urban and rural) per 1 waste ton required on average 4.3 l of fuel.

The research results allow concluding that if two different waste transport companies would be active (two vehicles would run according to the same schedule) in the same area then the costs would be higher. Collecting one ton of waste would require travelling more kilometres as the other vehicles had already emptied some containers and less waste would be collected from the same area. If one vehicle collects all the waste in the same area, the vehicle would fill quicker with a lower fuel cost and less kilometres travelled per waste ton.

The waste station network existence and the use convenience as well as location and increased citizen awareness would help reach the recovery targets set for the year 2020.

By the year 2013 according to the Environmental Agency local governments had set up over 100 waste stations to receive recoverable waste created by local inhabitants throughout Estonia (Keskkonnaministeerium 2014b). Every county has at least one waste station and in areas with higher population densities there are more – as in the case of Harju, Järva and Rapla counties. Counties with only one waste station in their territory may face the situation where the waste producers are not motivated or do not have the possibility to use the waste station.

The Swedish parliament believes that waste handling should aim to maximise benefit to the environment and society. Local governments, producers, households and companies must all participate in waste handling benefit maximisation. In Sweden, local governments are responsible for the collection, transportation, recovery and removal of waste (Avfall Sverige 2013). Since the year 1991 local governments are obligated to establish a waste management plan which includes measures for reducing waste quantities and reducing their hazards. The local governments have the right to decide if waste handling should be done separately or jointly with otherlocal governments. Current legal regulations allow for the same principles in Estonia. Cooperation helps maximise the possible environmental and social benefit which ensures efficient waste management and competence in making decisions concerning the field. Since the year 2005 it is prohibited to send biodegradable waste to landfill sites in Sweden. Most of the mixed municipal waste is sent to mass incineration to produce energy. In Stockholm, organised waste transport covers mixed municipal waste, biowaste and bulky waste. In front of apartment building there are containers for biowaste and mixed municipal waste. The containers intended for sorting by type are maximally in a 300-metre radius within each residential area and most Swedes sort waste produced at home (Milios 2013). The distance of package containers by type is fixed according to population density in Estonia (Jäätmeseadus 2017). In densely populated areas where there are more than 1000 inhabitants/km^2 there must be at least one collection point in a 500-metre radius. In areas where there are less than 500 inhabitants/km^2 there should be at least one collection point per 500 residents. The separate collection of paper and biowaste depends on the local government stipulations. In Tallinn for example the waste management regulations stipulate that in apartment buildings with at least five flats, paper waste must be collected in separate containers and buildings with at least 10 flats must have a separate container for biowaste.

In addition to sorting organisation regulations other different regulations may be established. The local government's waste management regulation may for examplerestrict emptying times of day, vehicle weight, container location etc. as described in Paper 1.

1.1 Waste handling furthering means

The government has at its disposal three broader sets of means for implementing environmental policy (Klarer et al. 1999; Dauvergne 2012; Fleming and FIIT 2006):

- Command and control means: e.g. exterior air quality standards, different pollution source emission standards, technology and product standards etc.;
- Economic instruments: e.g. pollution fees/taxes, user fees, product fees/taxes, deposit systems, resellable emission permits, tax advantages and subsidies;
- Convincing and other means: e.g. public and interest group participation, information strategies, voluntary agreements, environmental training etc.

The OECD (The Organisation for Economic Co-operation and Development) typology distinguishes different economic instruments (Klarer et al. 1999; OECD 2003):

- Pollution charges/compensation/taxes: direct taxes which are based on the pollutant's quantity and quality measurements or estimated determination.

Year to year for example, the environmental fee for waste landfill has increased which forces reductions in the waste amount used for landfill.

- User fees/compensation/taxes: payments for collective services which are mainly collected by local governments as a means for financing the collection and handling of solid waste as well as wastewater.
- Product fees/taxes: implemented relative to products which become pollutants while in production, consumption or storage (example fertilisers, plant protection products, batteries etc.).
- Deposit systems: payments which are made at the time of product purchase. The deposit payment made is refunded if the product is returned; The company that distributes packaging onto the market is obligated to collect back its own packaging according to the packaging waste collection implemented regulations and organise the recovery of the packaging to the extent stipulated in the Packaging Act concerning recovery targets. The company that does not fulfil the obligation must pay the state packaging excise taxes.
- Incentive payments or taxes: instruments with the main aim of changing environment-detrimental behaviour.
- Expense covering fees/taxes: fees which aim to cover the costs of public use or environmental field, single consumer or social services costs. Such fees are usually used in the water supply, wastewater and waste maintenance field.

The taxes/income received are directed to cover concrete environmental expenses or are deposited in the general state or local government budget. Where a waste tax has been established, all the money collected should be entirely used for waste handling development.

Economic instruments are often more useful than other means. In cases where emission reduction is exercised using command and control methods, it is usually expected that all pollutants reduce their emissions to the same extent (meaning according to the same established standard) irrespective of the expenses necessary. Every pollutant can decide in the case of economic instruments if it is cheaper to pay the expenses related to the instrument or pay for emission reductions. There is a solution offered in Paper II according to the same system in which every person going to the island is given a bag for waste. When the person returns from the island to the mainland and delivers the bag full of waste, the person is refunded the amount paid for the bag. If the bag with waste is not returned, then the money paid will be used for developing the island's waste handling.

The extension of the polluter pays principle is the user pays principle. The principle has not been recognised so much in politics and legal documents, yet many countries de facto use such means for example with user fees (in case of water and waste) as well as fees or taxes for using natural resources (Kanakoudis and Gonelas 2014).

Problematic products use „the polluter pays" principle according to which the producer must ensure that the collection and recovery of the waste caused by the problematic product released onto the market by the producer takes place (Moora 2009; Corsini, Rizzi, and Frey 2017). Problematic products include accumulators, batteries, motor vehicles, tyres, electronic equipment etc.

Companies and consumers can be motivated by offering them different motivational packages in addition to economic mechanisms. For example, an award is given annually to those in the public and private sector who have defended the environment through their activities (Aasta keskkonnategu 2015). In the Portuguese city of Porto, the local government has created a system when a person visits a waste station and delivers waste the person collects points. The collected points can be used in different institutions as a discount – examples include cheaper cultural event tickets or discounts in restaurants or shops. Points are earned starting from a specific waste quantity and every waste type gives a different point amount.

There is a similar system to Porto's in Philadelphia: the so-called recycling rewards program. Residents have to enrol over the internet, after which they get a sticker to be placed on their recycling bin. The sticker has a RFID tag (radio frequency identification) and a UPC bar code (Universal Product Code). All joined residents receive reward points which they can use for coupons or discounts. The program has had good influence and participation has increased (Agency Environmental Services 2011).

1.2 Most widespread collection solutions

Waste producers have many ways for waste disposal. One can choose to deliver the waste to the specified point on one's own or have the waste removed from the home by someone.

It is important to collect waste by type for it to be useable as a resource. In principle, waste can be collected on two levels from the inhabitants:

- doorstep collection – door-to-door;
- bring system - waste collection point - drop-off site, waste collection station.

The most widespread system in many countries, incl. Estonia, is the door-to-door collection system (USEPA 1989; Dahlén et al. 2007; Christensen 2011) which is used in densely populated and low-density areas. Paper III describes the door-to-door collection method's positive and negative aspects. The system's main advantage ahead of other collection methods is the user convenience. The waste is removed from the waste producer's door, so the waste producer does not have to worry about transportation or storage. The system's negative aspect is traffic congestion as the waste vehicle needs to visit every home and empty the container regardless of size (0.08-4500 l). The collection method is good when large containers are being emptied as one stop allows removing a large waste amount. Emptying small containers especially in low-density areas means that a lot of fuel and kilometres are required to collect one waste ton. Drop-off site is also useable in both collection areas but is usually used for collecting recyclable materials. A waste collection station is a fenced off supervised area to which inhabitants themselves can deliver waste that has been pre-sorted at home (Kriipsalu 2001). In Estonia waste collection stations will usually accept municipal waste against a fee. Waste collection stations are also used in both densely populated and low-density areas. Depending on the bringsystem type, the location should not be very distant from the waste producer. Such solutions are very widespread in Europe, for example, Denmark, Finland, Luxembourg, France and elsewhere (Hogg 2002; BiPRO; and CRI 2015; Hage, Söderholm, and Berglund 2009; Linderhof et al. 2001). One possibility for waste collection throughout the world, especially in densely populated areas is pneumatic collection. The person places the waste in the appropriate reception opening which is usually located at the waste creation site and then the waste is sent through a pipe to the collection centre. (Kaliampakos and Benardos 2013) Constructing the collection system is expensive, but using the system is very convenient for people. Pneumatic collection eliminates waste vehicles and their associated unpleasantness in the collection area. The system and its advantages as well as disadvantages are described in detail in Paper I.

According to literature, the following, less frequently used collection methods can be found in low-density areas (USEPA 1989; Ministry of Local Government Provincial Councils 2008):

- Directhaul – people take their own waste to the landfill site or handling centre. The method is used in low-density areas where collection is not practical.
- Mail-box – people leave their waste in plastic bags by the mailbox from where it is picked up according to a fixed schedule on the assumption that waste transport can use the same route as the mail truck.
- Bell Collection, the waste vehicle travels through an area and the collector calls "dustbin" or plays music known to the consumers as the waste vehicle's music. The consumer can then deliver the waste to the vehicle.

The first two described options would be suitable for use in Estonia. The third option probably is not suited as such „musical" solutions are not widespread in Estonia and people prefer to know exact dates and times of collection.

For example, in Porto, Portugal there is a system in use called handcart collection, which is a version of the door-to-door system. Workers collect waste containers – bags from the roadside, yards or rooms where the waste producers have left them. The collected waste is reloaded onto further transport means which may be a hand-drawn cart, electric car, tractor or other means. The vehicle transports the waste to the reloading location or the final handling centre. The collection system is foremost used in areas with narrow or congested roads (Helder 2017; Ferreira et al. 2017). The weakness of collecting waste bags from outside is the threat that rodents and birds may damage the bags and strew the waste around the yard or street. In places where containers have been over filled in Estonia, it can be seen daily that birds, especially crows and seagulls, will peck open bags and strew the contents around the container. The resulting situation is unsanitary and visually unpleasant. In places where there is the intention to collect waste from the street or yard in plastic bags, they must remain outside for the shortest period possible to give less time for birds to damage them. People are restricted in their activities as they need to watch the time when the waste vehicle arrives. It is also uncomfortable for the waste transporter should the waste vehicle malfunction, the possibility of rapid collection disappears. When the waste transporter collects the waste bags from interior premises then the collection with waste bags is justified.

The city of Porto is located in Portugal and is a UNESCO World Heritage site. The city has 215 000 inhabitants and an area of 42 km2. In the year 2016 a total of 135 700 t of waste was collected (mixed waste 111 860 t, paper and cardboard 4977 t, plastic and metal packaging 2816 t, glass 5265 t, foodwaste 5088 t). The city agreed with the large waste producers (restaurants) in the old town that waste will be collected from them separately twice daily using the handcart collection system. The collection on the narrow streets takes place using small electric cars onto which the workers lift the waste containers or bags and transport them to the collection centre from where they are taken to the handling centre by a larger vehicle. The workers return the emptied container to the company and the waste bag taken away is replaced with a new one (Helder 2017; Ferreira et al. 2017). Tallinn old town restaurants and hotels are currently freed from collecting biodegradable waste separately due to space restrictions. The situation should definitely be changedand the area's waste producers should collect waste by type. Considering the large number of tourists the best solution for collecting biodegradable waste in the old town would be using the door-to-door system which would mean an additional waste vehicle in the old town area or using drop-off site to which the waste producers would have to transport the waste themselves (Paper I).

It is very important in waste collection to find effective logistics for waste collection according to the chosen collection system. Route optimisation or changes can result in reduced labour needs and equipment depreciation, save fuel and thereby reduce different emission figures. An effective and understandable system for waste producers results in increased client satisfaction (Rodrigues, Martinho, and Pires 2016; Vecchi et al. 2016).

The main factors influencing route planning and waste transport organisation are (Das and Bhattacharyya 2015; Laureri, Minciardi, and Robba 2016; Huang and Lin 2015; Inghels, Dullaert, and Vigo 2016):

- waste quantity per single collection time;
- distance between collections;
- loading time;
- traffic conditions;
- collection method;
- container emptying frequency;
- area;
- residence type;
- container type etc.

Waste producers desire an economical, simple and aesthetic transportation. Additionally, containers should blend in with the surroundings and not pose a threat to one's health (Schüch et al. 2016; Chateau 2007; Chung et al. 2012). Waste transporters want the waste producers to place the waste in the specified location in the specified manner so that loading would be fast and transport costs minimal (Kriipsalu 2001; Mes, Schutten, and Rivera 2014; Nowakowski 2017; Ferreira et al. 2017).

There are two possibilities with door-to-door collection – either kerbside in which case the person brings the container to the roadside themselves or backyard collection in which case the waste transporter transports the container from the person's yard. Kerbside collection is usually more economical than backyard collection. The latter method leaves the waste vehicle longer in idle gear, traffic is disturbed more and more time is spent on loading waste. While idling the vehicle still produces emissions that are dispersed into the air (USEPA 1989).

The vehicle choice in door-to-door collection depends on waste type and amount. The vehicle choice also takes into consideration the transportation route length and road quality. The waste vehicle authorized weight and load capacity may be established by legislation. In low density areas road width may also influence vehicle type. Large waste vehicle manoeuvring is restricted on narrow roads (Woodburn and Whiteing 2010; Pichtel 2014; USEPA 1989).

The door-to-door collection system requires the waste producers to sort their waste oneself at home and the waste containers or bags are emptied at agreed upon times. The waste vehicle moves from one building to the other and empties each container with a separate stop. The advantage of door-to-door collection is the convenience for people as waste is collected from each household. The drawback is the time and fuel costs of large waste vehicles as the vehicle must stop at each building, brake, accelerate and empty the container. The advantages and drawbacks are described in more detail in Paper III. The method allows collecting many types of waste at the same time – usually only two. The collected waste type is the largest or which has the highest market value. The transport company has two possibilities when collecting waste by type. The first option is to make several circuits. Each circuit collects only a specific waste type. Many circuits increase air pollution, noise as well as traffic density by waste vehicles. Many circuits are justified when the waste quantities are large.

The other possibility is to use a multi-chambered waste vehicle which would enable uniting the collection of different waste types. Table 2 shows that the collection by type using the door-to-door system is usually more expensive than the normal municipal waste collection (A. W. Larsen et al. 2009) and requires residents to be environmentally conscious with the desire to sort waste.

Table 2. Collection and treatment costs (DKK/ton) and equivalent Euro/ton (A. W. Larsen et al. 2010)

	DKK	EURO
Residual waste (k)	508	68.2
Residual waste (u)	720	96.6
Paper (k)	561	75.3
Paper (b+r)	311	41.7
Paper (u)	456	61.2
Glass (k)	561	75.3
Glass (b+r)	436	58.5
Glass (u)	587	78.8
Plastic (k)	561	75.3
Plastic (b+r)	436	58.5
Plastic (m)	2195	294.6

k: kerbside collection, b: bring scheme with drop-off containers, r: recycling centres, u: underground containers in city centre, m: monthly kerbside collection in city centre.

There are many different factors which influence the municipal waste collection cost: peculiarities of the municipality such as size and population density; collection area – distances, road network, hilliness; handled waste quantity and quality; technical means used for collection and transport (Callan and Thomas 2001; Bel and Fageda 2010; Dijkgraaf and Gradus 2004).

The separate collection of waste may incur additional costs which the revenue from material sales might not always compensate. The separate collection of waste reduces landfill and incineration costs (A. W. Larsen et al. 2010). The separate collection of waste (especially biowaste) also reduces CO_2 emissions caused when municipal waste is used for landfill (Teibe, Bendere, and Arina 2013).

In his research (Johansson 2006) compares different solutions for collecting waste and finds that using container filling sensors and emptying containers when they are sufficiently filled may save up to 20% of waste collection costs compared to the standard fixed schedule waste collection.

Door-to-door collection uses different waste containers. The door-to-door collection system uses the polluter pays principle which requires the use of identified waste containers and bags. Each waste container and bag have a unique code which enables identifying the waste producer. On the waste collection day, if the waste collector discovers the waste container or bag containing waste that does not belong there, the incorrectly placed waste is not collected. The waste producer receives notification with the reason why the waste was not removed. The system enables following every household.

Waste collection centres are open only at certain times and the waste producer can deliver all household waste kinds to the centre. Usually waste collection centres collect paper and cardboard, textiles, glass, metal and plastic packaging, biodegradable garden and park waste, bio non-degradable garden and park waste, wood, bulky waste, unusable electronic equipment and old tyres. Additionally, the containers used for collecting waste depend on the waste type collected and the waste quantity delivered by the waste producers.

Waste collection centres are guarded fenced off areas which may create situations where people illegally leave waste behind the fence. If a person happens to deliver waste at a time when the waste collection centre is closed, it would seem like a good idea to leave the waste behind the fence knowing that it will be taken care of. In case of waste which is accepted against payment, the desire may be to avoid paying. In the case of waste collection centres, their opening times, a convenient location and comfort of use are important.

The main problem with park waste is that waste producers deliver the waste in plastic bags and throw the waste onto the heap with the plastic bag. The existence of plastic bags disturbs further processing of the waste. People are unaware or too comfortable to behave differently. If people would know the following handling stages and be better educated in the waste field, they would understand that composted plastic does not decompose and disturbs the entire process. The finished material is contaminated by plastic.

Drop-off site areas are not bounded by fences. Residents can take their separately collected waste and place them in the appropriate container at the location.

Drop-off sites can be permanent or transportable. Permanent sites are set-up in public, easily accessible locations, e.g. parking lots of shopping centres or other frequently visited locations. Temporary drop-off sites are left in place for a day or couple of days. In case of temporary drop-off sites, it is important to inform people so that they know where and when the waste can be delivered. In case of using a drop-off site, the waste producer has the responsibility to take the waste from where it was created to the drop-off site.

A drop-off site usually has a designated container for each type of raw material. Estonia does not have a standard solution – colour and signage is different. Usually drop-off sites are used for collecting package waste (glass, plastic, metal etc.) paper and cardboard, biodegradable waste and textile waste.

Today almost all households have a car (in the year 2015 according to Eurostat data there were 514 cars per 1 000 people in Estonia (Eurostat 2017), thus it is easy to deliver waste to drop-off sites. Taking waste to drop-off sites can be combined with other trips. A car produces less air pollution and noise in comparison to a waste vehicle. The waste vehicle must only travel to one point to collect waste, saving the need to travel to every household. The transportation costs would decrease because a larger waste quantity is picked up from the drop-off site at once. Different sensors can be used to gauge the container's fullness, which allows optimising transportation costs as empty runs or trips to half full containers will be eliminated.

1.3 Transport effects on people's health and the environment

Transportation causes great effects on the environment and many economic branches while decisions in environmental and economic fields strongly influence transportation demand, planning and organisation. In addition to influencing the environment and health, transportation produces other direct socio-economic effects (M. Jüssi et al. 2010; Mari Jüssi and Poltimäe 2011), such as:

- traffic congestion;
- traffic accidents;
- effects on mobility and accessibility for residents – a varied and integrated transportation system usually improves the residents' mobility and accessibility, reduces geographic distances as well as often contributes to economic and standard of living development.

The above described effects can be reduced, for example by planning waste collection to times when traffic flow is lower. It is obviously not sensible to plan waste collection into the middle of the night in residential areas as it could be disturbing for the residents. As described in Paper I, in Tallinn's old town there are time restrictions for waste collection, so residents, people in accommodation places and tourists visiting the old town's sights are not disturbed. Collecting waste with electric vehicles would reduce noise and in such a case waste collection could also take place at night.

Waste vehicles usually still use unrenewable energy resources and therefore influence the local environment (create noise and emissions in their operational area) and the environment as a whole by producing greenhouse gas emissions (OECD 2011). Negative factors on the local level may include dust, odours, truck's mass, possible tyre marks on the streets and possible vibration. Communities which use diesel-powered waste vehicles are posing significant threats to the environment and the residents' health (Fontaras et al. 2012; OEHHA 2017).

Transportation pollution plays a major role in people's general immunity weakening. Air pollution also contributes to heart disease, cancer, obesity, concentration and stress-related diseases as well as osteoporosis and diabetes (Hendrikson&Ko 2013).

The main harmful effects of transportation to the environment and thereby to human health have been described as follows:

i) Noise is an unwanted sound. More specifically, noise is an annoying, unpleasant, or otherwise injurious sound to human health and well-being. Noise can be defined both as a nuisance and annoyment to the individual and the environment as the sound reaching the body may cause either physical or mental damage (Lahti 2010; Münzel et al. 2014).

The main source of noise in waste collection is the waste vehicle which has numerous causes, for example the vehicle's engine, the hydraulic system's work cycle when emptying the container and the compacting mechanism. the main noise producers in case of waste vehicles are the sounds produced by different engines (Pallas, Chatagnon, and Lelong 2014). The waste vehicle's frequent acceleration and braking causes noise. In addition to the engine noise, the noise produced by emptying the container is problematic especially in the case of metallic containers. The report produced by Jobling (2012) describes that a noise level up to 140 dB is perfectly normal for plastic containers. The waste loader is often in an environment where the noise level exceeds 137 dB. Such noise levels can damage one's hearing, thus the worker should definitely use noise protection means. The noise level also depends on what waste is in the container. The largest noise producer in municipal waste is glass which, when emptied into the truck, falls against metal or breaks causing noise. The noise level to residents depends on distance. The closer one is to the waste vehicle, the greater the noise. The compactor systems of New York's waste vehicles have legislated noise boundaries while in operation – the noise must not exceed 80 dB measured 10.5 m from the waste vehicle. There are also times established during the day – between 11 PM – 7 AM – during which the vehicle's noise must not exceed 85 dB measured 15 m from residential properties (De Blasio Mayor and Sapienza 2016). Estonia does not have similar fixed restrictions concerning noise produced by waste vehicles. The environment minister's regulation 71 „Exterior air noise limit values and methods for measuring, establishing and evaluating noise levels" Appendix 1 (Riigiteataja 2016) has only established limit values for different areas. In residential areas the traffic noise limit value is 60 dB at night and 65dB during the day on the side of the noise sensitive building's streetside.

