Master's degree thesis

LOG950 Logistics

Romsdalshalvøya Interkommunale Renovasjonsselskap (RIR): Systems for collecting glass/metal packaging from households - consequences

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Summary

The importance of introducing new Municipal Solid Waste collection (MSW) systems to collect MSW from households and assessing the strengths and weaknesses of them has been an interesting field of research for almost all the waste collection companies. The purpose of this study is to introduce MSW collection systems and find the corresponding consequences.

In order to accomplish this study, the author carries out an excessive literature review to find the most efficient methods to collect MSW from households and subsequently evaluate them to determine which introduced MSW collection systems would fit better.

This study is designed mostly based on RIR's needs. This company is responsible for the collection of MSW from households in seven municipalities in Norway. They have the intention to collect glass/metal packaging from households instead of collecting them from drop-off centers in the near future. One of the major parts of this paper is the cost analysis which tries to estimate costs associated with several possible systems.

This paper will mostly consider MSW collection systems in the developed countries. This is due to the fact that, the current MSW collection system used by RIR is to a great extent efficient and modern.

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Chapter 1: Introduction and background

For many communities throughout the world, management of Municipal Solid Waste (MSW) is a priority (Li and Huang 2006). In fact, health, environment, aesthetics, land-use, resource, and economy can all be affected to a great extent by improper MSW management (Henry, Yongsheng, and Jun 2006). Finding the best possible methods to collect municipal solid waste (which is a part of the whole MSW system) has been an interesting research area in recent years, since there are many different methods which can be applied and implemented. Collection system consists of three main activities separation, transport and collection of recyclables (Jahre 1995a). It would be necessary to explain that the complexity of addressing MSW collection problems have positive relationship with patterns of waste generation and the quantity of waste (Tchobanoglous, Theisen, and Vigil 1993). Figure 1indicates how the whole system works from the beginning (Extraction) to the waste treatment and recycling in a conceptual manner:

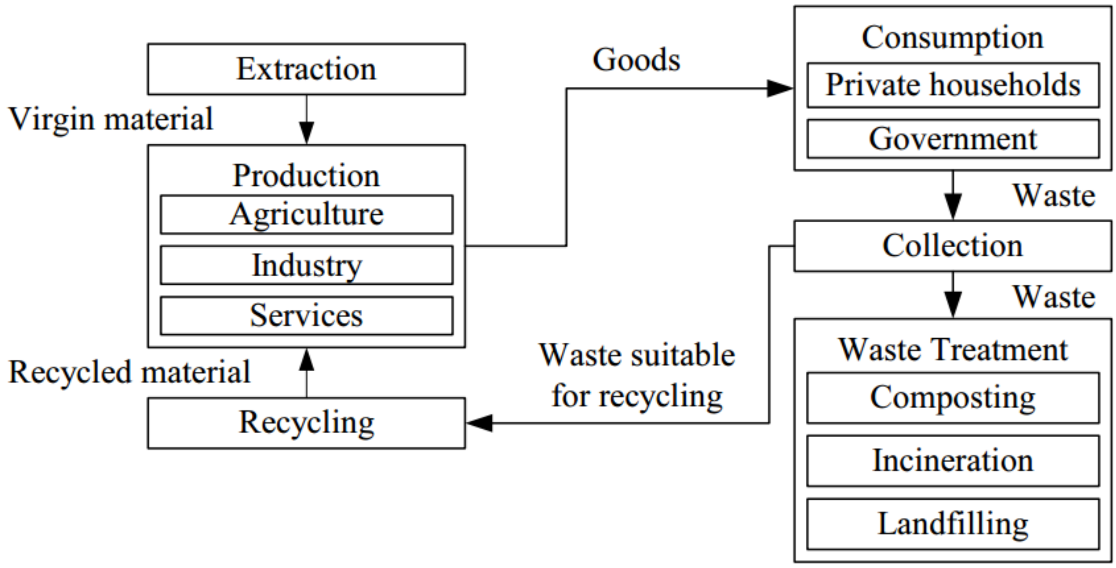

Figure 1: The main elements of the conceptual framework (Bartelings 2003)

1.1 Municipal solid waste management and reverse logistics

In order to find the link between MSW management and logistics, the first step is having a clear view of what logistics means and involves, all the perspectives and definitions synchronize logistics as the provision of actions such as procurement, production, sales, and distribution with demands. To be more accurate, it also encompasses process of moving and handling goods and materials from the beginning to the end of the production, sale process and waste disposals to satisfy customers and to help companies to gain competitive advantages. It involves creating, planning and monitoring of goods and information. The appropriate definition *for reverse logistics* may be "*the process of planning, implementing and controlling the efficient cost effective flow of raw materials, in process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal"* (Kinobe, Gebresenbet, and Vinnerås 2012, p. 1106).