Waste collection is usually planned early in the mornings or late in the evenings, especially in city centres when traffic density is low, because this enables work to be completed safely, efficiently and with least traffic disruption. The arrangement makes collection noise more noticeable to (residential) people. In some places the waste vehicle needs to move backwards which requires using reverse beeping for safety reasons which is an additional noise pollution source.

A person's health and well-being may be influenced by noise in many ways. Usually noise disturbs or makes working, resting and sleeping more difficult. Noise can also interfere with information exchange and studying. Constantly being in noise may damage the ears and weaken the hearing capability. There are possibilities for additional physical and psychological effects, including stress (Hays, McCawley, and Shonkoff 2017; Lahti 2010).

ii) The exterior air is a very important component of our living environment which influences the residents' health. The exterior air quality is defined as the cleanliness of the exterior air that we breathe in on a daily basis. The exterior air quality is decreased by different contaminating substances which have direct or indirect effects on people's health (Orru 2007).

The air can be polluted in cities as well as the countryside and the pollution source can be man-made or naturally caused. The main sources of air pollution in Tallinn are traffic (cars, trucks, buses etc.) household heating and various industrial companies (Orru 2007; Mari Jüssi and Poltimäe 2011).

Air pollution is detrimental to human health and the environment. In the last decades thanks to different domestic and pan-European regulations air emissions have been reduced, resulting in improved air quality. In some places the air pollution concentration is still too high and causes problems for air quality (European Environment Agency 2013, 2014).

The main emissions caused by burning diesel fuel in waste vehicles which are regulated by different EU regulations are: (DieselNet; OECD 2011)

- carbon monoxide (CO), g/kWh;
- hydrocarbons and nitrogen oxides (NO_X), g/kWh;
- particulate matter (PM), g/kWh;
- sulphur dioxide (SO_2), g/kWh.

All of the mentioned pollutants can have a negative effect on human health. Carbon monoxide, for example, may cause heart disease and damage the nervous system as well as be the reason for headaches, dizziness and fatigue. Hydrocarbons and nitrogen oxides also have damaging effects to people – influencing the lungs and spleen. Those suffering lung diseases may face complications and experience respiratory infections. Particulate matter emissions may cause lung disease, heart attacks and heartbeat irregularities. Effects of PM on the central nervous and reproductive systems have also been evidenced as well as being a possible cause of cancer. Sulphur dioxide may cause general uncomfort and anxiety, reduce lung functionality and disturb the normal functioning of respiratory channels (European Environment Agency 2014).

Air pollution effects can be different. The effects may be noticed in people's health, on plants, animals and even buildings. Based on research (Orru 2007) which was conducted by the University of Tartu and focused on evaluating exterior air quality effects on people's health in Tallinn, the conclusion was reached that life of Tallinn's inhabitants is shortened by 7.7 months due to air pollution. In the old town, life is shortened by 11.3 months due to pollution.

In addition to soil and water contamination caused by air pollution, transportation pollutes the environment with heavy metals (Li et al. 2017), polyaromatic hydrocarbons (PAH) (Keita, Nicolle, and Bakali 2016; Clément et al. 2015) as well as with chemicals used to repel roadside plants (Marques et al. 2017). The mentioned pollutants may damage plants, reduce the soil's fertility and be detrimental to human as well as animal health. Nitrogen oxides stemming from transportation have an important role in the Baltic sea and inland waterways eutrophication (Voss et al. 2011).

Greenhouse gases occur mainly in fossil fuels (oil, coal, shale, natural gas, etc.) through combustion in energy production, transport, energy inefficient industries, as well as intensive agriculture.

The most important greenhouse gases produced by humans are (Riigikogu keskkonnakomisjon 2010):

- carbon dioxide (CO_2);
- methane (CH_4);
- nitrous oxide (N_2O);
- freons - hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).

The greenhouse gases produced by burning transportation fuels (carbon dioxides – CO_2, N_2O, CH_4) amount to 14% of the world's human activity caused greenhouse gas emission figures. After energy production and industries, transportation is one of the three largest areas which uses fossil fuels (M. Jüssi et al. 2010).

The biggest transportation related CO_2eq emissions in Tallinn are caused by passenger cars, with heavy vehicles producing slightly less emissions, whereas buses produce the least pollutants according to (M. Jüssi et al. 2010). We see that passenger cars are the main greenhouse gas producers when we view Estonia as a whole (Diagram 2).

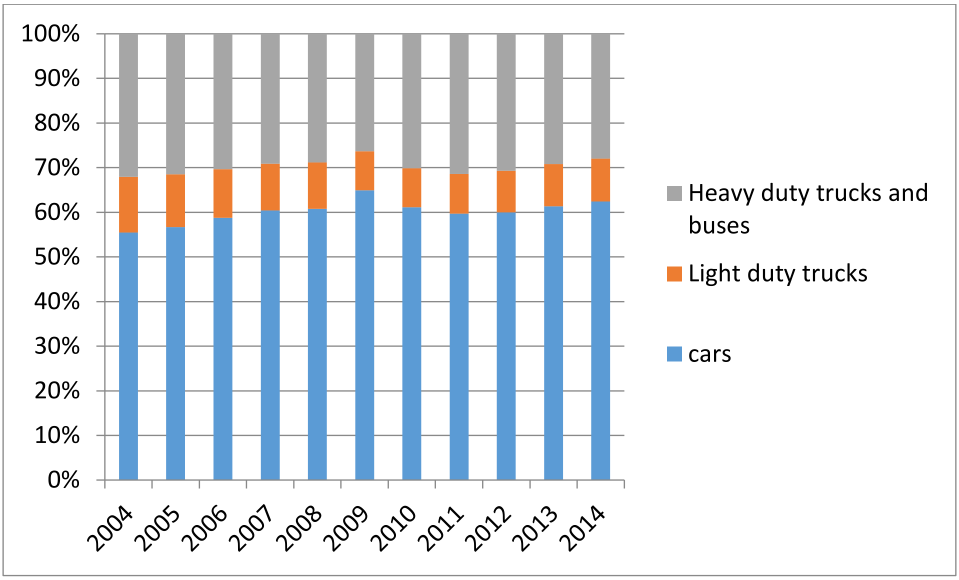

Diagram 2. Transportation sector's main greenhouse gas producers in Estonia by percentage (European Environment Agency 2017)

Based on research (Mari Jüssi 2011) "Reducing Carbon Emissions from Major Municipal Services in Tallinn," it is found that 10% of Tallinn transport CO_2eq emissions come from road building and maintenance, buses and waste vehicles. The following table (Table 3) shows the CO_2 eq that these companies produce annually.

Table 3. Tallinn's largest public utility undertaking's kilometres, fuel consumption and CO_2eq emissions in the year 2010 (Mari Jüssi and Poltimäe 2011)

Field	Annual total run km/vehicle	Annual fuel consumption 1000 l	Fuel consumption l/km	CO_2eq t/a	CO_2eq emission distribution %
Road maintenance	27500	2407.5	0.086	8016	15
Road cleaning	22333	1203.6	0.054	4007	7
Buses	63333	7942.0	0.125	26442	50
Waste transportation	50021	4404.2	0.088	14663	28
Total	163187	15957.3		53128	100

Increases in CO_2 emissions bring with them different effects, for example (Marjanovic, Milovancevic, and Mladenovic 2016; Zhou et al. 2017; Veettil et al. 2017):

- global warming, the greenhouse effect;
- climate change effects (tornadoes, hurricanes, extreme summers and winters, floods, droughts);
- glaciers melting and rising sea levels for surface water;
- changes in the flora and fauna.

It is no less important to consider the workers of companies providing transport services. Research conducted in Florida showed the main illnesses and their frequencies suffered by people employed in waste handling. In the following table (Table 4) the waste handlers' health risks and their causers are presented.

Table 4. The Reported Exposures and Related Health Effects for Waste Collectors (Englehardt et al. 2000)

Reported Exposures	Reported Health Effects
Diesel Exhaust	Eye irritation, asthma, decreased lung function, upper respiratory tract irritation, lung cancer
Carbon monoxide	Potential cardiovascular, neurologic, asphyxiation
Polycyclic Aromatic Hydrocarbons	Potential carcinogenic
Dust	Eye irritation, organic dust toxic syndrome (ODTS), non-allergic pulmonary disorders, impaired lung function
Microorganisms	Dry cough, exercise induced dyspnoea, asthma, chronic bronchitis, ODTS, chest tightness, fever, chills, flu symptoms
Endotoxin	Fever, chest tightness, airway irritation, headache, joint and muscle pain, nausea, fatigue, non-allergic pulmonary disorders, impaired lung function, acute gastrointestinal symptoms
Fungal spores	Allergic alveolitis, asthma
Aerosols from waste	Eye and nose irritation, nausea, vomiting
Improper chemical disposal	Burns, fires, explosions, eye and skin irritation
Sharp and broken objects	Lacerations, punctures, abrasions
Heavy traffic	Pedestrian accidents, broken bones, bruising, death
Machinery	Crushed body parts, broken bones, lost limbs, musculoskeletal, aches, twisted muscles, sprains, permanent disability
Heavy lifting	Disorders of the neck, shoulder and back, tendon diseases, extreme, pain, lumbar disc prolapse, increased pulmonary ventilation

2 Material and methods

The given research examined waste collection and related problems:

- densely populated areas – Tallinn's old town;
- low-density areas – ten villages throughout Estonia;
- small islands – Kihnu, Naissaar, Prangli, Ruhnu and Aegna;
- specific institution, which was a higher education institution in Tallinn.

Tallinn's old town was chosen to represent a densely populated area because it is a UNESCO World Heritage Site with dense population in terms of residents and the HORECA (hotels, restaurants and catering) segment. In summary, other UNESCO cities of same category were examined – Porto and Florence.

Diagram 3 shows the old town's land use by designated purpose according to the year 2011 real estate research. The construction register included a total of 579 buildings within the old town (Sepp 2014), most of which are used for business purposes (41%), followed by residences (36%) and public use (23%) (Pindi Kinnisvara AS 2011).

Waste collection is problematic in the area as the roads are narrow, access to containers complicated as it is not permitted to keep containers on the street in the old town. During the day there are very many tourists on the streets. There are many accommodation places and residents that do not wish to be disturbed by noise during quiet night hours. The waste collector cannot perform according to one's own will as the city has implemented restrictions for activities in the old town territory through numerous legal instruments.

The waste handling's current situation of ten randomly chosen villages was used to represent low-density areas (Diagram 4) – Laugu, Oeti, Nadalama, Vaskrääma, Tuulevälja, Kärde, Vaivere, Vaila, Smolnitsa and Oru.

The developed research questionnaire involved conducting interviews – 137 households were interviewed. The questionnaire aimed to get responses to the following questions:

- existing collection schedules;
- people's satisfaction concerning waste delivery possibilities;
- if and what waste types people collect as sorted;
- frequency of visiting collection sites;
- disturbance caused by waste vehicles while collecting waste;
- knowledge about the rural municipality's waste related regulations.

In low-density areas a waste vehicle must travel long distances to collect a small amount of waste. Currently the most frequently used door-to-door collection method does not support waste sorting.

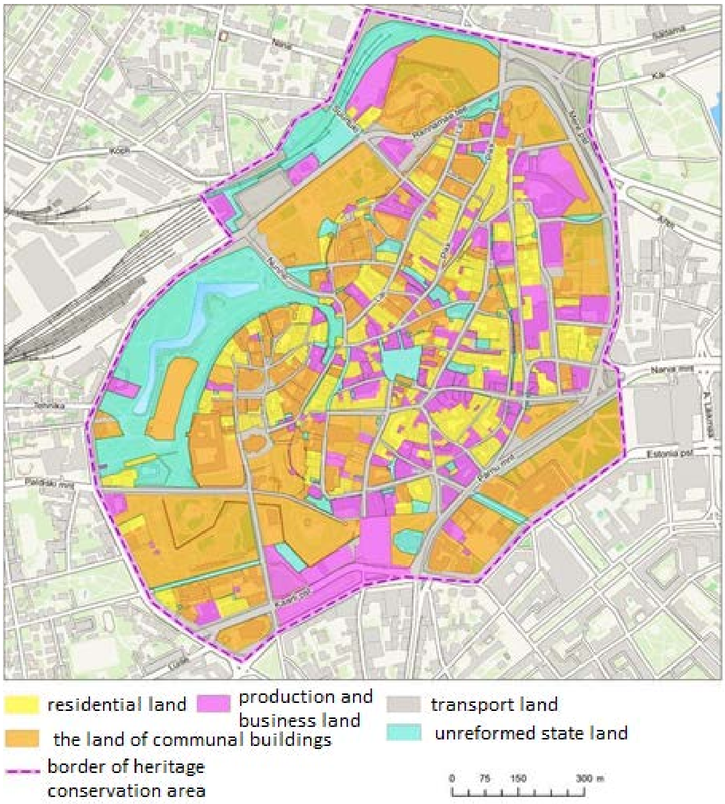

Diagram 3. Land's designated purpose within Tallinn's old town (Sepp 2014)

Diagram 4. Researched low-density villages (brown) and small islands (blue)

In the small island category, five Estonian islands were chosen - Ruhnu, Aegna, Naissaar, Kihnu and Prangli (Diagram 4) and the waste collection methods were examined complete with the waste's transportation to the mainland. The islands and their waste handling are described in Paper II with the exception of Kihnu Island of which an overview is provided in the current paper.

Each region and situation should be approached taking into consideration its peculiarities, therefore the collection system's creation and implementation in a specific institution was examined – a professional higher education institution with approx. 190 employees and 2 600 students in Tallinn (Paper IV). In the experiment's framework the waste amount and type were established, and a collection method created enabling waste sorting. The experiment confirmed that people have different attitudes and the implementation of waste sorting might not be realised according to the planned result.

The data for performing research was obtained from waste collecting and transporting companies, local governments, local residents and people responsible for waste management, through conducting waste audits as well as visual inspections.

European emission standards set the acceptable limits for exhaust emissions of new vehicles sold in the European Union member states (Table 5). Basically, the emission standards are defined in a series of European Union directives with the progressive introduction of increasingly stringent standards (DieselNet).

The 1999 EU adopted Directive 1999/96/EC, which introduced Euro III standards (2000), set voluntary, more stringent emission limits for extra low emission vehicles, known as "enhanced environmentally friendly vehicles" (TransportPolicy.net).

Based on waste management rules that are currently valid in Tallinn, waste collecting vehicles shall comply with the minimum requirements of EURO III if the procurement documents do not provide for a higher requirement (Tallinna Jäätmehoolduseeskiri 2014).

In the year 1993 the Euro standard series was started aiming to reduce harmful exhaust emissions of which nitrogen (NO_x) and particulate matter (PM) are the most important.

Since Euro 1, the allowed level of NO_x has been reduced by 95% and for particulates by 97% to the Euro 6 levels.

Table 5. Permitted emission limits according to different standards (DieselNet)

Stage	Year	CO, g/kWh	HC, g/kWh	NO_x, g/kWh	PM, g/kWh
Euro I	1992	4.5	1.1	8.0	0.36
Euro II	1996	4.0	1.1	7.0	0.25
Euro III	2000	2.1	0.66	5.0	0.10
Euro IV	2005	1.5	0.46	3.5	0.02
Euro V	2008	1.5	0.46	2.0	0.02
Euro VI	2013	1.5	0.13	0.4	0.01

Emissions are calculated as described in Paper I. Air pollution emissions are calculated according to the amount of burnt fuel.

Air pollutants are calculated according to the amount of energy released in the process of burning diesel fuel.

$$Q\ (kWh/kg) * N\ (kg) = E\ (kWh) \qquad (1)$$

where Q is the calorific value of diesel fuel, N is the amount of fuel consumed and E is energy.

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

$$\rho = m/V \qquad (2)$$

where ρ is fuel density, V is volume and m is molar mass.

EU Emission standards for trucks and buses present chemical exhaust emissions for diesel engines (CO, HC, NOx, Particles). The formula (1) determines energy after which we can calculate the emission figures formed in the process of burning the given amount of diesel fuel, according to the target number in the emission standards (formula 3).

$$\text{energy (kWh) x emission target (g/kWh) = emission figure (g)} \qquad (3)$$

To find out the amount of generated CO_2 the average formula of diesel fuel $C_{12}H_{23}$ is used. The reaction developing in the process of burning diesel, is expressed in formula 4.

$$C_{12}H_{23} + 17.75\ O_2 = 12\ CO_2 + 11.5\ H_2O \qquad (4)$$

$$n_d = m/M = 4.91\ mol \qquad (5)$$

$$m = n_d * (n * M\ (CO_2)) \qquad (6)$$

where n_d represents diesel fuel moles, M is molar mass, n is moles and m is mass.

According to formula 6, burning 1 litre diesel fuel, 2.593 kg CO_2 will be produced.

$$4.91\ mol * 12\ mol * 44\ g/mol = 2.593\ kg\ CO_2$$

3 Results and discussion

Currently the most common collection method in Estonia is the door-to-door system. The system is utilised in densely populated and low-density areas as concluded in Paper I and Paper III. It is important to consider utilising other waste collection methods to reduce emissions and increase the effectiveness of collecting sorted waste. Each location should be considered separately and the best solution for the given location should be utilised. A collection method suited to one low-density area might not be appropriate in another low-density area such as a small island or for densely populated city centres. Pneumatic waste collection is suitable for densely populated areas, but set-up costs are high and may be complicated depending on the area. In Tallinn's old town, for example, it is likely that excavations will reveal archaeological finds that need to be preserved. The same happened in Florence where underground containers were established in the old town and valuable archaeological remains were found (Ponzini 2017). The pneumatic collection method and the accompanying emissions are described in detail in Paper I.

Investments are required to develop drop-off points in low-density areas. Depending on the containers used at a drop-off site, it might be necessary to prepare a hard-surfaced area so that the containers can be moved, and the waste vehicle can empty them. Using underground containers requires extensive excavations to allow their placement.

It is important to review and analyse the existing collection schedules and emptying frequencies to reduce emissions. The current emptying schedules can be optimised by reviewing the existing emptying day which could lead to reduced emission production while collecting waste as shown in Paper I. Collection should be organised such that in every area or street the vehicle travels on specific days.

Diesel-powered waste vehicles pose significant threats to the environment, health of residents in the communities they serve and the workers who maintain and operate them.

The waste amount in the USA has increased according to USEPA. If in the 1960s a person created waste at the rate of 1.22 kg/day (Clark et al. 1998), then current waste production is at 2.58 kg/day (Hoornweg and Bhada-Tata 2012). According to the World Bank (2012) report, in Estonia a person creates waste 1.47 kg/capita/day and the same report predicts the amount to be 1.70 kg/capita/day for the year 2025. As the waste amount is increasing and in some areas collection by type is taking place the waste vehicles need to do more runs which increases the fuel consumption and the produced emissions into the environment.

The waste vehicle's fuel consumption and emissions are largely dependent on vehicle mass, age, speed, route length and driver's skills.

Using different sensors and cameras Clark et al. (1998) analysed New York's waste vehicle's use cycles. The analysis showed that in densely populated areas waste vehicles are running in idle gear in one position for 60% of the time (Diagram 5).

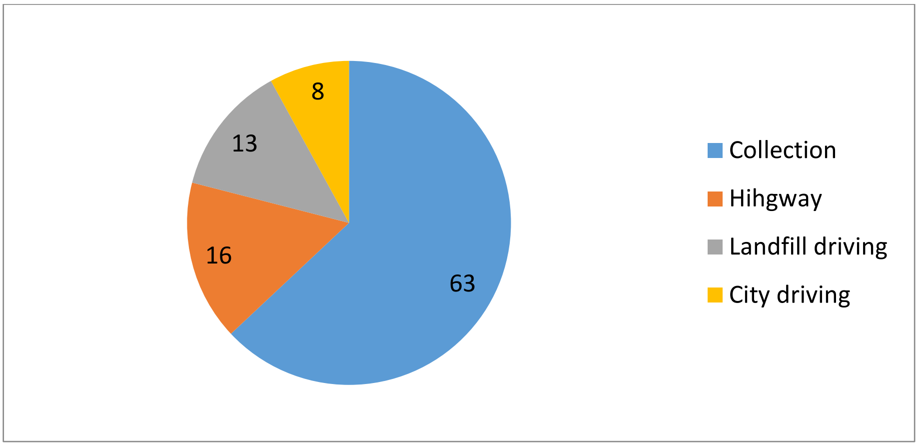

Diagram 5. Waste vehicle's work periods by percentage in densely populated areas (Clark et al. 1998)

The research of Sandhu et al. (2016) and Cannon (2017) show that on average a waste vehicle uses fuel at the rate 84l/100km given the specifics of their task which involves frequent stopping and acceleration. Such fuel consumption means that waste vehicles are among the largest fuel users on roads. In Tallinn's old town a waste vehicle's fuel consumption was 43l/100 km (Paper I). In the USA a waste vehicle travels 40 200 km per year and uses 33 700 litres of fuel on average, whereas 91% of the vehicles have diesel engines. According to Mari Jüssi and Poltimäe (2011), a waste vehicle in Tallinn travels 50 000 km/year.

Based on the data in Table 3 concerning fuel used (Mari Jüssi and Poltimäe 2011) the waste collection field's emission figures in Tallinn have been calculated (Table 6). The resulting CO_2 emission given the fuel consumption is 11 420 tons per year. Considering that waste collection is in second place after buses in terms of fuel consumption, then waste vehicle use most definitely requires regulation and route optimisation for reducing fuel consumption and thereby emission figures. The same conclusion was reached in Paper I.

Table 6. Estimated emission figures in tons based on fuel amount used per year in Tallinn

	EURO III	EURO V
CO, t	8.5	63.9
HC, t	28.1	19.6
NO_x, t	213.1	85.2
PM, t	4.3	0.9

When the legislation change (registered waste transportation) enters into force according to which people receive the opportunity to choose the waste transportation service provider themselves in Estonia, it will mean that in the same area there are different service providers emptying containers. The market opening brings with it increased emissions into the environment. In terms of air quality, it would be better if in one area there would be one vehicle that travels according to an optimised schedule so that situations where on one day a waste vehicle empties one building's container and the next day a vehicle comes to empty the container of the neighbouring building, are avoided. If vehicles of different companies operate in the same area, then the local government should implement rules on which days traffic is permitted to somewhat optimise emptying schedules and emission creation. In addition to producing more emissions, increased transportation would raise other environment detrimental effects – increased noise levels, traffic density and wasted resources.

The SA Säästva Eesti Instituut (2014) reached the conclusion that the collection and transportation of mixed municipal waste (95 000 t/y) produces much less greenhouse gases CO_2eq under organised waste transportation (approx. 500 CO_2eq (t)) than in the case of registered waste transportation (open market) (ca 1200 CO_2eq (t)) (Diagram 6).

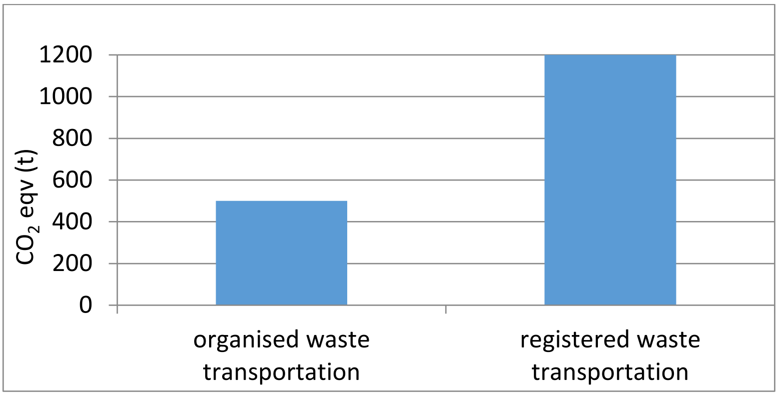

Diagram 6. CO_2eq (t) quantities produced according to two waste transportation solutions (SA Säästva Eesti Instituut 2014)

Under organised waste transportation it was assumed that the system is implemented in the entire city of Tallinn. In each area, waste transportation would be awarded to the company that won the tender. It was assumed under conditions of local government registration on the open market that the emissions are produced by the three waste transport companies operating in Tallinn which each have approximately the same market share. The modulation based on the assumptions showed that there are approx. 2.4 times more emissions in the city of Tallinn under open market conditions than in the case when mixed municipal waste is collected with organised waste transportation. The emissions created would be even larger would there be more than three waste transportation companies active on the market, as the same waste amount would be transported with a larger total number of kilometres (SA Säästva Eesti Instituut 2014).

Based on the SEI Tallinn Foundation and Paper I results, considering emissions it would be better to continue with the organised waste transportation system as it is and not switch to the registered waste transportation. The current transportation circuits should be analysed where possible and optimised. Paper I described Tallinn's old town as a densely populated area and it was concluded that currently the waste vehicle emptying schedule is not optimised and the schedules can be made more efficient. An optimised schedule would mean that the waste vehicle would visit the old town more seldom, use less fuel and reduce emissions as well as save human resources and produce less traffic congestion in the old town.

According to research by A. Larsen et al. (2009) in a Danish city centre area waste was collected at the rate 3.0 l/t of waste (Table 1). Research conducted in Tallinn's old town showed that in the old town to collect waste on average the fuel requirement was 4.4 l/t of waste. Usually fuel consumption depends on different factors such as the collection area characteristics, container size, vehicle, driver's experience, distance, acceleration etc. In Larsen's research two areas were considered: Aarhus and Herning. In the research the city centres were dominated by apartment buildings from which waste was collected mainly in 0.6 m^3 containers which were usually placed behind the building so that the waste vehicle did not have direct access to the container. The characteristics of Larsen's research area were different from Tallinn's old town (the collection area is described in Paper I) where waste is collected in smaller containers (usually 0.24 m^3) and under more difficult circumstances (the containers are in courtyards, locked behind fences, in underground wells or other similar locations requiring more emptying time) then it is understandable that more fuel is required for collecting waste in Tallinn's old town. As the fuel amount used in Tallinn is larger, so are the resulting emissions. In Denmark 7.8 and in Tallinn 11.4 kg CO_2 are produced per ton of waste.

The results of comparing A. Larsen et al. (2009) research's fuel quantities used in the city centre and the resulting emissions with the research in Tallinn are expressed in Table 7 according to vehicles corresponding to EURO III and EURO V requirements. In both cases it can be seen that a vehicle corresponding to more stringent requirements produces less emissions and its use is friendlier to the environment.

Table 7. Emission figures per municipal waste ton collection compared (A. Larsen et al. 2009) and Paper I results according to different emission requirements

	amount of pollutants			
	EURO III Denmark (A. Larsen et al. 2009)	EURO III, Estonia (Vilms, Voronova, and Loigu 2015)	EURO V Denmark (A. Larsen et al. 2009)	EURO V, Estonia (Vilms, Voronova, and Loigu 2015)
CO, g	61.0	89.4	43.5	63.9
HC, g	19.2	28.1	13.4	19.6
NO_x, g	145.1	212.9	58.1	85.1
PM, g	2.9	4.3	0.6	0.9

The use of alternative fuels would help reduce emission creation. If possible, biodiesel should be added to diesel. Contemporary diesel engine vehicles produced in the year 2011 were researched by Maimoun et al. (2013) in Orange County, Florida. The vehicles were in use in the city and the period examined was one hour of waste collection between 6 and 7 in the morning. The emissions of various alternative fuel engines were compared with diesel engine emissions. The article concluded that alternative fuels would reduce emissions. Reductions would depend on what alternative fuel is used or how much of it is added to the principle fuel.

The Sandhu et al. (2016) research draws the conclusion that the waste vehicle's entire driving cycle uses the most fuel and produces most emissions while collecting waste. The transport to the handling centre and driving within the centre account for a small share. Vehicles equipped with catalytic converters have 90% lower NO emissions than vehicles without converters. Similarly, vehicles with particulate matter (PM) filters produce 90% less emissions than vehicles without filters.

The emission figures released are dependent on the vehicle's speed (Table 8) as evidenced in the Maimoun et al. (2013) article. Higher speeds decrease emissions. Usually a waste vehicle travels at a low average speed continually braking and accelerating. Constant braking and accelerating as well as a low speed prevent cooling the engine and a lot of energy is required to keep the engine in motion due to the waste vehicle's weight.

Table 8.Emission dependency with the vehicle's speed (Maimoun et al. 2013)

Emission	8.5 km/h g/km	20.3 km/h g/km	32 km/h g/km	Idling g/h	Average g/km
CO	6.8	4.6	3.4	26.2	9.1
NOx	19.8	12.9	11.0	86.8	29.3
CO_2	2170	1510	1290	7930	2770

Collecting paper waste (door-to-door) with the kerbside method, the vehicle's fuel consumption per paper waste ton was higher than when collecting municipal waste (A. Larsen et al. 2009). The increased consumption was caused by less paper waste being picked up with each stop. When recyclable waste collection causes great fuel consumption then it is necessary to reconsider the used collection methods. As the research showed that the fuel amount is larger per ton of waste it might be more sensible to use a drop-off site or waste station instead of collecting paper waste with the kerbside method. In densely populated areas the waste amount collected is larger than what would be received from waste producers when using a drop-off site or waste station collection method. When most waste is collected kerbside, Tanskanen and Kaila (2001) state that people are more active and more material is received but at the same time fuel and labour costs also increase. The collection of biowaste was investigated by Bendere (2011) who reached the conclusion that transportation costs increase as distances increase, as more fuel is required. Under the given circumstances biowaste should be handled as close as possible to the creation area. In low-density areas biowaste should be composted at home.

The above allows to conclude that collecting recyclable materials with the door-to-door system might not be justified especially when taking into consideration the emissions the system produces. In low-density areas the waste amount received from people is small and the waste vehicle must travel a great distance to collect one ton of waste. However, the material received is clean and therefore the company might be interested in collecting it. In densely populated areas, especially in areas with apartment buildings, door-to-door collection is justified as there are many people in one apartment building and the waste amount collected with one emptying is larger.

The collection of sorted waste in densely populated areas involves many challenges which make it difficult to constantly achieve strong results (From Science to Solution 2008).

Challenges include:

- Access and space: Many buildings have not been designed in a way that permits collecting sorted waste and therefore space is not available for different collection containers.

- Tenant and manager transience: a sustainable collection solution is lacking in case the tenant and manager change.
- Education and outreach: notices sent by the city or collector usually only reach the owner or manager. The waste producers do not receive info they require.
- Contamination: caused by lack of education and recycling motivation or illegal dumping into recycling containers.
- Insufficient and unenforced contract: the contract should stipulate expectations, emptying schedules, service level as well as data collection and transmission means.
- Priorities: people are usually preoccupied with other matters such as coping socially or economically and sorting waste or thinking about waste handling is not important. Tenants usually do not have to pay separately for waste and therefore are not motivated to collect waste as sorted in order to save money.

3.1 Low-density area drop-off site

In low-density villages, most waste producers live in individual homes and there are only a few apartment buildings which means the door-to-door collection method is not the best solution considering the emissions produced. To collect waste from the waste producer, the waste vehicle must drive to each waste producer's household and stop to empty the container or pick up the bag. The waste producer must ensure that the waste container or bag is accessible for emptying on collection days. When the container or bag is not accessible, the waste vehicle makes an empty run for which the waste producer is obligated to pay for. In low-density areas the waste producers are located far away from each other. The door-to-door collection method causes noise and air pollution produced by the waste vehicle which also increases the traffic volume. The waste vehicle's weight may also pose a problem as it can damage village roads. There are households which are not accessible to the waste vehicle, for example in the case of homes accessible by earth-track.

A more detailed situation description can be found in Paper III where it is concluded that considering the emissions produced the door-to-door collection method is not the best solution for waste collection in low-density areas.

People living in low-density areas usually have at least one car per household for there are no other transportation means available or connections are limited. If the village centre has a drop-off site or the pole of attraction a waste station to where sorted waste can be delivered, then the residents of low-density areas can combine waste delivery with other drives to the city, school, work, store etc. The possibility and its advantages are described in Paper III. The big advantage of waste stations is that waste producers can deliver their recyclable waste free of charge to the station. Payment is necessary only for a limited number of waste types. The results analysed in Paper III concerning emissions show that municipal waste should also be taken to drop-off sites and door-to-door collection should be discontinued. Using drop-off site for municipal waste and sorted waste types gives people the possibility to sort waste and deliver the waste close to their home. Currently the given possibility does not exist in low-density areas and waste producers must travel very far to deliver waste, which is costly in terms of time and money. The situations are not seldom in which the county's waste station is further than the other county's waste station, but when visited requires proving that one belongs to the given county. Creating drop-off sites would allow collecting sorted waste which would be too expensive under the door-to-door system as well as producing too much environmental pollution. Older people who do not use cars could have their waste delivered to the drop-off site through a relative, acquaintance or the person providing the elderly with food and other necessities such as the social services provider.

Drop-off sites established in village centres should use underground containers (for example Molok type). The containers have a large capacity and therefore do not require emptying that frequently. Containers that are not emptied frequently produce less emissions when waste is being transported. The lower emptying frequency implies there is less emptying related noise too, in coparison to smaller wheeled containers. Those containers containing biowaste or which are contaminated with biowaste need to be emptied more frequently than clean material (e.g. paper and cardboard, packaging) containers. In containers with biowaste, decomposition processes begin which cause disturbance – e.g. odour, insects etc. Comparing underground and above ground containers, the first have the advantage of being underground where the surrounding area's temperature is maintained, and decomposition does not start as fast when the weather warms as with above ground containers. In cold conditions it is ensured that the waste will not freeze, and the container does not fill so quickly. Underground containers are comfortable to use by consumers and many consider them visually more appealing. Use comfort concerns the container's opening height which is not high and therefore comfortable for the waste producer. Negative factors might be the initial construction needs and natural conditions such as a high water table, which might make placing the container impossible or costly.

The city centres of Florence and Porto use underground collection containers (Helder 2017; Ferreira et al. 2017; Ponzini 2017). The location of each underground container in Tallinn's old town requires thorough consideration as their emptying might be problematic. Depending on the waste vehicle's emptying mechanism, a lot of vertical space may be required and that might not be sufficiently available in the old town (archways). Suitable solutions were found in Porto and Florence. Each location needs to be approached from its possibilities and existing conditions.

There is also the possibility to use roll-off containers at drop-off sites. These containers require a hard surfaced area which permits exchanging the containers (USEPA 1989). Such containers are not very convenient for people as to free oneself of the waste it must be tossed over the container's edge, unless a trestle has been built. Top-opening containers place the waste at the weather condition's mercy. Top-closed containers mean that the person must enter the container which is not a pleasant experience in general.

Village centre drop-off sites should collect the most frequently created waste – municipal waste, packaging, biowaste (if the local government has not obligated composting on one's own property), paper and cardboard. Other waste, such as electrical and electronic equipment waste (WEEE) as well as hazardous waste have at the pole of attraction or area's largest city waste stations that can be used by everyone not just the inhabitants of a specific county or municipality. In people's homes, sheds, garages there are so-called historical waste articles which people find easier to collect and store at home. When a major cleaning is done, the need arises to deliver the waste. If the waste producers are aware of the waste station's location and using it is convenient for them, the waste can be delivered to the station. Local governments occasionally provide and should continue doing so, collection runs for hazardous waste and WEEE which residents can deliver at their home. Examples of hazardous waste include batteries, leftover oil, expired pesticides, leftover medication and other similar items.

It is possible to use various means to gauge the container's fullness from the distance to avoid the waste vehicle from driving to a low-density area's drop-off site without reason. Various systems have been created for evaluating fullness, measuring quantities and collecting data - software-based routing, Geographic Information Systems (GIS), Radio-frequency Identification (RFID), sensor intelligent bins, image processing solutions etc (Akhtar et al. 2017; Malakahmad et al. 2014; Al Mamun et al. 2015; Hannan et al. 2011; Tristram 2009).

The current research has made a life-cycle analysis of village interior waste vehicle transportation in low-density areas. The scenarios' (door-to-door and drop-off) environmental impact have been modulated using the life-cycle assessment method and the corresponding software SimaPro 8.3.0.0. Inventory analysis data was evaluated using the ReCiPeMidpoint (H) V1.13 / EuropeRecipe method, where effects were evaluated in four categories – climate change, human toxicity, particulate matter formation and fossil fuel depletion.

Two different solutions have been compared – drop-off site in the village centre and door-to-door collection. The modulation aimed to determine which solution's single collection cycle produced the least environmental impact.

The results of the village interior collection circle modulation showed that a drop-off site produces less environmental impact than a door-to-door collection cycle. The impact extent is mainly contingent upon kilometres travelled and fuel consumed in the process. The distance to the village centre's drop off site is shorter than the distance to each home when collecting using the door-to-door system, therefore the environmental impact of a drop-off site circuit is smaller.

In a low-density area the vehicle travels 5 km to and from a drop-off site in the village centre on average and makes 13 runs per year. In one year 11.5 t municipal waste are collected from a village on average (average population 54 persons).

As seen in Diagram 7 below which shows percentual impact to climate change of the two different collection methods, the drop-off site solution is definitely better in low-density areas as its impact is smaller.

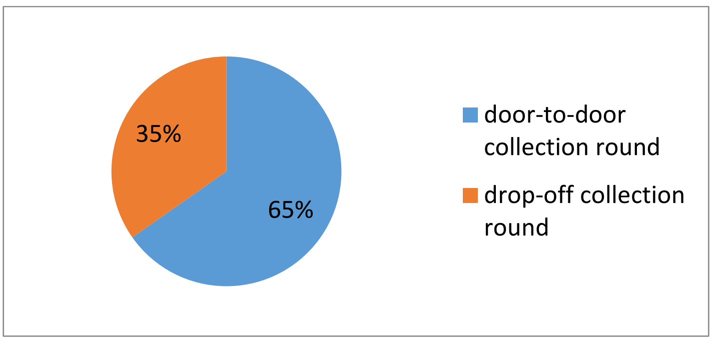

Diagram 7. Door-to-door collection circuit impact compared with drop-off site collection circuit in the climate change category

In the following Diagram 8, different impact categories and different process contributions have been percentually compared. Waste collection has the highest impact on climate change and particular matter creation. Human toxicity and fossil fuel depletion are more influenced by diesel production and its effect is more of a global nature and less of local importance.

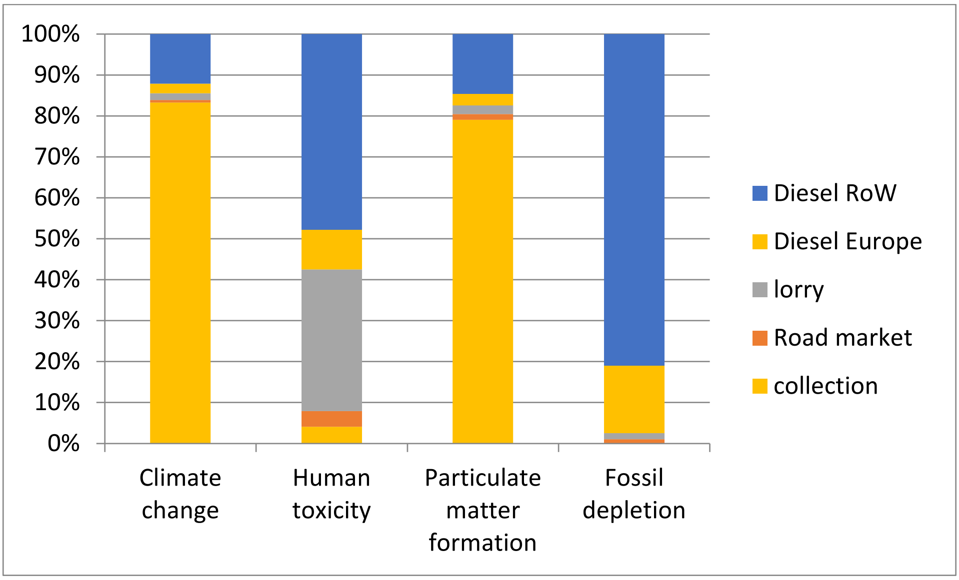

Diagram 8. Impact categories and different process contributions compared percentually

3.2 Waste collection from small islands

Waste collection on small inhabited islands in Estonia is usually organised such that the residents have the possibility to deliver waste to a waste station on the island from where the waste is transported to the mainland as needed. The bigger problem with waste is on small islands with no or limited permanent residents and where the island is a tourist attraction (Aegna, Naissaar). The problems in the latter case are littering as well as waste collection and its transportation to the mainland. Possible solutions for waste handling and its financing are discussed in Paper II using Prangli and Ruhnu islands as examples.

Kihnu Island is Estonia's seventh largest (16.4 km^2). The island has permanent residents – about 200 households and around ten active institutions-enterprises. According to 2009, 2010 and 2011 data of AS Kihnu Veeteed, the island is visited by 18 000 non-resident visitors per year of which 4 000 per month visit the island in the summer months on average. In the winter the number of tourists is almost non-existent, unless there is an official ice road. The island initially had a landfill site which was closed on 01.01.2002 and since then waste has been transported to the mainland. When the landfill site was closed the old cattle barn was used for collecting waste. In 2008 the barn was converted into a techno centre with rescue service offices, bottle return, gym and waste station. The island has a permanent ferry (capable of transporting vehicles) connection with the mainland, therefore the waste transportation is not as big of a problem as with Aegna and Naissaar described in Paper II.

Examining the SEI research data (Diagram 9) shows that there are no significant waste composition differences in the different regions (Tallinn, small cities, countryside which includes small islands). One can conclude that the municipal waste composition is approximately the same in densely populated areas and low-density areas. One could assume that in low-density areas (islands) the composting of biowaste is possible and therefore the biowaste share should be lower, but the SEI data shows the opposite.