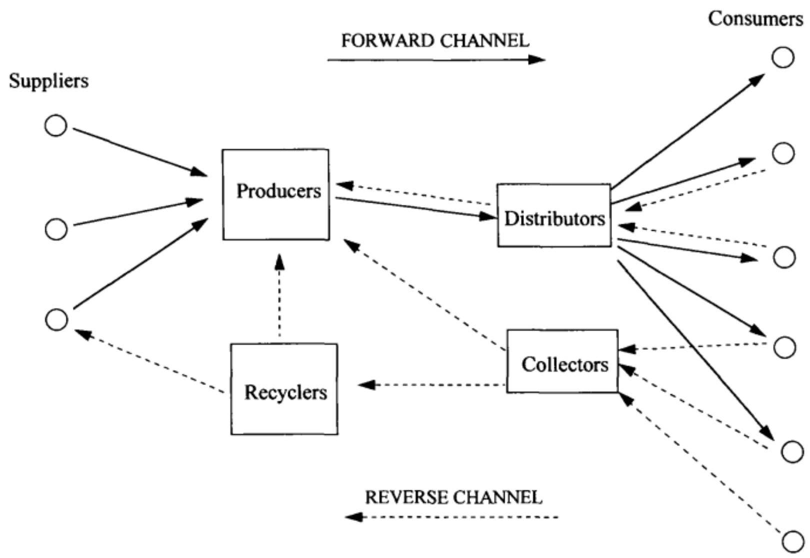

Figure 2: Framework of reverse distribution (Fleischmann et al. 1997)

MSW management can be regarded as a reverse logistics problem in supply chain management (Bautista and Pereira 2006). In fact, an MSW management system can be considered a reverse logistic problem which is more challenging since it involves social responsibility, environmental impacts and some other relevant factors. Furthermore, both reverse logistics and MSW management systems have approximately the same dominant objective, which is minimizing logistics costs. This is due to the fact that, 60%-90% of the total operating costs of MSW management systems are constituted by logistics costs (Yu 2012).

1.2 MSW management in Norway

The main methods used for treatment of municipal solid waste in Norway can be split between incineration and recycling, meaning that other ways such as landfilling do not play important roles. In fact, the usage of landfills has been decreased. At the same time, the rate of using incineration method has increased during recent years. A large amount of waste produced in Norway is exported to Sweden to be incinerated .The amount of municipal solid waste was increased by 41 percent from 2001 to 2010 in Norway (Kjær 2013).

WASTE POLICY 2014

The new government and the new parliament have put forward some opportunities for new political visions. Waste Norway has regular contact with both politicians and civil servants with the goal of increasing resource utilization of the waste and their message is as follows:

"Waste is an important resource and can be considered as raw material for the production of new products and biogas and energy. An optimal utilization of this resource requires investment in technology and new value chains" (Grundt 2014).

The regulatory framework must both stimulate the market and the development of necessary infrastructure for the benefit of society and waste policy. We need political vision, intersectional collaboration and new national targets. Future waste requires the solutions of tomorrow (Grundt 2014).

1.3 RIR (Romsdalshalvøya Interkommunale Renovasjonsselskap)

RIR (Romsdalshalvøya Interkommunale Renovasjonsselskap) is responsible for taking care of MSW in seven municipalities with around 48,500 inhabitants who live in Molde, Aukra, Eide, Fræna, Gjemnes, Midsund and Nesset in Norway. The number of households served by RIR is approximately 20,000. RIR organizes sorting and recycling stations in all municipalities. They collect residual waste, paper, food scraps and plastic packaging from the subscriber, while glass, hazardous waste, clothing / shoes and glass/metal packaging are brought by the holder to collection points or recycling centers. The actual operations are carried out by one contractor. The contractor performs all the work with the collection and management of recycling centers. The company has annual sales of approximately 84 million NOK. Finally, they have been successful to achieve ISO 14001 and ISO 9001 certificates.