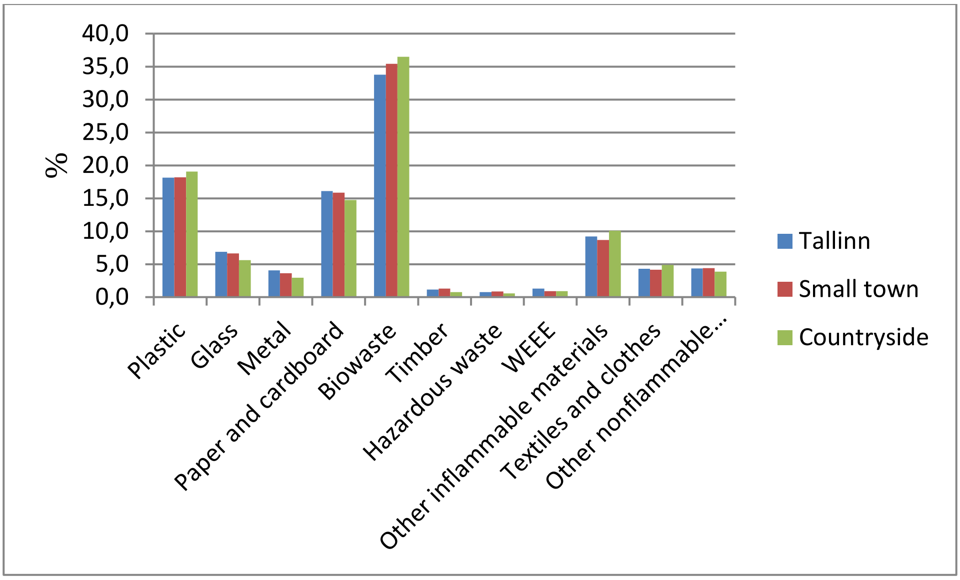

Diagram 9. Mixed municipal waste type composition by area (mass percentage) (SEI Tallinn 2013)

The SEI research used rural municipalities in the counties as countryside representatives, for example Järva County was represented by Imavere, Koigi and Paide rural municipalities and Pärnu County by Varbla and Tõstamaa rural municipalities etc. All have apartment buildings in their centre, but the research does not indicate how many households participated in the research. One can assume that in apartment buildings, regardless of location, Tallinn or Imavere, similar waste is produced as the people's behavioural habits are similar.

The average population of Kihnu rural municipality is 509 people according to Statistics Estonia (Eesti Statistika 2017). The collected waste quantities are different per year and were larger in the years 2007 and 2008, thus for these years the waste amount per person is also higher. In the year 2010 the waste amount collected on Kihnu Island was very small for unknown reasons. In the years 2013-2015 the waste amount has been stable, remaining at 75 kg/pers/y (Diagram 10), but these results are below the SEI research average of 200 kg/pers/y. There are many possible reasons for why less waste is being produced or delivered on the island: consumption has decreased; less opportunities for making purchases, waste is burnt in burning brands or fires, waste is buried or delivered in some other means.

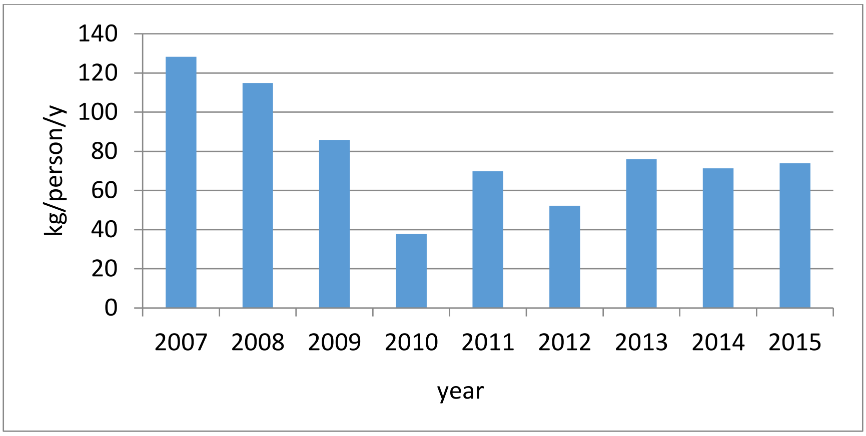

Diagram 10. Kihnu rural municipality waste amounts kg/pers/y (Keskkonnaagentuur 2017)

There are large differences in waste collected per year (Table 9) as seen when analysing Kihnu's waste data. There are some years in which nothing has been collected or the difference range is extensive from year to year.

Table 9. Collected waste types and amounts in tons on Kihnu Island (Keskkonnaagentuur 2017)

	2007	2008	2009	2010	2011	2012	2013	2014	2015
Paper and card-board	0.06	n/d	n/d	1.86	0.66	n/d	1.20	0.21	n/d
Glass	n/d	n/d	n/d	n/d	0.14	n/d	n/d	n/d	n/d
Hazar-dous waste	n/d	0.00	0.34	0.00	0.58	0.44	0.18	0.16	0.94
WEEE	n/d	n/d	1.00	n/d	n/d	0.54	n/d	n/d	0.28
Metals	n/d	0.04	n/d	n/d	n/d	n/d	n/d	n/d	n/d
Packaging	3.65	5.05	13.83	3.59	8.11	5.12	7.30	5.41	7.46
Biodegra-dable waste	n/d	n/d	n/d	2.00	2.00	3.00	5.00	3.00	2.40
Mixed municipal waste	61.59	53.40	28.50	11.82	24.11	17.47	25.08	27.55	26.59
TOTAL	65.30	58.49	43.67	19.27	35.60	26.57	38.76	36.34	37.67

The waste quantity differences are evident when comparing Prangli and Kihnu islands. In the year 2013 paper and cardboard waste was collected at the rate of 1.7 kg/pers/y at the Prangli waste station (Table 10), whereas on Kihnu island the amount was 2.36 kg/pers/y and the corresponding figures for packaging waste were 1.9 kg/pers/y and 14.34 kg/pers/y.

Table 10. Waste amounts collected at the Prangli waste station 2012 - 2013. (Põld 2014)

Waste type	Unit	2012	2013
Car tyres	kg	180	220
Paper and cardboard waste	kg	280	300
Packaging waste	kg	275	350
Glass (incl. sheet glass)	kg	100	140
Treated timber	kg	150	170
Complete electric and electronic equipment	pc	4	6
Refrigerators	pc	3	4
Scrap metal	kg	1000	2000
Unsorted construction waste (excl. eternit)	kg	300	250
Hazardous waste:	kg	0	0
Mercury; mercury lamp; chemicals; Dangerous substances packaging; acids; medication; detergents containing dangerous substances	kg	0	0
Batteries	kg	2	3
Old oils	pc	40	60
Paint waste	kg	25	47
Oil filters	pc	10	8

The Kihnu waste station is equipped with a pressure container (multilift) for collecting mixed municipal waste, containers and equipment for collecting recoverable waste and reducing their volume. A composting field is available for composting garden and park waste. The Kihnu waste station's charges have been established by the Kihnu Rural Municipality Council (Kihnu valla jäätmehoolduseeskiri 2008). The waste types accepted free of charge are mixed packaging, hazardous waste, old tyres, electronics waste, bulky waste, construction glass, paper, scrap metal as well as paper and film packaging. Chargeable waste includes mixed municipal waste, construction waste and biodegradable waste.

The mixed municipal waste container is emptied twice per year and taken to the Paikre landfill with a multilift vehicle where it was previously deposited. Currently, technology at the Paikre landfill has been updated and waste can be used to make refuse derived fuel. Waste is transported only if there is a ferry running between the island and mainland and there is a sufficient waste quantity.

The growth of visitors to the island in tourism season by tourists and real estate owners causes an increase in waste creation. At times of larger events there are not enough accommodation places, thus people pitch tents where they please. Many leave the waste behind at the place where they pitched the tent. The tourists that visit the islands must take responsibility for handling the waste they produce. Paper II describes responsibility options. People's awareness can be increased through informing and educating, for example by placing informative signs at the port which explain what leaving waste behind on the island entails. More effective would be the collection of a so-called waste tax from tourists. One option would be that the person would buy a waste bag from the mainland and when returning a full bag of waste, the person gets a refund. If the person does not return the waste bag to the mainland, then the amount paid is used to develop the island's waste management.

People moving around on the island can place their waste into waste containers by stores, the port or other institutions. There are six roadside waste containers on the island which are emptied by the rural municipality's gardener. The waste containers are emptied approximately once a week in summer season and once every two months in winter. The minimal amount of waste containers is certainly one reason for littering. Another reason is people's hostile behaviour towards the environment. It is widespread among waste producers to burn all kinds of waste (plastic bottles, packaging, bulky waste, municipal waste etc.) in fires. Similar problems have been described in Paper II on the islands Aegna, Naissaar, Prangli and Ruhnu.

In Finland in the Kemiönsaar archipelago on the islands Rosale, Hiittisten and Högsåra the mixed municipal waste collection has been solved using a property related waste tax. The waste tax is based on the waste maintenance board approved tariffs. The waste tax is an annual tax invoiced once per calendar year by the city government administrative unit. The permanent residence annual tax amount is established by the number of residents and composting extent. The waste tax is paid for each permanent home or cottage (building). In exceptional cases according to its judgement the waste maintenance board may establish a different waste tax then what is established in the tariff (Table 11) (Rouskis OY 2013).

Table 11. Annual waste tax per property (Rouskis OY 2013)

Housing	Housing waste tax (€/home/year)
Permanent home, food waste is not composted	137.60
Permanent home, food waste is composted	105.00
Permanent home, single inhabitant, food waste is not composted	82.40
Permanent home, single inhabitant, food waste is composted	59.50
Cottage, food waste is not composted	105.00
Cottage, food waste is composted	80.15

Mixed waste regional collection containers can only be used for municipal waste created daily. Bulky waste, construction waste, home appliances, hazardous waste and electronics must be taken to the waste station. Collection sites are usually locked, but users have keys for the waste containers. Biowaste can only be composted in the composter which is not accessible to pests (e.g. rodents). (Rouskis OY 2013)

3.3 Taxation

The most reasonable means for developing waste handling would be to use a waste tax. The tax must be sufficiently large to motivate people to change their habits. Collecting the tax gives the state or the local government the possibility to create drop-off sites or other necessary collection centres. Private companies might not be interested in developing waste maintenance to such an extent and will do as little as possible or as much as legislation obligates.

The problem “who pays how much” would not exist for example in case of a state waste tax in case of using joint containers. The current research is not focused on waste tax creation and the related peculiarities. In case a person lives in Tallinn but moves to a countryside residence for the summer months, how should such a person be taxed is an example problem. A waste tax is one possibility for improving waste maintenance financing.

There are problems in Tallinn’s old town for finding waste container locations. Buildings have been built without consideration for waste containers. Space may be found for a municipal waste container but making the collection of sorted waste possible does not exist for there is no space for additional containers. The same problem persists in large cities or other densely populated areas. Often in buildings with many flats there is no space for different containers. Currently when new apartment buildings are being built, legislation in Tallinn and in most of the states of the USA requires that a separate room must be designed for collecting waste.

There are cases in Tallinn’s old town where there is the desire to build a waste building in the courtyard, so that the residents could collect sorted waste. The question that arises is whose land it is which the building is built onto, who pays and how much. Should residents and companies pay the same fee for delivering waste or should companies pay more as they create more waste? A restaurant produces more food waste than a household, for example. There could be a company in the building that does not produce any biowaste whatsoever. If there would be a waste tax, then everybody pays and can use the offered service. Using a solution where the waste building in the courtyard is used by the buildings and tenants (residents and companies alike) around it, then access to it should be with a key. Where possible, such waste buildings should be developed in cooperation with several buildings, which despite residents and companies having to move more to deliver their waste, would help them act according to legislation which obligates the waste to be sorted.

A similar system functions in the city of Porto, where drop-off sites have been developed for residents and companies to which they can deliver their waste. The residents are used to the system and agree to take the west beyond the property boundaries. The people of Porto pay a waste tax which is different in different parts of the city but is based on the water consumption at the property. As the city collects the tax from the people, there is more money available for waste management organisation. There are many drop-off sites in the city centre which use underground containers to which residents can take their waste. (Helder 2017; Ferreira et al. 2017)

Currently the price of emptying a waste container depends on its size and not on sorting in Estonia. The waste producer has no motivation for sorting waste, as the container must be full on the emptying date as payment is always made according to a full container.

The minimal container collection frequency in case of waste transportation is:

- In homes of densely populated areas – at least once every four weeks;
- In densely populated areas where biowaste composting is ensured at the waste creation site – the municipal waste can be transported once within every 12 weeks;
- In low density areas – at least once every 12 weeks.

Implementing a differentiated waste tax according to how much the waste producer sorts would enable changing the frequency of municipal waste container emptying. The lower the number of visits the waste vehicle makes to the waste producer, the lower the emission figures produced.

3.4 Separate collection of waste

According to the Environment minister's regulation „Municipal waste sorting order and basis for classifying sorted waste" RT I, 19.12.2015, 5", waste producers must collect the waste types described in Table 12 separately at the creation location. Sorting is necessary to ensure the sorted materials have higher quality and increase its recoverability, improve the sorting efficiency and to avoid unnecessary wasting of energy as well as human resources during secondary sorting or separation of mixed municipal waste. Municipal waste sorting and collection by type is organised by the local government administrative unit itself or in cooperation with a recycling organisation, producer's association and other waste handlers who collect or recover waste.

Different waste types can be collected using different collection methods which are indicated in Table 12. Several waste types are suitable for different collection methods. The most appropriate solution in the given area can be found considering the local conditions and needs.

The waste management situation depends largely on the local government's activities, which has many obligations in the field. In order for Estonia to have a unified waste managament and handling system, the municipalities must cooperate with each other. Cooperation should result in economic gains, lower maintenance costs and unified collection areas should have unified service fees. Waste handling infrastructure should be created independently of the municipality, so that it is comfortable to use and accessible to the waste producer.

The waste management plan is a document that makes plans for waste maintenance solutions, municipalities should cooperate. In certain areas, especially in low-density areas, people move from their administrative territory into other poles of attraction. If a person lives on the border of a municipality and its pole of attraction is 30 km away, the waste station of the neighbouring municipality could be in a pole of attraction 15 km away.

Japan is a good example of successful waste handling (Hershkowitz and Salerini 1987). In Japan materials that are recycled are considered as resources, not waste. As Japan is dependent on imports, the consideration is understandable. In Japan most people live in areas with population densities greater than 4000 people per square kilometre. In Japan cooperation exists between all government levels and a lot of opportunities are given to the local level to improve the waste management organisation based on the local conditions.

The reasons why Japan is so far advanced is because the following problems occurred early:

- no suitable land for landfilling;
- littering of soft-drink containers;
- waste amount increase;
- increased collection cost;
- illegal dumping;
- the need for more recycling.

Table 12. Possible collection solutions for different waste types

	Possible collection method							
Waste type	1	2	3	4	5	6	7	8
paper and cardboard (20 01 01)	+	+	+		+			+
plastics (20 01 39)			+				+	
metals (20 01 40)			+		+			+
glass (20 01 02)			+					
Biodegradable garden and park waste (20 02 01)	+	+	+	+	+	+		
Biodegradable kitchen and restaurant waste (20 01 08)	+	+	+					
Non-biodegradable garden and park waste (20 02 02, 20 02 03)			+		+			
packaging (15 01), including paper and cardboard packaging (15 01 01), plastic packaging (15 01 02), wood packaging (15 01 03), metal packaging (15 01 04), composite packaging (15 01 05), glass packaging (15 01 07), textile packaging (15 01 09) and other packaging corresponding to the municipal waste concept described in the Waste Act's § 7	+	+	+		+		+	+
timber (20 01 38)			+		+	+		+
textile (20 01 10, 20 01 11)		+	+	+		+		+
bulky waste (20 03 07)	+		+	+	+	+		
problematic product's waste (20 01 21*, 20 01 23*, 20 01 34, 20 01 35*, 20 01 36)			+	+	+	+	+	
domestically created hazardous waste (20 01 starred „*" waste)			+	+	+	+	+	

1-door-to-door, 2-drop-off site, 3-waste station, 4-seasonal collection – local government ordered for a specific route, period and waste type, 5-special order – the waste owner requests waste transportation as needed, 6-temporary collection point – a collection point is created for a predefined period with the appropriate containers for the waste collected, 7-producer's liability organization – collection according to the producer's liability organization procedures, 8-buying up – the waste owner can convert waste with commercial value into cash.

The local governments in Japan have equal rights and obligations for waste handling management, but they do not use the same strategies. Decision making is done on the local government level, as municipalities have different characteristics – economically, socially and environmentally. The general aim is to remove waste from the creators living environment quickly and safely.
Municipalities are required to:

- educate the public regarding solid waste disposal;
- collect, transport and dispose of municipal waste;
- improve technological performance;
- record and maintain data.

In the city environment Japan finds that sorted waste is best collected in drop-off sites. Usually a block of 15-40 households are grouped around a collection site.

In the USA according to the Agency Environmental Services (2011) data, different states have different solutions for collecting waste and requirements concerning types which must be collected separately. Systems used include PAYT, waste tax, some free of charge services, e.g. garden waste collection. The requirements are also differentiated by single family homes and apartment buildings with over 100 flats.

In the USA, traditionally the county government dictates which waste transporter collects waste from single family homes using kerbside collection or the county provides the service itself. In multi-family homes counties either offer services themselves or establish different requirements for the service providing company. The research From Science to Solution (2008) discovered that the county's role in waste management is to set up policy and/or be in a supportive role providing facilities and processing infrastructure. According to State Law (Padilla 2011) in California for example, recycling services are required in any multi-family dwellings with over 5 units. For years, the requirement is in force, yet collection has not been successful. The main problem is contaminated waste. The state lacks concrete data, as no research has been made and most multi-family accounts are picked up on commercial routes by front end loaders.

According to the Agency Environmental Services (2011) in California yard trimmings are not accepted at landfills, therefore cities offer special collection for yard trimmings every other week. It is no allowed to process yard trimmings with municipal waste. As the city itself offers the service, there is a separate administrative unit with duties to educate the waste producers, analyse waste quantities and possibilities for their reduction, analyse collection schedules and routes, map and liquidate problems etc.

In densely populated areas of the USA waste collection services are usually offered once a week and more frequently in case of apartment buildings. Offering collection services is especially important in warmer climate areas as a warmer climate encourages decomposition processes which produce odours. In Miami in areas with single family homes there is an automatic collection system according to which the waste producer must place the waste container on the street by a certain time. There are requirements in place concerning the container's distance from fences, homes, cars, street posts etc. A side loading vehicle with grapplers pulls up to the container, lifts the container to empty it and returns the container to its position. The system works well in areas with single family homes where there is a lot of space but would not function in densely populated areas. Collection is fast but requires driving the same street twice to collect waste from both roadsides.

In addition to knowing their area's special characteristics, the local governments and other decision makers need to involve the waste producers as early as possible in the waste handling planning process (USEPA 1989). Introduction and education need to correspond to local requirements and be ongoing. The decision makers need to understand the audience listening to them when planning waste producer education – the training plan must be created according to the listeners. The listener must understand what is being said. The introduction and training concerning the waste programme parts requiring people's participation is especially important – for example sorting through which the state recovery targets can be achieved.

It is necessary to educate waste producers concerning the environment, so that they know how to use drop-off sites, waste stations or door-to-door systems for sorted collection. The same conclusion was reached in Paper IV. In the described school the emissions related to waste transportation did not decrease, but waste recovery increased. Developing a sorting system for a single institution makes clear the understanding that the same waste collection principles cannot be applied to each institution, area, city or village. It is important that each location/area is approached with the specific characteristics and conditions in mind. At the school waste producers and school cleaning staff who were a link between the waste producers and the waste container received training. The new collection system implementation was successful as seen in the Paper IV results. In the beginning cleaning staff was trained, but the staff turnover was larger than anticipated and the supervisors trained new recruits less than expected. The staff turnover indicated that training must be ongoing and consistent. Training is necessary in all stages. When students saw that cleaning staff collected sorted waste into a single bag, the word spread that sorting does not make sense as everything is put together in the end anyway. The same rumour is spread in cities or the countryside when residents see separately collected waste containers emptied into the same municipal waste vehicle. The people do not see the background – the container may have contained municipal waste or been contaminated otherwise and therefore unsuitable for recovery. Waste producers should be trained to reduce the possible waste volume in containers as this is one possible means for reducing the container's emptying frequency which helps reduce the vehicle produced emissions.

The waste producers can be educated using different informative tools – different state-wide waste themed campaigns with TV clips, advertisements, info brochures, training days etc. The media can be used for informing by distributing articles concerning the environment which explain the need for avoiding waste and provide advice on sorting waste.

Conclusion

The main aim of the thesis was to research the existing collection methods in so-called problematic regions and the related emission figures produced by waste vehicles in order to offer collection methods that would have less impact on the environment.

As in most of Estonia, in the areas under observation (Tallinn's old town as a densely populated area, low density areas represented by 10 Estonian villages and five small islands), the door-to-door collection system was used. The given solution is convenient for waste producers, as the waste is removed from the property or property boundary. A person only needs to place the waste in the container and in the case of individual homes to make sure that the container is accessible on the collection day in order to be relieved of the waste.

In the observed densely populated area of Tallinn's old town which is a UNESVO World Heritage site, the biggest problems with waste collection are dense population, narrow streets, container accessibility and large waste amounts (Paper I). The city of Tallinn, given that the old town is a touristic site with heritage protected buildings and the area is frequented by tourists, restrictions (emptying times, waste vehicle weight etc.) concerning waste transportation are in place. An analysis of the existing emptying schedules showed that optimisation is possible which would lead to reduced emissions. Currently there are situations where every home has emptying frequencies of once per week but emptying takes place on different weekdays. The city of Tallinn stipulates that waste vehicles used in Tallinn's old town must minimally correspond with EURO III requirements. If EURO III vehicles would be replaced by EURO V corresponding vehicles, CO emissions would be reduced by 28% and PM figures by 80%. Currently the waste vehicle creates approx. 84 kg CO_2 with one collection round, but the waste vehicle is then under filled. Would the waste collected with a collection round increase (10t) per year, the CO_2 emissions would be reduced by 9 tons.

The biggest problem in low-density areas in collecting waste is the small waste amount which is collected with a long collection round. The waste producers are far away from each other and the waste vehicle requires a lot of fuel and time to reach every waste producer. Additionally, access to the container might be more difficult due to the road's load capacity or lack of snow removal in winter. In Paper II it was shown that the current door-to-door collection system should be replaced by a village drop-off site to which the waste producers can deliver their sorted waste. The current door-to-door system does not support sorted waste collection and in low-density areas sorted waste collection using the door-to-door system would require an additional vehicle or additional collection round which would increase the emission figures. The waste producer would be required to take the waste to the village drop-off site on one's own. The trip can be combined with some other necessary travel (shop, work, school etc.), so the emissions produced would be equivalent to zero. Comparing the door-to-door collection with the drop-off site collection solution, the latter would allow reducing the CO_2, PM and NO_x quantities created by almost half. The emission figure created is dependent upon the fuel consumption, then the advantages of a drop-off site are evident as the waste vehicle only needs to travel to one point instead of many waste producers and the waste amount received from the point is significantly larger. Additionally, the time required to collect waste is reduced, similarly to vehicle related problems (road damage, noise, odour etc.). The emission figures could further be reduced, if low-density areas, like in Tallinn's old town for example, would stipulate the requirement to use waste vehicles that minimally correspond to the EURO III requirements.

In summary, the following activities would lead to a reduction in resulting emissions:

- using alternative fuels in waste vehicles;
- optimising collection routes such that empty runs would be minimised and collection in the same area would take place on the same day;
- exchanging lower emission requirement waste vehicles against higher emission requirement vehicles;
- reorganising waste collection methods such that the waste vehicle need not travel to every waste producer's property, for example using drop-off sites in low-density areas, with the same drop-off site being used for sorted waste;
- local government cooperation, so that the area's waste producers could comfortably relieve themselves of waste and similar investments are avoided if done jointly by several municipalities.

If in densely populated areas and low-density areas of the mainland the concern is reducing emission figures, then on the islands and especially the small islands the problem is waste collection and its transport to the mainland. Numerous research papers on small islands with areas more than 200 km^2 and population more than 7000 have been prepared. Looking at Estonia's small islands which are defined by the Permanently Inhabited Small Island Act, their area and population is significantly smaller, thus on a world scale we could talk about micro islands. The focus problem in waste collection on the islands is the exponential waste growth during the tourism season. There are many small islands with a low number of permanent residents (for example Aegna with two persons), but in the summer months the island is visited by thousands of tourists and sunbathers who come to the island to spend time with picnic baskets and leave the resulting waste on the island. Islands that have permanent connections with the mainland do not have so many problems transporting the waste to the mainland as the islands without connections. In the latter case the local government needs to order a separate vessel for the waste transportation from the island to the mainland. Local governments often lack funds for developing waste management, then often islands do not have sufficient public containers which can lead to waste producers leaving their waste in nature. People's lack of knowledge or carelessness may also be causes for leaving waste in nature. The use of private boats increases in the navigation season, which also increases the number of visitors to the islands. In the small island harbours there are waste containers and if waste has been produced, boat owners want to be relieved of it quickly, so they leave the waste on the island. In the case of small islands, it would be important that the responsibility for waste collection and transportation would rest partially with the island's visitors, in other words the polluter pays principle should be implemented. Usually the tourist is not the municipality's inhabitant to which the island belongs and therefore the tourist currently makes no contribution to the waste maintenance development. One possibility would be to increase the tourists' environmental awareness and using different informative posters to explain why waste should not be thrown into nature, burnt in fire, thrown into the sea and why it should be taken back from the island to the mainland. The waste producers might not be motivated by such a gentle approach. Another solution would be to request payment for the island's tourist's waste collection and transportation. The fee could be added to the ferry ticket cost or the port fee. The possibility of using a deposit system also exists according to which a person can buy a waste bag from the mainland for a certain cost and if the bag is returned to the mainland filled with waste, the deposit is refunded.

There is no state-wide waste tax in Estonia. The winner of organised waste transportation tenders is the bidder with the lowest price. The company, by offering a low price is not capable of making investments and often the company is not interested in investments as the waste collection organisation task has been placed on local governments. The current legislation, however, does not offer financial opportunities to local governments to develop waste maintenance. By implementing a waste tax in Estonia the state could organise waste maintenance through local governments. The current solutions are unsuitable to waste producers. When a waste producer is further away from its municipality's pole of attraction than from the neighbouring municipality's pole of attraction, the person would want to deliver the waste to the closer waste station where proof of belonging to the municipality may be requested. A person would be free to choose which waste station to use, if a waste tax was in use. The more convenient it is for a waste producer to deliver waste the more waste will be recoverable.

In the future many questions related to the current doctorate thesis can be investigated.

Various economic instruments exist which can be used to influence and direct people's habits. The largest investigation area could be the description of economic instruments and an analysis for finding the most suitable ones. One point currently raised was the implementation of a state waste tax. A future research could be the methods and opportunities inherent in implementing a waste tax.

The circular economy package accepted by the EU places many additional obligations on the state, it is important to collect waste as sorted. Much attention must be turned to informing people or other means must be found which motivate people to collect waste as sorted.

Current argumentation looked at possibilities for reducing emissions and solutions were offered for waste collection, but the socio-economic factor was not taken into consideration, which is another subject which deserves future investigation.

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Abstract

Waste handling management in city centres, low-density areas and small islands and its effect on formation of air emission

Currently waste is more a resource than unutilisable material that can or should be stored in landfill sites. Waste contains a lot of useable material. Waste should be collected separately already by the waste producer so that the material remains clean and can be recovered.

Currently the door-to-door collection system in Estonia does not support waste recovery, especially in low-density areas where distances are large and transportation costs per waste ton collected are high.

The current thesis investigated the waste collection solutions of three areas – the densely populated Tallinn's old town, 10 villages in Estonia's low-density areas and five small islands. An analysis of the existing solutions was made and recommendations concerning the investigated areas were made for solutions that produce less emissions and are more suitable.

Each investigated area had its own problems. In Tallinn's old town there are narrow streets with numerous tourists and cars, in villages a waste vehicle might not even be able to reach a waste container dependent on road conditions etc. Choosing collection systems for different areas, the area's characteristics must be considered as well as the local indicators.

The analysis showed that to reduce emissions in Tallinn's old town, the current waste vehicles corresponding to EURO III requirements should be replaced with vehicles conforming to EURO V or higherrequirements. The existing collection schedules should be optimised, as currently the vehicle travels on the same street on many days despite waste being collected from waste producers once a week. Developing a pneumatic waste collection system in densely populated areas would rid the area of vehicles and the connected disturbances (noise, odour etc.).

A waste vehicle in low-density areas needs to use a lot of time and kilometres to collect a small waste quantity. Emissions and other environmental disturbances are high in comparison with low-density areas, where drop-off sites are used. Waste producers can bring waste to drop-off sites themselves, combining the trip with some other aim (for example going to work or shop). Currently collecting waste as sorted is difficult in low-density areas, as sorted collection stations are located far away or the closer one is situated on the territory of another municipality that does not accept waste from other municipality residents (or does so against a fee). A village centre drop-off site would solve the problem.

The biggest problem in collecting waste on small islands is not collecting it from residents but from tourists visiting the island. Islands with no or limited permanent residents are faced with the problem of seasonally created large waste quantities that need to be transported to the mainland which is a costly undertaking for which tourists do not provide compensation. Considering the polluter pays principle, the tourist should still take responsibility for the waste brought and left on the island by the tourist, as the

waste requires transport back to the mainland for handling. A possible solution would be a waste tax which could be incorporated into the ferry ticket or port fee.

The current thesis proposes as one solution the creation of a state waste tax for financing waste collection development. The waste tax could eliminate the current problem, where the resident of one municipality cannot use the waste station on the territory of another municipality. The tax could also solve the problem in densely populated areas where space for waste containers is limited, so many containers for the same waste type would no longer be required, despite the containers belonging to different owners.

The waste producers need to be environmentally educated so that they are aware of the possibility to collect waste as sorted and familiar with different collection methods.

The conclusion was reached that each area requires a waste collection method that takes into consideration the peculiarities of the area. A unified door-to-door collection system throughout Estonia is not justified and alternative methods must be provided that produce less emissions. Different collection methods offer waste producers more possibilities for collecting waste as sorted and thereby increase the quantity of waste collected as sorted.

Lühikokkuvõte

Jäätmekäitluse organiseerimine linnakeskustes, hajaasustusaladel ja väikesaartel ning selle mõju õhuheitmete tekkele

Jäätmed on tänapäeval pigem ressurss, kui kasutuskõlbmatu materjal, mida saaks või peaks prügilasse ladestama. Jäätmetes leidub palju kasutuskõlblikke materjale, mida saab kasutada. Lähtuvalt sellest, tuleks jäätmeid koguda liigiti ja seda juba jäätmetekitaja juures, et saaks kätte võimalikult puhta materjali mida taaskasutusse suunata.

Hetkel Eestis enamlevinud jäätmete ukselt-uksele kogumise süsteem seda aga ei toeta. Eriti näiteks hajaasustusaladel, kus vahemaad on suured ja transpordikulu ühe tonni kogutud jäätmete kohta on suur.

Antud töös uuriti kolme piirkonna – tiheasustusalana Tallinna vanalinna, hajaasustusaladel kümmet Eesti küla ja viite väikesaart – jäätmete kogumislahendusi. Analüüsides olemasolevaid lahendusi pakuti töös välja vähem õhuheitmeid kaasatoovaid ja sobilikumaid jäätmete kogumislahendusi uuritud piirkondadele.

Igal uuritud piirkonnal on jäätmete kogumisel omad põhilised probleemid. Näiteks Tallinna vanalinnas on kitsad tänavad rohkete turistide ja autodega, külades, olenevalt teeoludest ei pruugi jäätmeveok üldse jäätmekonteinerini jõudagi jne. Erinevatele piirkondadele kogumislahendusi valides peaks kindlasti arvestama iga piirkonna eripärasid ja sellele kohale iseloomulike näitajatega.

Analüüsides tiheasustusalana Tallinna vanalinna selgus, et õhuheitmete vähendamiseks tuleks praegune EURO III nõuetele vastav jäätmeveok vahetada EURO V või kõrgema vastu. Optimeerida tuleks kindlasti olemasolevaid veograafikuid, sest hetkel sõidab veok samal tänaval mitmel päeval, kuigi jäätmetekitajate juurest kogutakse jäätmeid üks kord nädalas. Veokite kaotamiseks ja seeläbi ka erinevate häiringute (müra, hais jne) eemaldamiseks sobiks tiheasustusalale rajada pneumaatiline jäätmete kogumissüsteem.

Hajaasustusaladel peab jäätmeveok kulutama palju aega ja veokikilomeetreid, et koguda väike kogus jäätmeid. Seega nii õhuheitmete kui muude keskkonnahäiringute osakaal on suur võrreldes lahendusega, kus hajaasustusaladel kasutataks jäätmete kogumispunkte. Jäätmete kogumispunkti saavad jäätmetekitajad tuua jäätmed ise, ühildades sõidu muul eesmärgil tehtava sõiduga (näiteks tööle või poodi). Jäätmete kogumispunkt külas võimaldaks jäätmeid koguda liigiti, mis hetkel hajaasustuses elavatel inimestel on keeruline, kuna liigiti kogumislahendused asuvad kaugel või lähemal asuvad on teise KOV territooriumil, mis ei võta (või teeb seda raha eest) vastu jäätmeid teise KOV elanikelt.

Väikesaartel ei ole suurimaks probleemiks mitte jäätmete kogumine elanikelt vaid saart külastavatelt turistidelt. Püsielaniketa või väheste püsielanikega saarte puhul on probleemiks hooajaliselt tekkivate suurte jäätmekoguste transportimine mandrile, kuna see on majanduslikult kulukas ja turistid ei panusta sellesse. Lähtuvalt saastaja maksab printsiibist peaks siiski ka turist vastutama selle eest, et tema saarele toodud ja jäetud jäätmed mandrile käitlusesse jõuaks. Üheks võimalikuks lahenduseks oleks jäätmemaks, mis makstakse näiteks laeva sõidupileti või sadamamaksu osana.

Ühe lahendusena jäätmete kogumise arendamiseks pakutakse antud töös välja ka riikliku jäätmemaksu loomist. Jäätmemaksu olemasolu võiks kaotada hetkel levinud probleemid, kus ühe KOV elanik ei saa kasutada teise KOV territooriumil asuvat jäätmejaama. Või olukorra tiheasustusalal, kus ruumi niigi vähe jäätmekonteinerite jaoks, on ühes hoovis mitu konteinerit samale jäätmeliigile, sest kõik konteinerid kuuluvad erinevatele omanikele.

Jäätmete liigiti kogumise ja erinevate kogumisvõimaluste tutvustamiseks tuleb kindlasti tegeleda ka jäätmetekitajate keskkonnaalase harimisega, et nad oleksid võimalustest teadlikud.

Töös jõuti järeldusele, et igale piirkonnale tuleb jäätmekogumis lahendust pakkudes läheneda arvestades selle piirkonna eripära. Kogu Eestile ühtne ukselt-uksele jäätmete kogumise süsteem ei õigusta ennast ja alternatiivina tuleks pakkuda ka muid lahendusi, mis on vähem õhuheitmeid tekitavad. Erinevad kogumislahendused pakuvad jäätmetekitajatele rohkem võimalusi jäätmete sorditult kogumiseks ja seeläbi suudetakse suurendada ka jäätmete liigitikogumise määra.

Appendix

Publication I

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THE PROBLEMS OF MUNICIPAL WASTE COLLECTION IN CITY CENTERS AND AIR POLLUTANTS FORMED IN THE PROCESS

M.VILMS*, V.VORONOVA* AND E.LOIGU*

** Department of Environmental Engineering, Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia*

SUMMARY: Waste collection is obstructed by heavy traffic, and air pollutants, formed in the daily process of discharging waste containers by garbage trucks, pollute air and harm human health. The current research investigates the amount of air pollutants (CO_2, CO, HC, NO_x and PM) formed in the old town, the city centre of Tallinn, when the current waste collection system is applied, and how the amount of pollutants could be reduced. The calculation of air pollutants was carried out according to the amount of the burnt fuel. Today the trucks which comply with EURO III requirements are allowed in the city centre. If the truck complying with at least EURO V requirements was taken into use, the decrease in pollution would be considerable. Creation of the pneumatic system would give the Old Town advantages. It would eliminate the noise and exhaust gases generated by garbage trucks, the dropped or leached waste; in addition to that, visual disturbance of seeing garbage trucks would be eliminated and pipeline transport would be more hygienic.

1. INTRODUCTION

Municipal waste collection from people is a major problem for the enterprises engaged in waste collection as well as for the public authorities. The public authorities have to consider the requirements enforced by the EU (European Waste Directive) and arrange waste collection accordingly. When collecting waste in city centres the problems are caused by increased amounts of waste that have to be collected from waste generators as well as rapid increase of cars in the city environment. Roads and streets are full of cars which obstruct the movement of garbage trucks. The parking cars, among which garbage trucks have to manoeuvre, also cause problems. The longer the period when garbage trucks are operating in the city centre, the more exhaust gases they generate which cause air pollution and endanger people's health. Movement of vehicles in city centres, which are usually full of tourists, pollutes the town environment and heavy trucks damage road surface.

The current research investigates the amount of air pollutants (CO_2, CO, HC, NO_x and PM) formed in the old town, the city centre of Tallinn, when the current waste collection system is applied, and how the amount of pollutants could be reduced.

What waste types people can give away and how effective waste collection and separate collection of waste is, depends on how waste collection is organised. The way municipal waste collection is organised influences (Best and Kneip, 2011; Best et al., 2011; Eisted et al., 2009).

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Waste collection must be carefully planned because according to different research collection is economically the most costly municipal waste treatment expense (50-70%) (Chang et al., 2007, Economopoulou et al., 2013).

When collecting waste garbage truck transport has to be minimized; for this purpose it is possible to build transfer stations (Josimović et al., 2015), so that big trucks need not stop at each container; instead, smaller trucks could collect smaller amounts of waste and take it to the stations.

Garbage trucks consume huge amounts of fuel compared to their mileage (Nguyen et al., 2010) and the reason for this is the vehicle's driving profile during waste collection: the truck has to stop frequently to discharge a container, which causes long idling times.

The topic of waste transport has been analysed from various aspects. The possibilities are to use alternative garbage trucks (Bender et al., 2014), various container systems (Rives et al., 2010), sensorized containers (Vicentinia et al., 2009).The aim is always to optimize collecting rounds so that collection costs would be minimal, but client satisfaction would be maximal (Martijn et al., 2014).

One possibility to reduce garbage trucks' traffic load in city centres and turn separate collection of waste agreeable to the consumer is to implement pneumatic waste collection system.

With pneumatic collection system the waste producer discharges the waste into a special box or chute, in the bottom of which there is a temporary storage chamber (to increase efficiency it is not reasonable to send one bag of waste at a time into the chute). At certain intervals or at certain filling stage the system will operate, opening the primary pressure valve and the pressure valve at the waste chamber to create vacuum that will suck waste into the system's transportation pipeline (d- 200-500 mm) (the same pipeline can be used to transport different waste types). Along the transportation pipeline, which is mainly situated underground, the waste is sent to the collection point where waste is separated from air. The air is refined of odour and the volatile particles are eliminated by filters. The waste is sent into a refuse compactor or pressing machine and afterwards, to a treatment site according to waste types. Transportation in pipelines reduces greenhouse gas emissions and the inconveniences of the door-to-door method of waste collection (odours, noise, combustion gas emissions, etc.), as well as allowing better waste reuse and recycling. (Fernández et al., 2014)

Considering together the different technologies and companies, over 1600 pneumatic collection systems are under construction or in operation in over 30 countries in Europe, North America, Australia, South East Asia and the Middle East (University Transportation Research Center 2013)

In many articles the environmental impact of different waste collection systems has been assessed by Life cycle analysis (LCA) method. It has been found out that pneumatic collection system has certain advantages (Iriarte et al., 2009; Punkkinen et al., 2012).When trucks are replaced with underground pipelines, traffic congestion, accidents, noise and CO_2 emissions, caused by truck traffic, will be reduced (Kogler, 2007). Removing waste collection containers from streets will reduce the problems of hygiene, container overloading and unpleasant odours.

As for economic consideration, a great investment is required to establish the system (Teerioja et al., 2012), but lower operational costs (more efficient operation) will pay back the investment in the longer perspective (Honkio 2009; Teerioja et al., 2012) analyses the creation of door-to-door and pneumatic collection system in the already completed city region.Kogler, (2007) analyses the same phenomenon, but in a new development area. In both cases the conclusion is the same – the system would be functional and would help reduce operational costs.

Nakou et al., (2014) has studied the municipality of Maroussi, which combines a densely populated residential region and a commercial centre with many visitors on a daily basis. It is a

Table 1. Advantages and disadvantages of the pneumatic collection system[a].

Advantages	Disadvantages
Minimized operation cost and long term savings	Heavy construction operations needed requiring high investment costs
Ability to collect apparently all waste streams	Cannot collect large items, bulky wastes, WEEE and has difficulties with glass wastes
Flexible system with the ability to easily adopts to changes	After installation the flexibility of the system is reduced
Minimized usage of garbage collection trucks in urban areas	Truck transportation is not eliminated
Minimized noise, aesthetic pollution and odor problems	Risk of problems related to pipe blockages
Release of surface space for community needs or development	Public willingness and training to proper disposal required
Enhanced safety for collection workers (hygiene, accidents, etc.)	Experienced workforce is required

[a] Kaliampakos et al., 2013

typical example, where the conventional collection method is challenging due to the space limitations. Nakou compares in his research the pneumatic and conventional methods and finds that the amounts of emissions on transport per year are reduced by 90% "see Table 1" when pneumatic collection system is used.

Punkkinen et al., (2012) has analysed the emissions generated during door-to-door collection and pneumatic collection by life-cycle phase. In his article he comes to the conclusion that pneumatic collection system produces in the life-cycle phase more emissions (68% GHG emissions and 94% SO_2).

2. METHODOLOGY AND DATA

2.1 Description of the examined object

The central part of the city centre of the capital of Estonia, situated in Northern Europe, (area of 30.6 km^2) is the heart of Tallinn. Different enterprises, commercial centres, traffic hubs, public institutions, accommodation enterprises, sightseeing objects and residential areas are situated there. The most densely populated area and the major sightseeing object for the tourists visiting Tallinn is the Old Town. As of 2013, over 6 million people visited Tallinn, 84% of them also visited the Old Town. As of January 2013, the population of the Old Town is 3959, the territory is 93.9 ha, the circumference is 3.79 km; there are 72 streets and 579 buildings entered in the building registry. There are 2295 flats in the Old Town, 1744 of these being residential areas and 551 commercial areas.

Since 1966 the Old Town of Tallinn is National Heritage Conservation Area. UNESCO Committee has pointed out the uniqueness and exceptional integrity of Tallinn Old Town as the well-preserved medieval North-European trading town, where the characteristic traits of a unique economic and social community have been preserved to a significant extent.

2.2 Description of the existing waste collection system

For collecting municipal waste door-to-door system is used in the Old Town of Tallinn, i.e. each client's waste container is discharged on the client's property. The waste excluded from organised waste collection (e.g. hazardous waste, bulky waste, problem products and packages) can be taken to the waste station or collection point by people, in other words, bringsystem is used.

In terms of waste collection, the Old Town is considered to be a complicated area. The streets are narrow, there are ascents and descents between the upper town and lower town, space is limited for trucks to manoeuvre. The waste containers are not placed in the streets, but stand in locked inner courtyards, which makes discharging them time-consuming. While the buildings can be quite tall, the entrances are low and garbage trucks are not able to maneuverer to the container in the courtyard.