1.3.1 RIR plant

The RIR facility is built around the landfill in Årødalen. A lot of activities are conducted there. However, there is not much material added to the landfill nowadays.

Figure 3: RIR plant (RIRwebpage)

The plant can be considered more as transshipment spot than a landfill. This is due to the fact that, almost all the wastes which go into the port in Årøsetervegen 56 are transported to other areas by using other equipment and larger containers. The wastes are transported to treatment plants as raw material for new production, instead of just being collected in a garbage dumping site (RIRwebpage).

This site also includes a small power plant that produces electricity by using methane gas which is formed naturally in the landfill. Produced methane goes through a pipeline to a gas engine that produces electricity. Excess heat from the exhaust and cooling water is used as the "short-distance district heating" of the administration building and the car wash which reduces the need for electrical power for the operation of their buildings (RIRwebpage).

1.3.2 Current pattern of collecting solid waste from households

Most of the households served by RIR have standard subscription which consists of both outdoor equipment that will be collected after a fixed interval, and some indoor equipment (RIRwebpage).

Equipment	Collected
80 l rolling bin for biowaste	Weekly
140 l rolling bin for paper	Monthly
140 l rolling bin for residual waste	Biweekly
140 l sack for plastic packaging	Monthly

1.3.3 Collection points

The collection of glass/metal packaging and textiles are executed by some containers which are usually located around grocery stores or gas stations. Hazardous waste is also collected by the same method. Figure 4 shows the collection points both for glass/metal packaging and textiles (R) and hazardous waste (F) in Molde and Figure 5 shows the method by which they are collected (RIRwebpage).

Glass and metal packaging

Metal containers are cans, imported beer and soda cans, lids, foil and so forth. Other metals that are not packaging must be delivered to the recycling stations orjunkyard. Glass packaging includes bottles, glass jars, glass food jars, etc. This means, collection points are not provided for window glass, fireproof glass, crystal, porcelain or ceramic (RIRwebpage).

Clothes and textiles

Clothing, shoes, belts and toys that can be reused are the main components for these drop-off centers. However, In Fretex containers, it is also possible to drop other fabrics such as bedding and old t-shirts. Containers marked Fretex are collected by RIR's employees**.** UFF is another organization that is authorized by RIR to set out their containers at collection points where they do not have Fretex containers (RIRwebpage).

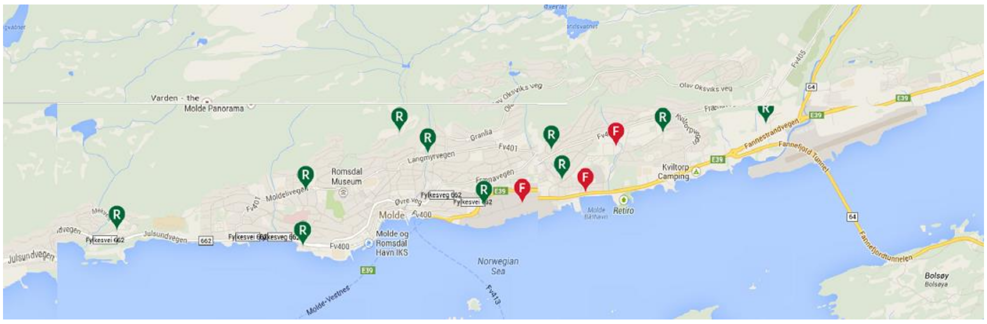

Figure 4: Collection points (R) in Molde (RIRwebpage)

Figure 5: Collecting glass/metal packaging from drop-off centers

1.4 Research method and objectives

The objective of this study is to introduce new systems for collecting glass/metal packaging for a company called RIR which organizes sorting and recycling stations in seven municipalities in Norway, and subsequently to find the consequences of applying the introduced systems which can be categorized as follows:

1. Using existing system but applying different pattern.
2. Applying Pay-As-You-Throw (PAYT) system (weight-based billing).
3. Using different color bags to sort MSW by households.
4. Applying two different methods simultaneously.