Local government has enforced several restrictions to waste collection in the territory of the Old Town, to protect the unique nature of the Old Town. The streets are very narrow, mainly covered with cobbled stone. For protection, the weight limit of 12 tons for truck has been established. All the garbage trucks moving in the Old Town have to comply with at least EURO III requirements. Waste collection is allowed only in the morning from 7 till 12 o'clock.

In the summer period waste collection in the narrow streets becomes even more complicated, as outdoor cafes occupy a big area of the streets. There are many catering and accommodation enterprises in the Old Town. The municipal waste composition of these enterprises is different. Problems are mainly caused by waste from catering establishments, which is not (or not carefully) separated from municipal waste. Big amounts of food that get into the garbage truck may cause leachate leakage from trucks. The operation of garbage trucks can also be obstructed by tourists visiting the Old Town. It is not possible to start waste collecting at very early hours, because the residents of the Old Town and the people staying at the accommodation establishments complain when the noise of discharged containers wakes them up early in the morning.

2.3 Emissions calculation

Air pollution emissions is 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 found out.

$$Q\ (kWh/kg) * N\ (kg) = E\ (kWh) \qquad (1)$$

where Q is calorific value of diesel fuel, N is the amount of consumed fuel and E is energy.

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

$$\rho = m/V \qquad (2)$$

where ρ is fuel density, V is volume and m is molar mass.

EU Emission standards for trucks and buses presents chemical exhaust emissions for diesel engines (CO, HC, NOx, Particles). Having found by the formula (1) the energy, we can calculate the emission amounts, formed in the process of burning the given amount of diesel fuel, according to the target number in the emission standards (formula 3).

$$\text{energy (kWh) x emission target (g/kWh) = emission amount (g)} \qquad (3)$$

To find out the amount of generated CO_2 the average formula of diesel fuel $C_{12}H_{23}$ is used.

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

$$C_{12}H_{23} + 17{,}75\ O_2 = 12\ CO_2 + 11{,}5\ H_2O \qquad (4)$$

$$n_d = m/M = 4{,}91\ mol \qquad (5)$$

$$m = n_d * (n * M (CO_2)) \qquad (6)$$

where n_d is moles of diesel fuel, M is molar mass, n is moles and m is mass.
According formula 6, burning 1 liter diesel fuel, 2,593 kg CO_2 will be produced.

$$4.91 \text{ mol} * 12 \text{ mol} * 44 \text{ g/mol} = 2{,}593 \text{ kg } CO_2$$

3. RESULTS AND DISCUSSION

Mostly plastic containers measuring 0.14 – 1.1 m^3 are used in the Old Town, for metal containers make a lot of noise when discharged. It is also allowed to use plastic bags (0.14 m^3) “see Figure 1”.

During one week of the analyses period 1467 containers from 786 objects had to be discharged; 53.3 tons of municipal waste was collected, which would account for 13.5 kg per a resident of the Old Town in a week. The average amount of municipal waste per resident in Tallinn is about 500 kg per year or 9.9 kg per week (SA Säästva Eesti Instituut, 2014). Municipal waste was collected every day; the biggest amount of waste, 10.7 tons, was collected on Saturday whereas the smallest, 4.5 tons, on Friday. On average, 7.6 tons of municipal waste is collected in the Old Town every day.

In 130 objects the municipal waste containers are discharged once a week. 22% of the clients have their containers discharged twice a week and in 26 objects (8%) containers are discharged every day. When analysing the existing graph and the waste amounts, collected in the Old Town daily, it would be possible to rearrange the graph so that there would be no waste collection at least on one day of a week. The amounts of waste of this day could be collected on the previous or following day. The analysis also reveals that even in the same street waste discharges take place on different days, although all containers are discharged once a week. With route optimization, it would be possible to collect all the containers in one street on the same day.

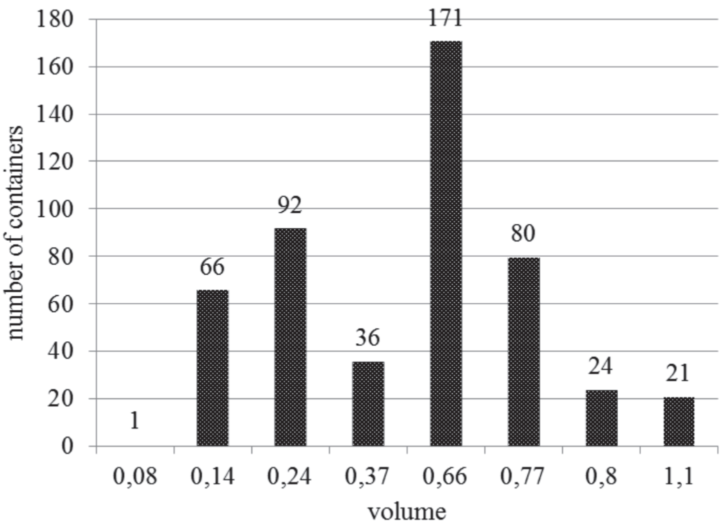

Figure 1. Differentiation of containers in examined object.

Daily traffic of trucks in the Old Town creates air pollution which is dangerous for people living in the Old Town and for those moving in the area.

Table 2 presents the results obtained when analysing the transportation graphs and calculating the weekly amounts of air pollution

As it can be seen “see Table 2”, the biggest amount of waste was generated on Saturday, when the biggest amount of fuel was used to make one collection round; hence the biggest quantity of air pollution was produced when burning fuel. As much as 117 kg of CO_2 per collection round was created this day. The amount of CO_2 would be less if the existing collection system was revised. There are days when the truck is clearly not fully loaded. With better route planning it would be possible to save at least one day when the truck need not make a collection round in the Old Town. This in turn would mean that 52 collection rounds a year would be saved and by 4.3 tons less CO_2 would be generated.

Today the trucks which comply with EURO III requirements are allowed in the city centre. If the truck complying with at least EURO V requirements was taken into use, the decrease in pollution would be considerable: by 30% of CO and HC, 60% of NOx and 80% of PM. pollution and 80% of PM pollution would be created. The Figure 2 presents the comparison of pollution quantities generated when using the trucks complying with EURO III and EURO V requirements.

In Estonia several surveys have been conducted to find out what people throw in their municipal waste containers. The results of two surveys of municipal waste sorting are presented in the table 3. The results are grouped in four different waste categories which people are obligated to collect separately by the present regulations. The largest percentage of municipal waste is biowaste. The percentage of biowaste in the city centre district which includes the Old Town is 32.4%; this is similar to the average of Tallinn (33.7%).

According to the results of the present research 2756 tons of municipal waste per year is collected in the Old Town. It can be seen “see Table 4” that when dividing the yearly amount of municipal waste by different waste categories and different fulfilment degree of a truck, then how many transportation trips a year must be made to be able to collect the amount of waste that is generated today. At present the average weight of the freight is 7.61tons. According to the analysis it turned out that from time to time the freight weight is 4.5 tons; thus, lower than average freight weights have been presented. The smaller is the truck’s freight weight, the bigger is the number of collection rounds to be made and the bigger is the generated amount of air pollution.

Table 2. Air emissions generated per week.

day	CO, g	HC, g	NO_x, g	PM, g	CO_2, kg
monday	607	191	1446	29	78
tuesday	608	191	1448	29	78
wednesday	813	255	1935	39	104
thursday	610	192	1451	29	78
friday	610	192	1451	29	78
saturday	914	287	2177	44	117
sunday	406	128	968	19	52
total	4568	1436	10876	218	583

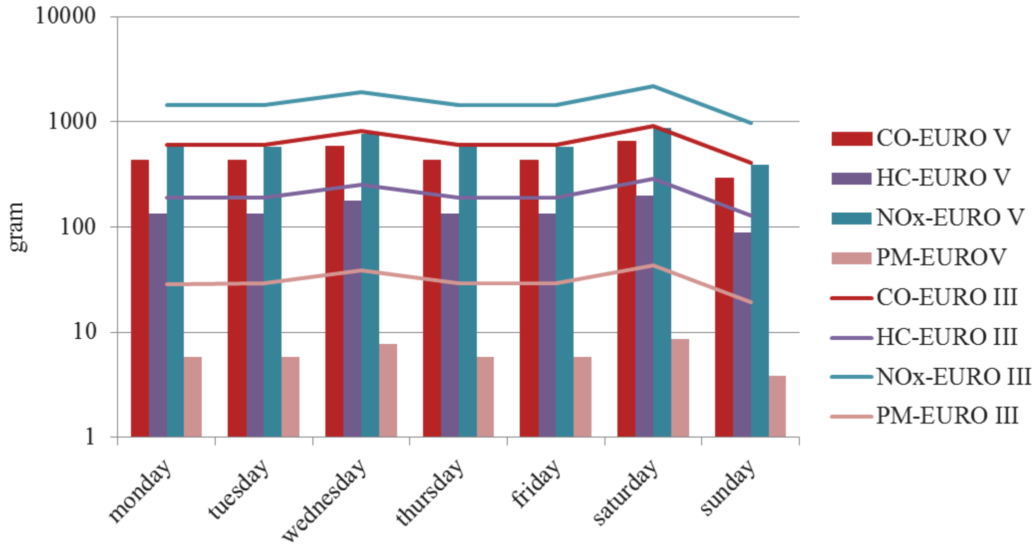

Figure 2. Comparison of pollution quantities generated when using the trucks complying with EURO III and EURO V requirements.

Table 3. Waste fraction percentage in municipal waste, % [a].

year	2008	2013	2008	2013	average	
fraction	city center		Tallinn		city center	Tallinn
biowaste	32,7	32,1	35,7	31,9	33,2	31,9
packaging waste	29,8	26,1	30,0	28,1	28,1	28,1
wastepaper	20,6	18,3	17,3	14,9	16,8	14,9
municipal waste	16,9	23,5	17,0	25,1	21,9	25,1

[a] SA Säästva Eesti Instituut

Table 4. Collection rounds per year, depending on the cargo tonnage.

cargo tonnage, t	6	7	7,6	8	8,5	9	9,5	10	10,7
biowaste	147	126	116	111	104	98	93	88	83
packaging waste	120	103	95	90	85	80	76	72	67
wastepaper	84	72	66	63	59	56	53	50	47
municipal waste	108	93	85	81	76	72	8	65	61
total	459	394	362	345	324	306	290	276	258

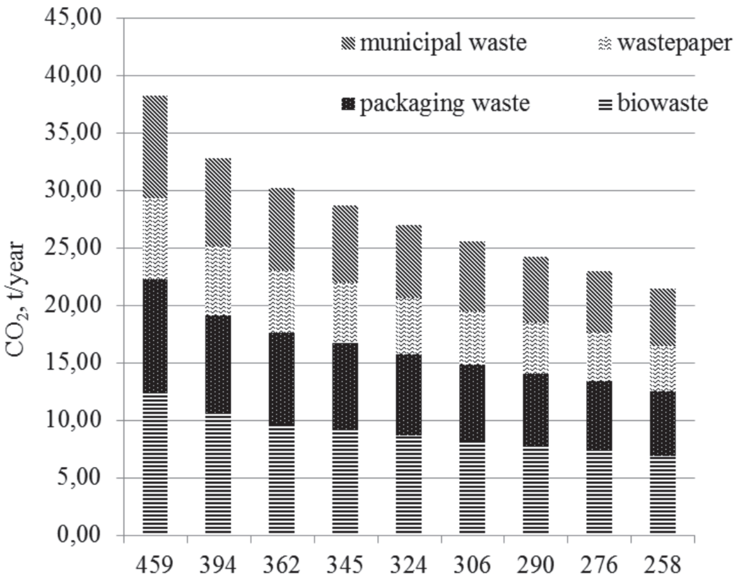

Figure 3. CO_2 pollution generation (yearly) at the different numbers of collection rounds.

Provided that every year 2756 tons of waste has to be collected in the Old Town and the load weight is always 7.61 tons, less 2 collection rounds would be necessary to make. According to the present schedule, one collection round per day or 365 rounds; with separate waste collection 362.1 or 363 rounds. In this way the generation of air pollution cannot be considerably reduced.

Assuming that one truck can carry 10 tons and optimizing container discharges so that the truck would be filled to maximum, considerable efficiency could be achieved in transport a much less air pollution would be generated; in this case 276 collection rounds would have to be made. This would also mean that the collection rounds would not take place on a certain day, but at certain intervals (e.g. every two days).

Today 83.82 kg of CO_2 pollution is generated during one collection round. This amounts to 30 tons of CO_2 per year. In case the truck was filled to maximum (10t), the yearly amount of CO_2 would be 21 tons and the truck would make 258 collection rounds in the Old Town “see Figure 3”

Changing the schedule of garbage truck so that containers would be discharged every two days would be inconvenient to the client, and such rearrangement could bring along the situation that people take their waste somewhere else (dumping). Pneumatic waste collection system would be a very good option. If pneumatic collection existed in the city centre, the noise, air pollution or other disturbances related to the movement of garbage trucks would not occur.

If separate waste collection took place in the Old Town and garbage trucks were used for waste collection, separate waste collection in the Old Town would not be reasonable, because it is not possible to guarantee maximum filling of garbage trucks and, therefore, trucks need to move around too frequently and would cause disturbances.

Based on the example of CO it can be seen how the number of collection days influences generating CO pollution. If the existing system of 362 collection days was optimized in such a way that the total weight of waste loaded in the garbage truck was bigger than 7.6 tons per trip,

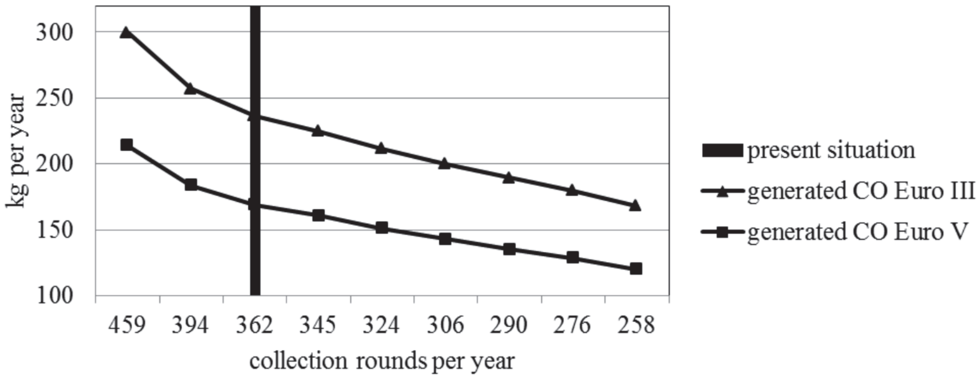

Figure 4. Comparison of CO emissions EURO III and EURO V requirements in different numbers of collection rounds.

less air pollution would be generated.

The following graph "see Figure 4" presents the amount of generated CO emission according to different number of collection days. The fewer collection days there are, the less CO emission is generated.

Another way to generate less pollution would be to sort municipal waste, e.g. people separate packaging waste and take it to the collection point (according to the Packaging Act packaging collection point has to be situated within the range of 500 m).

If the trucks that comply with EURO V requirements were used in the city centre, the amount of air emissions could be reduced by 30%.

Creation of the pneumatic system would give the Old Town advantages. It would eliminate the noise and exhaust gases generated by garbage trucks, the dropped or leached waste; in addition to that, visual disturbance of seeing garbage trucks would be eliminated and pipeline transport would be more hygienic. The pneumatic system would prevent burdening and destruction of cobblestone pavement, which is inevitable when garbage trucks are used.

With most systems available on the market the most distant waste collection point can be at the distance of 2 km from the transfer station. The longest diameter of the Old Town is 1.45 km. Therefore, the Old Town would need only one transfer station, where the pipeline from the Old Town would be emptied. In addition, the waste generated in the city centre area could be collected in the same transfer station "see Figure 5".

CO_2 emissions of the pneumatic collection system have been examined by different authors, who have come to the conclusion that the amount of emissions (LCI – life cycle inventory) depends on two main factors – the system's load factor, which in turn is connected to waste generation, and on the type of energy used in the country where pneumatic system is applied. Usón et al., (2013) draws a conclusion in his study that if the pneumatic system's load factor is 13%, CO_2-eq collection per one ton of waste is four times bigger than in case the load factor is 100%. With conventional systems CO_2-eq emission collection is the same, regardless of load factor. Eisted et al (2009) finds in his article that the calculated range by pneumatic collection is 17.5 – 77.1 kg CO_2-eq/t; the CO_2-eq emissions range calculated by Uson et al., (2013) is 33.2 – 146.9 kg CO_2-eq/t. In his article Punkkinen et al., (2012) reaches a conclusion that with pneumatic system the generated amount of CO_2-eq is 56.4 kg per CO_2-eq/t. When calculating CO_2-eq, Punkkinen includes in CO_2-eq calculation the CO_2-eq, generated while producing

Figure 5. 2 km radius which covers Old Town and city center area where could be a hypotetical pneumatic collection system

equipment, as well as the power consumption, needed to keep the system in operation. Proceeding from consumed energy per one ton of waste, the amounts of generated CO_2-eq may be different. As for Punkkinen, the range is 26-133 CO_2-eq/t.

According to LIPASTO (a calculation system for traffic exhaust emissions and energy consumption in Finland), the truck complying with EURO V requirements generates 2.6% less CO_2-eq than the truck in compliance with EURO III requirements. At present, the truck in compliance with at least EURO III requirements is allowed in the Old Town. It was calculated that currently a truck is generating 11.8 kg CO_2-eq while collecting one ton of waste. In case the truck complying with EURO V requirements was used, the generated amount of CO_2-eq would be 11.5 kg. Considering the yearly amount of waste the amount of CO_2-eq in the Old Town would be reduced by 0.8 tons if EURO III trucks were replaced by EURO V trucks.

Comparing the amounts of CO_2-eq generated by pneumatic collection system and presented in different surveys, the amounts are bigger than these generated currently in the Old Town with door-to-door collection “see Table 5”. However, when using pneumatic collection system the disturbances caused by the garbage truck at present – noise, odour, burdening of roads etc. – would be eliminated.

Table 5. CO_2-eq.emissions per waste tonne collected from door-to-door and pneumatic collection systems

	CO_2-eq (kg/waste tonne)
door-to-door collection EURO III	11,8
door-to-door collection EURO V	11,5
door-to-door collection[a]	9,2
pneumatic collection[a]	24,3
pneumatic collection[b]	35,66

[a] Uson

[b] Punkkinen

4. CONCLUSIONS

Dense population and narrow streets of the Old Town determine that the residents cannot us large volume containers. 0.14 m^3 plastic bags and 0.24m^3 and 0.77 m^3 plastic containers are used most frequently in the Old Town. The majority of waste is collected on Saturdays and the least amount on Fridays. On Saturdays the number of tourists in the Old Town is the biggest; therefore, waste collection could take place on some other day of the week. According to calculations, 13.5 kg of municipal waste per person is generated in the Old Town. This accounts for 700 kg per person annually, whereas the average in Estonia is 200 kg per capita. The bigger amount per person is due to the fact that there are plenty of accommodation and catering establishments in the Old Town.

The research revealed that for 42% of the clients waste collection takes place once a week and for 22% - twice a week; 8% of the clients are serviced every day. The research also revealed that in spite of the fact that the containers are situated on the same street and they are discharged once a week, waste collection takes place on different days. Proceeding from these data and rearranging the collection schedules the number of days when a garbage truck collects waste in the Old Town can be reduced.

Optimization would allow to reduce the amount of generated emissions. One of the research objectives was to find out the quantity of emissions (CO, HC, NOx, PM, CO_2 and CO_2-eq) generated at present when the trucks must comply with EURO III standard requirements, and to compare the data with the situation if using the trucks which comply with EURO V requirements. The results revealed that the differences in generated emissions with EURO III and EURO V truck can differ by several times. The yearly amount of generated CO emissions decreased by 28%, whereas PM amount decreased by 80%.

The quantity of emissions depends on the amount of the burned fuel. In the examined area of the Old Town 4.2 litres of fuel was used while collecting one ton of waste.

Replacing the trucks complying with EURO III requirements by the trucks in compliance with EURO V requirements in densely populated areas would be the simplest way to reduce the quantity of emissions generated, therefore, reducing the impacts on the environment as well as on people's health.

Pneumatic waste collection system would be a good option. The existence of pneumatic collection in the Old Town would eliminate the noise, air pollution and all other disturbances connected to the movement of garbage collection trucks.

When analysing different articles it turned out that with pneumatic collection the calculated emission quantities would be within the range of 17.5-146 kg CO_2-eq/t, depending on whether product's life cycle analysis has been considered. When only the process of collecting and transporting waste is considered, the quantities of generated CO_2-eq per ton are within the range of 17 – 77 kg, depending on the type of energy used in the country. In Tallinn Old Town the door-to-door system generates less CO_2-eq/t in the collection and transportation process than the hypothetic pneumatic system; however, pneumatic waste collection system has certain advantages. The cobbled roads of the Old Town would be freed of garbage collection trucks and the disturbances they generate, such as emissions from burning fuel, congestion, visual disturbance, odour etc. Before establishing pneumatic system it is essential to assess the feasibility of it from the social and economic aspects.

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Non-deposit system option for waste management on small islands

Monica Vilms and Viktoria Voronova

Abstract

This paper analyses waste management on small islands (on a global scale these are micro-islands). In the context of the paper, small islands are islands that have an area less than 50 km^2. The study presents an overview of the problems connected with waste transport from islands to the mainland. Waste generation on islands is very much related to tourists. If tourists do not handle waste properly, it will cause problems. Four small Estonian islands in the range of 3–19 km^2 are studied in detail. For these and other small islands, the main problem is the waste produced by tourists, or related to tourists and waste transport to the mainland. Currently, the local municipality has to arrange and finance waste transport. In fact, and based on the polluter-pays principle, the tourists should bear the cost of waste management. There are different tax options available in order to collect the money from tourists – waste tax, harbour tax, tourist tax, donations, environmental tax and others. The study results revealed that the best possible solution for Estonian islands may be a non-deposit system – including an additional charge on ferry ticket prices. The extra money should cover the costs of waste management and waste shipping. The tourists arriving in their own boats should pay a harbour tax, which includes a waste tax to compensate for the cost of waste management.

Keywords

Waste tax, harbour tax, waste shipping, tourism waste, small islands waste, waste management

Introduction

There is a lack of studies on how waste management is arranged on islands that have an area less than 50 km^2. In several studies, a small island is defined as an area of more than 200 km^2 with the population of 7000 people and more (Mateu-Sbert et al., 2013; Mohee et al., 2015; Sealey and Smith, 2014). In Estonia, according to the Permanently Inhabited Small Islands Act (Püsiasustusega väikesaarte seadus, 2003), there are 11 small islands and three large islands – Saaremaa (2671 km^2), Hiiumaa (989 km^2) and Muhu (198 km^2).

On small islands, tourism is very popular and people essentially want to go there for the nature (beaches, nature reserves, landscape parks, etc.). During tourist visits, waste generation increases; landfilling is not an option and all the waste that is generated has to be transported to the mainland. Tourism can offer high levels of employment and income for local people. However, tourists and the tourism sector are also a source of environmental impact (high levels of noise, air and water pollution, changing views and landscapes, waste generation). Aguiló et al. (2005) have also pointed out that electricity consumption increases and groundwater levels drop besides the double increase in waste generation.

All tourists generate municipal solid waste (MSW). This has a negative impact on both the environment and budgets of local governments who have to arrange waste management on their territory. Still, tourism can also have positive environmental impacts, e.g. the creation of national parks and wildlife parks, conservation of beaches and forest. Residents have to pay via taxes for all the public services offered by the regional government, yet it makes no difference whether the service is meant for residents or tourists.

Many articles describe the phenomenon of MSW growth as a result of the seasonal increase of the tourist population in different areas and regions (Espinosa Lloréns et al., 2008; Shamshiry et al., 2011; Willmott and Graci, 2012). Therefore, in these areas waste management is important and MSW has to be collected, transported and processed in an environmentally sound and cost-effective way (Chen et al., 2005).

On small islands, the separate collection of recyclables is particularly necessary because islands are environmentally more vulnerable to growing amounts of solid waste (Tutangata, 1999). Most residents of small islands collect waste separately, provided they have the possibility to do so, because they care about their home island. The same cannot be said about tourists. Even if

Department of Environmental Engineering, Tallinn University of Technology, Tallinn, Estonia

Corresponding author:
Monica Vilms, Department of Environmental Engineering, Tallinn University of Technology, Ehitajate tee 5, 19086 Tallinn, Estonia.
Email: monica.vilms@gmail.com

Table 1. Islands description and MSW generation on the islands of Naissaare, Aegna, Prangli and Ruhnu.

Name of island	Area, km^2	Number of residents	Distance from mainland, km	MSW generation (t year^{-1})	Upkeep of waste station (€ year^{-1})	Number of tourists (people year^{-1})	Waste generation per resident	Waste generation per tourist, kg
Naissaar	18.6	2	19	22	4700	15000	11 t	1.5
Aegna	3	2	14	6.6	2700	8000	3.3 t	0.8
Prangli	6.4	100	10	12.6	9000	10000	126 kg	1.3
Ruhnu	11.9	64	96	5	12000	5000	78 kg	1.0

tourists collect their MSW and do not dispose of it in nature, Mateu-Sbert et al. (2013) found that one resident separately collects an average of 47.3% more than one tourist.

Sealey and Smith (2014) have described how islands can be 'zero waste' environments where waste is not a problem but a resource. 'Zero waste' means that waste is not disposed of in a landfill or incinerated. All waste materials are composted, reused or recycled. A 'zero waste' island can promote itself as a sustainable tourism destination and for some groups of tourists this adds value.

The main problems caused by tourists on Estonian islands are camping and campfires in places not intended for this. Burning waste in campfires leads to environmental pollution. Financially, the biggest problem is the removal of waste from the islands to the mainland.

The aim of this paper is to analyse the problems of financing MSW management and waste transport on four small Estonian islands and to provide weighted solutions for decision makers.

Materials and methods

To obtain an overview of the research question, a detail observation has been conducted based on gradation of the research methods. On-site interviews with open questions (the island's residents, tourists, waste management companies, waste station operator, local authority representatives, etc.) were carried out. Additionally information has been gathered from existing sources, statistical and scientific articles. The surveys were carried out in 2013–2014.

In the present research, legislation is analysed in detail in the light of the Estonian Acts, which is based on EU legislation. Considering the journal readership, this topic is not discussed in depth.

The main legislation regulating waste handling is the Waste Act (Jäätmeseadus, 2004). The Act states that a local government within the administrative territory in which live more than 1500 inhabitants has the obligation to arrange organized waste collection and transport. In rural areas, the arrangement of organized waste transport is not an obligation according to the Waste Act because it is not economically feasible. At local level, waste handling is regulated, in addition to the Waste Act, according to the local government waste management plan and waste management rules. The local government primarily organizes waste management in its territory in line with the Waste Act. The principle of producer responsibility is implemented for packaging and products that are defined in the Waste Act as a 'product of concern'. The Waste Act does not set any producer responsibility obligation on local government. However, it is not possible to organize municipal waste management and promote separate collection without handling waste that is under the principle of producer responsibility. Local government income for waste handling comes from pollution charges that are paid by the companies that operate on the local government's territory.

Small islands

Estonia has over 2200 islands (318 of them larger than 1 ha), of which just three – Saaremaa, Hiiumaa and Muhu – are deemed big islands. According to the Permanently Inhabited Small Islands Act (Püsiasustusega väikesaarte seadus, 2003), there are 11 small islands where people reside or where they have their main habitat. These are the islands of Abruka, Kihnu, Kessulaid, Kõinastu, Manija, Osmussaare, Piirissaar, Prangli, Ruhnu, Vilsandi and Vormsi. However, some of them only have a few residents. Not all of the islands are accessible, but there are many uninhabited islands where tourists or visitors go during the summer. The most well known of these are Naissaar, Aegna, Suur-Pakri and Väike-Pakri.

Tourists mainly visit islands because of the nature (landscape reserve, nature reserve), beaches and coastal water. For this reason, the uninhabited islands are the places where most waste is generated by the tourists. That is why it is very important to promote environmentally responsible tourism (Sullivan-Sealey and Cushion, 2009). Four islands (Prangli, Aegna, Naissaar and Ruhnu) were chosen for investigation, as they are the most visited and easily accessible for tourists. These islands also have problems with waste collection and transportation (Tamme and Rivis, 2011).

This paper presents the arrangement and options for waste management on four Estonian small islands, where visitors and tourists generate waste, which is a major problem on all the above-mentioned islands. Short descriptions of the islands are given in Table 1.

Approximately 5600 tourists visit Aegna every year by ferry; the corresponding number for the island of Prangli is 5200. Monthly visits by ferries to the inhabited Prangli and uninhabited Aegna are presented in Figure 1. As many tourists visit the islands on their own or take travel agencies' boats, the estimated annual number of tourists on the island of Aegna is 8000 and that on Prangli is 10 000. The ferries to Aegna navigate from May to October. If the ice conditions during the winter season are good, it is possible to use ice roads to visit some of the small islands. In

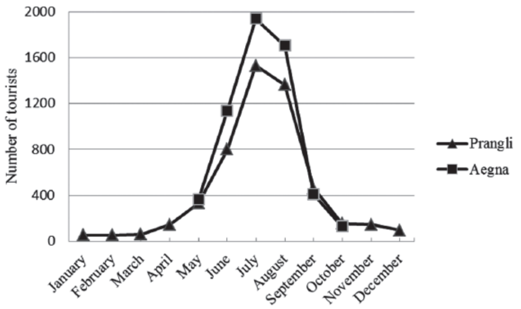

Figure 1. Number of tourists visiting by liner the inhabited Prangli island and the uninhabited Aegna island.

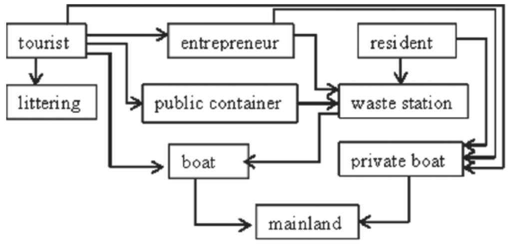

Figure 2. Waste routes to the mainland.

2011, when the ice became thick enough, more than 400 tourists visited Aegna within a period of 2 months, February and March.

Waste is generated through different types of human activities. Waste transport by ship from the islands to the mainland is generally problematic and costly. The Estonian Waste Act does not place an obligation on the arrangement of waste transport in low-density areas, which include the small islands. The budgets of local governments, which have to arrange waste management (included that on uninhabited and inhabited islands), are tight; therefore, it is complicated to cover all the costs involved in waste collection and ferrying this waste to the mainland. In addition, it is in contrast to the polluter-pays principle. Although the tourists visiting the island generate waste, they do not contribute financially to the budget of the municipality. The situation is better on the islands that have a year-round ferry service to the mainland (Vormsi and Kihnu). In this case, waste can be transported with refuse vehicles. However, when the weather conditions become bad, waste transport is disrupted.

Waste management

All four islands have a waste station, which is located in the port area. Waste stations are mostly funded by the state through grants. A waste station is a roofed, wood-framed building with an area of 19–58 m^2 and a concrete floor. The area is surrounded by a fence. In most cases, there is a bale press for waste to reduce the total volume of waste during shipping. A waste station is open on certain days at certain times of the day. For example, on the island of Aegna the waste station operates from 1 June to 30 September, and is open twice a week, on Saturdays and Sundays. However, tourists also come to the island on weekdays and they do not have the opportunity to use it. Most stations collect the following types of waste: packaging, metal scrap, paper and cardboard, hazardous waste, electrical and electronic equipment, glass, tyres, construction and demolition waste, and household waste. On some islands, e.g. Aegna, certain types of waste are taxed: household waste – €10 per 1 m^3; 100-l and 150-l garbage bags – €1.5 each; broken household appliances – €10 per item.

In the opening hours of the waste stations, there is an operator whose responsibilities include the collection and sorting of waste, cardboard, paper and plastic waste compaction and preparation for shipment to the mainland.

When the waste station is full, the operator organizes waste shipment to the mainland. In general, there will be more journeys made in the navigation period than outside the navigation period. On some islands, e.g. Aegna and Naissaar, there is no waste shipping to the mainland outside of the navigation period. If possible, a regular ship is used to transport waste in the navigation period; otherwise, a special ship is used.

The amounts of waste generated on the islands differ. On Ruhnu, the amount of MSW generation per capita per year is relatively low: 55–70 kg. On Prangli, the total amount of MSW to be shipped to the mainland is 12 600 kg annually. In addition, around 500 kg of waste paper is collected. On the islands of Naisaar and Aegna, the annual amounts are accordingly 22 000 and 6600 kg of MSW. Most tourists stay on the islands for only 1 day (Tamme and Rivis, 2011); therefore, on Naissaar, where there is a playhouse during the summer, waste generation per tourist is 1.5 kg and on Aegna it is 0.8 kg per day. In comparison, Gidarakos et al. (2006) assumed on the basis of the average quantity of MSW generated by resident that the mean produced quantity of MSW per tourist in Crete is 1.2 kg per day in the 2001–2002 period. This quantity is quite similar to the results for Menorca of 1.31 kg per day (Mateu-Sbert et al., 2013). UNEP (2003) has estimated that tourists travelling in Europe generate about 1 kg^{-1} day^{-1} solid waste.

There are no waste composition statistics available for Estonian islands. The results of separately collected waste on Prangli island show that most waste comprises generated packaging waste (350 kg year^{-1}) and paper and cardboard waste (300 kg year^{-1}). Figure 2 shows the possible paths of waste movement. A local resident has two waste transport options – carrying waste to a waste station or shipping it by private boat to the mainland. In addition to these two options, residents can choose to dump the waste illegally. Conversely, tourists have many more options. Unfortunately, observation on the islands showed that there are problems with littering. Tourists dispose of their waste in nature, burn it in open fires or dump it in the sea.

Waste transport and financing

All the residents of the islands have the obligation to collect waste separately. Finnveden et al. (2007) showed that the participation of people in source separation depends on how accessible the waste station is (opening hours, introduction by operator, user convenience, etc.).

Separately collected waste, which cannot be re-used on site, and mixed MSW must be delivered to the waste station by the waste holder. Paper and cardboard is mostly burned in ovens or open fires. Separately collected food and garden waste is composted. Problems are caused by the food waste generated by tourists. This waste will be transported to the mainland together with household waste. As the waste transport usually takes place once a month, biodegradable waste mixed with household waste causes problems such as foul odours, rodents, etc. The situation is especially bad during the summer when the outside temperature is high and the organic material begins to decompose very quickly.

Waste collection and transportation from islands is an activity that companies do not want to deal with. For example, in the period of 2007 to March 2014 waste collection and shipment from Prangli island was carried out by a waste handling company that has a subcontractor on the island. The subcontractor was responsible for collecting household waste once a month from the property of the island's residents as well as for arranging the shipment of waste to the mainland, where it was adopted by the waste handling company. In 2014, the waste handling company no longer wanted to continue and the price proposed to the municipality was too high.

The waste-related costs are mainly covered by the municipalities. On permanently inhabited small islands, where waste disposal is organized, the residents also have to pay for the waste management, such as emptying the containers. The price calculation is the following: the company makes a quotation in which all the expenses incurred on the territory of the municipality, island and the mainland have been taken into account. It means that the people who live on the mainland have to pay more for emptying their waste containers to cover the waste management costs on the island. Despite this, the municipality has to pay extra to collect and ship the waste to the mainland. On Prangli island for example (Table 1), with a population of about 100 inhabitants, the municipality expenses made on waste station maintenance and shipping were €9000; on Ruhnu island, the cost exceeds €12 000 per year (the entire budget of Ruhnu island for 2014 was €218 000). The main expense items are salary for the waste station operator, cost of boat rental and cost for transporting containers to the mainland.

On the islands with no residents, waste management and financing during the navigation period is arranged by the local municipality. On Aegna island for example, the costs per navigation period were €2700 and on Naissaare island €4700.

On these islands, all the waste transported to the mainland is generated by tourists. Therefore, it would be fair if the tourists themselves paid for the waste removal.

Results and discussion

Currently, there are no taxes for tourists on the islands of Estonia, and all the expenses related to waste management have to be covered by the municipality. In Estonia, the municipalities as well as their budgets are small, as the number of residents is small, but they have many duties and responsibilities other than waste management. For example, there are only 64 residents on Ruhnu island but the costs of waste management are over €12 000 a year.

To make up for the local government costs, and based on the polluter-pays principle, tourists should pay the costs associated with the collection of waste they generate. The best way to do this would be collecting a tax. There are different ways to collect taxes from tourists, e.g. donation, entrance ticket, environmental tax, waste tax, harbour tax, tourist tax, accommodation tax, etc. If the tax is collected, it must cover the waste transport expenses. Also, the name of the tax is essential, and the activities and objectives on which the collected tax money will be spent must be clear.

A great number of tourists, labelled 'typical sun and beach tourists', do not care much about nature, and according to studies they are not willing to pay extra for the purpose of environmental protection. The situation is quite different from tourists who can be labelled 'environmental steward tourists', 'nature orientated tourists' or 'frugal tourists' (Valle et al., 2012).

On the Mediterranean coastline, which is a mass tourism destination, tourism taxes and fees are very popular (Ekins, 1999). The application of tourism taxes offers the possibility to apply the polluter-pays principle.

An accommodation tax is very common throughout the whole world, and it is relatively easy to collect (Gooroochurn and Thea Sinclair, 2005), but as people take day-trips to small islands it is impossible to collect an accommodation tax, as people do not use this service (Table 2).

A deposit–refund system forces a consumer to pay a certain deposit, which is refunded upon the return of the product. It is a very common system for packages, containers and tyres. This system may also be applied on the islands in such a way that tourists would pay a deposit when they purchase a ferry ticket. Tourists are given a waste bag along with their ticket; when they take back the filled waste bag to the mainland, they receive a refund.

One possible way is to use donations. Only 19% of tourists responded favourably to the accommodation tax, which is earmarked for environmental protection (Valle et al., 2012). Another study, from the Croatian island of Hvar (Taylor et al., 2005), points out the opposite opinion and finds that the majority of tourists are willing to pay extra for environmental improvements. In Estonia, donations probably would not work because waste is an unpleasant issue for the majority of people, and they would not voluntarily agree to give money for waste management purposes.

The population of small islands and the quantity of waste increases significantly during the summer when people who permanently live on the mainland come to their summer cottages on the islands. They use the waste station but do not cover the costs associated with waste management. For example in Finland, Kemiönsaari municipality is an archipelago of over 5000 islands, 40 of which are inhabited year-round (Visitkimiton, 2015). Every property has to pay the waste tax. The waste tax of permanent

Table 2. Positive and negative aspects for various tax systems.

Tax	Positive aspect	Negative aspect
Donation	A person can decide how much he/she is willing to pay	People rather despise wastes and do not agree to make a donation
Entrance fee, waste tax on island, island tax	Each visitor pays	Presumes collector, manned port needed
Tourist tax	Each visitor pays, with liner ticket easy to collect	Presumes collector, for private boats manned port needed
Accommodation tax	Easy to collect	Includes only tourists who use accommodation service
Harbour tax	Easy to collect	Presumes collector, manned port needed
Deposit included in liner fare	Easy to collect	Extra job for shipping company, excludes arrivals by private boats
Deposit waste tax on island	Each visitor pays	Presumes collector/payer, manned port needed
Deposit harbour tax on the mainland	No waste is left on the island	Unclear in what mainland ports the deposit will be paid and refunded
State waste tax	All citizens of the country pay, the state provides waste management	Foreign tourists do not pay

Table 3. Existing liner ticket fares and fees to be added to compensate waste management expenses.

Island	Existing fare (€)	Minimum included tax (€)	Suggested included tax (€)
Ruhnu	40	0.99	1*
Prangli	12	0.89	1*
Naissaar	20	0.31	1
Aegna	6	0.34	1

*The residents have to pay for their waste management; thus, the burden on tourists would not be so big (Kihnu Veeteed, 2015; Tuulelaevad, 2015).

residents depends on the number of inhabitants and the composting rate. The tax for summer cottages is affected by the rate of composting: e.g. a summer home with no composting has to pay €119, but with composting the waste tax is €85.5 per $(\text{home}\times\text{year})^{-1}$ (Lounais-Suomen Jätehuolto, 2015). On the Estonian islands where people own summer homes, e.g. Prangli and Ruhnu islands, the municipalities may introduce a waste tax on the terms described above.

The main problems on small islands with no residents are caused by tourists. Therefore, tourists should pay a tax that is added to the ferry ticket price. Tourists arriving by private boats should pay a harbour tax that would cover the waste removal costs from the island to the mainland. Provided 15 000 tourists visit Naissaare and another 8000 visit Aegna annually, the minimum sum added to the ferry ticket price or to harbour tax should be €0.31 and €0.34 per tourist (Table 3), respectively. If this minimum tax is added to the local municipality budget, it will cover the waste collecting and shipping costs. However, as the minimum amount of money is small, the numbers of tourists are not the same each year and waste generation can vary, the amount of added money should definitely be higher. If this tax were €1, it would not affect the number of tourists or enthusiasts who would like to visit the islands. If 15 000 tourists paid €1 each, a considerable amount of money may be gathered to improve waste management on the islands. It may happen when tourists have paid for waste management, they feel like they can just leave their garbage on the island. At the same time, with greater financial opportunities the municipality can offer a better waste collecting service.

The same system may also be applied to permanently inhabited small islands. Adding €1 to the harbour tax or ferry ticket should differentiate between tourists and residents. If residents often go to the mainland, they will have to pay too much. In this case, tourists and residents should certainly be differentiated from each other and payments for the target groups should be different.

One possible option would be to establish a deposit–refund system and collect a deposit for waste transport costs from each tourist. When a tourist buys a ferry ticket, a deposit (e.g. €1) for the transportation of waste will be collected, and the tourist is given a garbage bag (e.g. 10-litre sized) along with their ticket. When the visitor to the island takes back the filled garbage bag to the mainland, he/she will be refunded the pre-paid €1 deposit. If applying this method, it is also worth considering imposing higher fees, as a €1 deposit might not be sufficiently motivating. When a tourist does not return any garbage bag to the mainland, the paid deposit will go to the local government budget and can be used to cover the waste management expenses.

As tourists arriving by private boats do not use ferry services, their harbour tax should include additional money to cover their waste management costs. If the port administration collects a harbour rate from ships, it also has to cover the treatment and disposal of waste (Georgakellos, 2007). One possible way is that the waste fee is separated from the harbour rate and all ships will pay for the amount of waste they hand over. Such a system can be easily applied on the mainland, but on islands it would require special equipment to weigh different types of waste. This system may also bring about a risk that the people who want to save money will not use the harbour waste containers and might throw their waste into the sea. It is also possible to establish a fixed waste fee in harbours, whether a seafarer uses the option to deliver the waste to the port waste containers or not. If visitors have to pay anyway, they will probably not throw waste into the water. If the waste fee in the ports of small islands is higher than on the mainland, it could happen that visitors on ships would choose to dispose of their waste on the mainland. Still, some islands do not have manned harbours and in this case waste tax or harbour tax collection is not possible. It may be helpful if the waste tax was obligatory for all vessels on the mainland – if seafarers have to pay, they will deliver the waste.

By analysing various tax systems, it becomes evident that the most appropriate system for small islands would be the one that collects money from tourists for waste management and shipping together with the ferry tickets or harbour taxes.

Conclusion

Small islands have a small population or are uninhabited. However, due to the small islands' attractive landscape and nature, many tourists want to visit them. A year-round ferry connection is available on the permanently inhabited islands, but on some uninhabited islands the connection with the mainland is only organized during the summer season. The navigation period also provides people with the opportunity to use private boats, thereby increasing the number of tourists. Tourists on small islands cause problems that are related to waste management and waste shipping to the mainland. The islands have to provide tourists with the opportunity to dispose of their waste; otherwise, they will burn waste in open fires, dispose of it in the sea or in nature. The transport of waste from the island to the mainland is expensive for local governments that administer the islands.

In addition, the situation whereby the local government pays for the collection and shipping of waste, while tourists do not contribute at all, is not in line with the polluter-pays principle. Currently, tourists carry waste to the island but do not bring it back to the mainland. The municipality organizes waste collection and transportation, financing all of these actions from its budget. In fact, the tourists should bear the costs that are associated with the waste. For this purpose, it is necessary to introduce a variety of tax systems. A voluntary donation for waste management will not work because most tourists are not willing to make a donation that would cover the costs of waste disposal.

The best possible solution to cover the costs of waste management would be:

(1) A harbour tax for private boats to cover the costs of waste management;
(2) A waste tax that is added to ferry tickets price

It would be possible to implement a deposit system in which each ferry ticket buyer pays a deposit and receives a garbage bag. If tourists return the filled bag, they will be refunded the deposit. This system, however, requires a collector and surveyor. In addition, it would be very difficult to determine or assess whether the tourists brought back all the waste that was generated. For private boats, a system of collecting a waste tax together with a harbour tax can be implemented. If the seafarers do not use the waste management facilities of the island's port, they will be refunded the waste tax. The drawback of this system is that people want to save money and they will not use the opportunities offered by the harbour. Because of that, a lot of waste may eventually end up in the sea. According to the analysis, a non-deposit system described above would be better than a deposit system.

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

Monica Vilms[1], Viktoria Voronova[2]

[1,2]Department of Environmental Engineering, Tallinn University of Technology, Tallinn, Estonia
E-mails: [1]monica.vilms@gmail.com (corresponding author); [2]viktoria.voronova@ttu.ee

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.

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

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

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

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.

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

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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Introduction of a New Waste Sorting and Collection System at a University

Monica Vilms[1], Oliver Kalda[2]

[1]*Department of Environmental Engineering, Tallinn University of Technology, Tallinn, Estonia*
[2]*Faculty of Architecture and Environmental Technology, TTK University of Applied Sciences, Tallinn, Estonia*
E-mails: [1]monica.vilms@gmail.com (corresponding author); [2]okalda@tktk.ee

Abstract. Nowadays the usage of source separation waste collection system is essential for all organisations. This paper describes a case of introduction of such a system at a university of applied sciences (UAS) in Tallinn. The project started in September 2015. The main goals of the project were to reduce the number of garbage cans in the UAS, reduce the amount of unsorted household waste and inform the school community about the significance of waste sorting and relevant environmental matters. The first step of the project was to execute a full waste audit in UAS to identify precise waste quantities which occurred on daily basis. During the week the environmental technology students weighed and sorted all the waste in all premises of the UAS. Based on the collected data, the new system comprised of 19 waste collection points with sorting instructions and adequate volume. The total number of garbage cans was reduced by 46% and mixed household garbage cans by 72%. The final step was to analyse the efficiency of the new waste collection arrangements. Results showed that the new system was well accepted and 80–85% of waste was sorted and collected in the new waste collection points.

Keywords: source separation, food waste, higher education, sustainability.

Conference topic: Environmental protection.

Introduction

Nowadays, the waste collection and management issues are important in all European Union countries. Every day large quantities of waste are also produced in Estonia, most of which is burned for energy or small amount is taken to landfills. However, a relatively large proportion of the burned or landfilled waste could be recycled instead. Therefore the development of efficient and environmentally friendly waste separation and collection systems is important. The separation should be done by the waste producers and such systems should be implemented in various institutions – offices, schools etc.

Efficient waste collecting systems can be established only if there is complete understanding of the composition of a waste stream and the activities that determine its generation (Farmer *et al.* 1997). In every examined area the waste composition can vary, depending of its generating source (Tchobanoglous *et al.* 1996; Armijo de Vega *et al.* 2008: S21–S26).

Ways of how to identify/explore waste streams of an organisation can vary, for example: visual waste assessments, reviewing waste management records, interviewing waste producer or waste management staff and extrapolating data from other institutions or from statistics. The best and the most effective way is to organize a direct waste analyses/studies, during which the exact amount and composition of the waste is measured (Dahlén *et al.* 2007: 1298–1305; Mason *et al.* 2003: 257–269; O 'donnell 2002; Smyth 2008).

To date there are many studies analysing household waste content and quantity (e.g. SEI Tallinn 2008; SEI Tallinn 2013; Ripa *et al.* 2017: 445–460; Aphale *et al.* 2015: 19–28; Liikanen *et al.* 2016: 25–33; Burnley *et al.* 2007: 264–283), fewer studies have been conducted in various institutions (e.g. Trung, Kumar 2005: 109–116; Pirani, Arafat 2014: 320–336; Radwan *et al.* 2010; Fagnani, Guimarães 2017: 108–118) and relatively few studies examine the waste management in higher education institutions (Ramírez Lara *et al.* 2017: 1486–1491; Armijo de Vega *et al.* 2008: S21–S26; Mason *et al.* 2003: 257–269; Smyth *et al.* 2010: 1007–1016).

In Estonia waste sorting by type has been implemented for example, in the following institutions Ministry of Environment, University of Life Sciences and Tallinn University. Of which only the first one was successful in implementation of the new system.

The main goals in UAS were development of waste collection system, reduce the number of mixed household garbage cans, reduce the amount of unsorted household waste and inform the school community about the significance of waste sorting and relevant environmental matters. Saladié (Saladié, Santos-Lacueva 2016) in his article indicates that informing is necessary. It was important to set up understandable, visible and easy to use waste collection points in different floors of UAS.

With the creation of the new system was intended to guide the students and universities staff to use new waste collection system to become eco-friendly school and a pioneer to other educational institutions. The vision to plan a new system was to collect all the waste what will be produced on a daily basis separately and deliver them for recycling.

Materials and methods

Study took place at the TTK University of Applied Sciences (UAS). The UAS is situated in the centre of the Tallinn city, has over 2,500 students and about 190 staff members. UAS has five faculties – Faculty of Architecture and Environmental Technology, Faculty of Clothing and Textile, Faculty of Construction, Faculty of Mechanical Engineering and Faculty of Transport – with 13 different 4-year study programs. UAS offers study programmes for daily learners, distance learners and in-service training courses in the Open University (TTK UAS 2016).

The study consisted of two fases – a waste audit (I study) and the analysis of the efficiency of the new system, which was repeated twice (II and III study). Before creating the new separate collection of waste system, the audit was needed to evaluate the composition and the quantities of the waste produced on a daily basis. The audit took place in September 2015 and lasted for one week. The audit examined the generated waste quantities and composition of household waste in all waste pins available (except toilets). Method used to collect essential waste data during all studies was divided into four actions:

- viewing the percentage of fulfilment of storage in each mixed household garbage can,
- sorting the waste (paper, packaging waste, biowaste and other) as described in Table 1
- weighing the waste,
- making notes of waste which was laid into a wrong part of the waste sorting. This was done only during II and III study.

Table 1. Sorting instructions used by the students

Category	Description of representative material
Paper and cardboard	printer paper, magazines, catalogues, coloured paper, envelopes, newspapers, corrugated cardboard
Packaging waste	Tetra packs, single-use tea and coffee cups, plastic beverage containers, plastic bags and packaging, metal cans, glass bottles, polystyrene disposable food packaging
Biowaste	Raw vegetables and fruits, coffee grounds and tea bags, food waste, bones, bread, tissue paper and other compostable material
Other	Textiles, clothing, pens, dirty packages, chewing-gum, cleaning rags, non-recyclable

After the new separate collection of waste system was put into practice the methodology described above was used again (spring and a year after the system was created) to check if the system works or need's improvement. It was also used to assessed how many mixed household waste pins where left in the university premises and how much waste was in them. All the data collection was done with the help of UAS students.

The new waste sorting system was created in accordance with the results of the first study results. The sorting guide and pins were designed and their dimensions calculated by the environmental technology and environmental management forth course students (Fig. 1).

Fig. 1. Designed waste collection point with sorting instructions

For the new waste collection points location was originally placed in every faculty and in the halls between faculties. Because the purpose was to give up small mixed household waste pins from the class rooms and offices. The new waste collection points had to be easily accessible and highly visible. New collection point's locations are shown in the Figure 2.

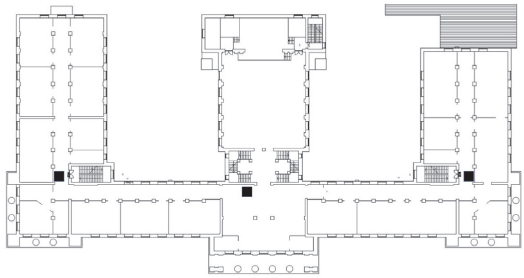

Fig. 2. New collection point's locations

During waste collecting system change there were different ways to inform students and staff for the upcoming change. It started with the European Week for Waste Reduction during what, there were held different environmentally friendly events such as promoting recycling clothes, quiz with prizes and movie night. The last and most important step of informing students and staff was sending a notification through UAS Study Information System.

In the court yard of the University there were containers for paper and cardboard (0,8m^3), mixed household waste (4.5m^3) and for bulky waste (4,5m^3). After the new system was created there were added new containers for packaging (1,1m^3) and biowaste (0,24m^3).

Discussion

During the first study we counted 286 garbage cans all of which were used to collect waste as mixed household waste. After the introduction of waste sorting system the number of garbage cans dropped as did the number of cans used to collect garbage as mixed waste. The 2th study results revealed that the number of 16 litre cans reduced to 155. Only 35 garbage cans from those 155 were used for separated collection of bio-, paper- or packaging waste and 120 were used for mixed waste. During the 3rd study there were 138 garbage cans in total, of which 104 were used for mixed municipal waste, 21 for paper waste and 13 for biowaste. Detailed figures of remaining garbage cans by floor are outlined in figure 3. 10% of mixed municipal waste garbage cans were used in classrooms and the rest in the offices. Considering that the university has about 190 employees, every third employee still has a mixed household garbage can under the table. Many employees are not willing to give up their garbage cans because they are used to having their own garbage can or they don't consider it necessary to collect waste separately. One possible solution for that could be to replace personal garbage cans with a set of united garbage cans (paper, packaging waste, biowaste and household waste garbage can) in each office. Therefore the amount of the garbage cans would not depend on the amount of the people who work in offices. This would decrease the amount of remaining garbage cans significantly.

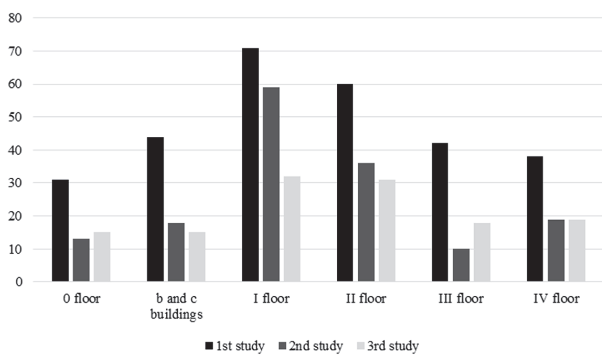

Fig. 3. Number of garbage cans in UAS by floor

The amount of waste produced at the university during the 1st study period was approximately 7500 litres, all of which was collected as mixed household waste into small garbage cans. The second study showed that after introducing the new waste sorting system, the amount of waste that was collected into the mixed household waste cans dropped to roughly 900 litres. Meanwhile waste collected into the new waste collection points was approximately 4200 litres. The higher total waste amount during the 1st study can be explained by the fact that the first waste audit took place during the autumn, when the school year just started and more students are in the house. 2nd study took place in the spring, when the last course students mostly work home and third course students are out of the university in their internship.

In overall the results were postitive. Around 80% of all the waste produced at the university during 2th study and 85% during the 3rd study was collected into the waste collection points and hence sorted. The waste laid into the wrong part of the sorting container (mostly packaging waste in municipal waste and other way around) was remarkably small.

Comparison of waste generation by floors show's that second, third, and B-unit generated a similar amount of waste during all studies. The quantities of waste in second and third floor remained in the range of 9–12 kg per week, and each study showed that the use of sorting containers increased. In B-building already 95% of produced waste is collected to waste collection points.

The most waste in UAS was generated on the 1st floor (Fig. 4), where the entrance to the building is located, so most people will use this floor. Additionally, there are many administrative offices on the floor which employees work on a daily basis. During the 1st and 2nd study the quantity of waste generated per week was around 30 kg, but decreased during the 3rd study by 45%. On the 1st floor, there was also a decreased in the number of cans for mixed household waste, but it cannot be the only reason why the mass of collected waste is reduced. On 4th floor the waste quantities decreased after the 2th study, but 3th study results showed 55% increase in the mass of waste. The reason is probably the timing of the 3rd study. It took place at autumn, a period when to the fourth floor of university was brought a large number of apples. Since autumn 2016 were very rich by apples, then both employees and students led apples to the university and thus increase the amount of biodegradable waste and the entire waste mass quantities.

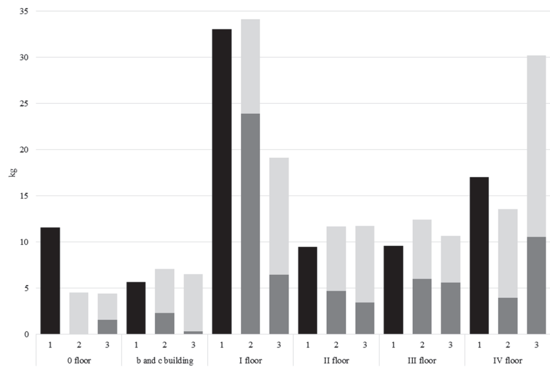

Fig. 4. Waste generation in different floors and during studies (black – mixed waste cans during first study, dark grey – amount of waste collected as sorted, light grey – amount of waste collected as mixed waste)

Meanwhile on the 2nd to 4th floor of the university, there was similar volume of the waste during first 1st study (around 700 litres) but a large difference of the waste volume on 2nd study. Most waste in spring was collected on the 2nd floor (approximately 900 litres in waste collection points and 200 litres in remained garbage cans), less on the 3rd floor (roughly 560 litres in waste collection points and 70 litres in garbage cans) and least waste collected, on those three floors, was on the 4th floor (approximately 400 litres in waste collection points and 70 litres in remained garbage cans).

At the basement floor (0 floor), there were two waste collection points placed (in library and e-learning centre) and the remaining garbage cans were taken in use as sorting bins. Also the canteen (where the most waste was collected during all studies) which is located on the basement floor went through a huge change. It withdrew small garbage cans and is now using large sorting bins to collect biowaste, household waste and packaging waste.

Lot of waste in UAS is generated in cafeteria. The biggest problem there is the high proportion of biowaste, which according to the 3rd study is around 20 kg per day. Most of the biowaste generated was food waste. Figure 5 shows that biowaste quantities have been particularly high during the 1st study. By the time of 3th study the biowaste quantities in the canteen has reached a kind of equilibrium and is generated in equal amount through out the week. 1st study coincided with time period when a new company took charge of the canteen management, and large quantities of food waste might be caused by the fact that the company did not yet take into account what is the number of consumers and customer preferences for food. Most of the raw material which reaches to the canteen is pre-treated – vegetables are peeled and meat products are cut and packaged. Thus, the majority of biowaste which proceed are the food which is left on the plate or overly prepared food. Amount of the food waste would reduce the higher quality of food serving, because at the moment there has been displeasure. Also planning the menu and the quantities in cooperation with the education department, who is aware of how many students are in the school at any given time, could help.

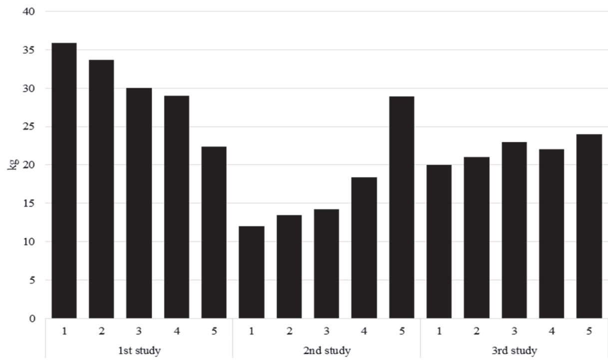

Fig. 5. Biowaste quantities in different study periods (numbers 1 to 5 shows the day of the study)

Conclusions

By the results of the first study a sorting guide and waste collection points were designed and dimensions calculated. The work was done by the 4th course students of environmental technology and environmental management. Waste collection points locations were choosen according to the habits of the school family. After the installation of waste collection points, students and employees were informed of the new arrangements.

The 1st study revealed that the largest numbers of garbage cans are and the most waste is generated on the first floor (excl cafeteria). This may be due to the administration and offices, where the daily work, and the lobby location at that floor.

The introduction of the new system has decreased the number of garbage cans in university from 286 to 138 pieces. The proportion of waste generated daily, which gathered on 2th and 3th study to waste collection points formed 80–85% of the total waste volume, which were produced in UAS. This is a very positive result in view of the new separate collection of waste system has been introduced only a year ago.

On the basement floor of the university a large part of mixed household waste garbage cans were abandoned. After the 1st study there was placed two waste collection points (in library and e-learning centre) and the remaining garbage cans were taken in use as sorting bins. Also the canteen went through huge change. Meaning it withdrew small garbage cans and is using big sorting bins to collect biowaste, municipal waste and packaging waste.

However, there is still a lot of biowaste in the canteen, which is mostly food waste. It is necessary to reduce that quantity. Providing better nutrition and preparing the menu considering how many students are in the university at specific time could be helpful.

The collected waste quantities in different study periods are different; the most stable are the amounts on the second and third floor and on the B-building. Large quantitative differences are on the fourth floor, with the last study, the waste quantities were increased almost 55%. On the first floor the 1st and 2nd study results of waste amount were similar, but during the 3th study the production of waste was 45% reduction.

Food waste and package waste represent two of the most significant material types for targeted waste reduction. The result presented in this paper shows the challenges that educational institutions may face when they want changes the institutions waste management more sustainable.

Disclosure statement

Authors declare that they don't have any competing financial, professional, or personal interests from other parties.

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Curriculum vitae

Personal data

Name: Monica Vilms
Date of birth: 24.10.1980
Place of birth: Tallinn
Nationality: Estonian

Contact information

E-mail: monica.vilms@gmail.com

Education

2013–2018 Tallinn University of Technology – PhD, Water and Environmental Engineering
2002–2006 Tallinn University of Technology – MSC, Enviromental Engineering
1999–2002 Tallinn Pedagogical University – BSC, Environmental Management
1996–1999 Tallinn Lillekyla Gymnasium – Secondary education

Language competence

Eesti keel – native language
Inglise keel – intermediate
Vene keel – intermediate
Saksa keel – basic

Professional experience

2017–........ TTK University of Applied Sciences, Institute of Circular Economy and Technology, Lecturer

2005–2017 TTK University of Applied Sciences, Faculty of Architecture and Environmental Engineering, Lecturer

Defended theses

Master theses: Household Waste in Tallinn City Household Waste Content and Amount. Supervisor Enn Loigu

Supervised master theses

Liis Tiit, master theses, 2014, Collection of municipal waste in the old town of Tallinn. Tallinn University of Technology.

Merlyn Paltsmar, master theses 2016, Municipal waste generation and collection in rural areas. Tallinn University of Technology.

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Elulookirjeldus

Isikuandmed

Nimi: Monica Vilms
Sünniaeg: 24.10.1980
Sünnikoht: Tallinn
Kodakondsus: Eesti

Kontaktandmed

E-post: monica.vilms@gmail.com

Hariduskäik

2013–2018 Tallinna Tehnikaülikool – PhD, vee-ja keskkonnatehnika uurimisrühm
2002–2006 Tallinna Tehnikaülikool – MSC, keskkonnatehnika
1999–2002 Tallinna Pedagoogikaülikool – BSC, keskkonnakorraldus
1996–1999 Tallinna Lilleküla Gümnaasium – Keskharidus

Keelteoskus

Eesti keel – emakeel
Inglise keel – kesktase
Vene keel – kesktase
Saksa keel – algtase

Teenistuskäik

2017–........ Tallinna Tehnikakõrgkool, Ringmajanduse ja tehnoloogia instituut, Lektor
2005–2017 Tallinna Tehnikakõrgkool, Arhitektuuriinstituut, Lektor

Kaitstud lõputööd

Magistritöö: Tallinna linna kodumajapidamistes tekkivate olmejäätmete koostis ja kogus. Juhendaja Enn Loigu

Juhendatud magistrimonica vtööd

Liis Tiit, magistrikraad, Olmejäätmete kogumine Tallinna vanalinnas. Tallinna Tehnikaülikool,

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