Using existing system but applying different pattern refers to the fact that, this system will mainly focus on the pattern of MSW collection. In other words, this system tries to take advantage of using existing facilities but in a more efficient manner so that collecting of glass/metal packaging from households becomes possible. In addition, the three other introduced systems would use this pattern. System 2 is based on the idea of increasing the participation rate by applying some scales to weigh the amount of waste produced by each household. In fact, this type of collection system contributes to reduce the amount of waste, in particular, residual waste. The third system will be suggested as a system which can contribute to increase co-collection degree. This system can make collecting two or more fractions at the same time possible so that it increases the efficiency of the collection system. At the end, the fourth system basically tries to combine different systems to achieve the best possible results.

1.4.1 Research question

The aforementioned category for collecting glass/metal packaging from households will be analyzed by three different aspects regarding environmental effects, social participation and corresponding costs, which give rise to these following main questions:

1. Which introduced system is the most suitable from the social point of view?
2. Which introduced system provides the company with the lowest corresponding costs?
3. Which introduced system is more environment-friendly?

1.4.2 Data collection

In order to find the best possible collection systems for this company and identifying their consequences, the author will go through the relevant literature to gain enough information about different systems and their results, in particular, in modern countries. To understand and to have a better view of this topic, some general information will also be presented in the beginning of Chapter 2. In Chapter 3 the author will take advantage of interviews to accomplish this part of the study. Interviews will focus on gaining information about how different systems affect the costs concerning different introduced MSW collection systems. Chapter 4 is assigned to discuss the corresponding consequences and draw a conclusion about the most efficient introduced system with regard to participation rate, costs, and environmental effects.

Chapter 2: Literature Review

2.1 Solid waste management

In order to define solid waste management it is required to have a clear understanding of waste and one of its subcategories which is solid waste.

"Waste is a by-product of human activity. Physically, it contains the same materials as are found in the useful products; it only differs from useful production by its lack of value. The lack of value in many cases can be related to the mixed and, often, unknown composition of the waste. Separating the materials in waste will generally increase their value if uses are available for these recovered materials. This inverse relationship between degree of mixing and value is an important property of waste" (McDougall et al. 2008, p. 1).

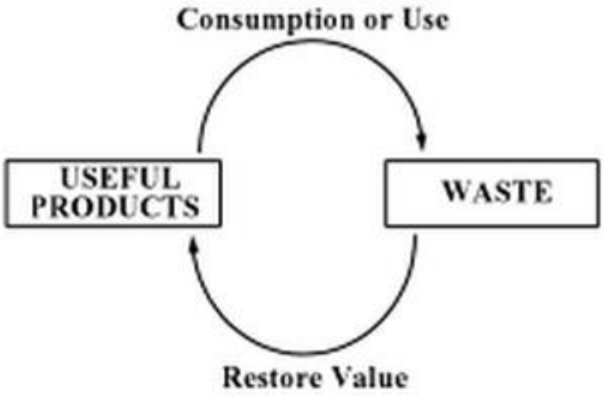

Figure 6: The relationship between waste and value (McDougall et al. 2008)

Waste can be classified by six subcategories which are as follows:

1. Physical state (solid, liquid, gaseous)
2. Original use (packaging waste, food waste, etc.)
3. Material type (glass, paper, etc.)
4. Physical properties (combustible, compostable, recyclable)
5. Origin (domestic, commercial, agricultural, industrial, etc.)
6. Safety level (hazardous, non-hazardous) (McDougall et al. 2008)

Management of solid waste can be defined as the discipline concerning the control of generation, storage, collection, transfer and transport, processing and disposal of solid wastes in a way that facilitates achieving the best principles of public health, economics, engineering, conservation, aesthetics and other environmental considerations which is also responsive to public attitudes. In its scope, all administrative, financial, legal, planning, and engineering functions which are involved in solutions to all solid wastes can be included to the Solid Waste Management (SWM) system. Finding the best possible solutions may involve complex interdisciplinary relationships among such fields as city and regional planning, political science, economics, geography, public health, demography, sociology, communications, and conversation, as well as engineering and material science (Tchobanoglous, Theisen, and Vigil 1993). Figure 7 shows a simplified interrelationship between the functional elements in a solid waste management system.

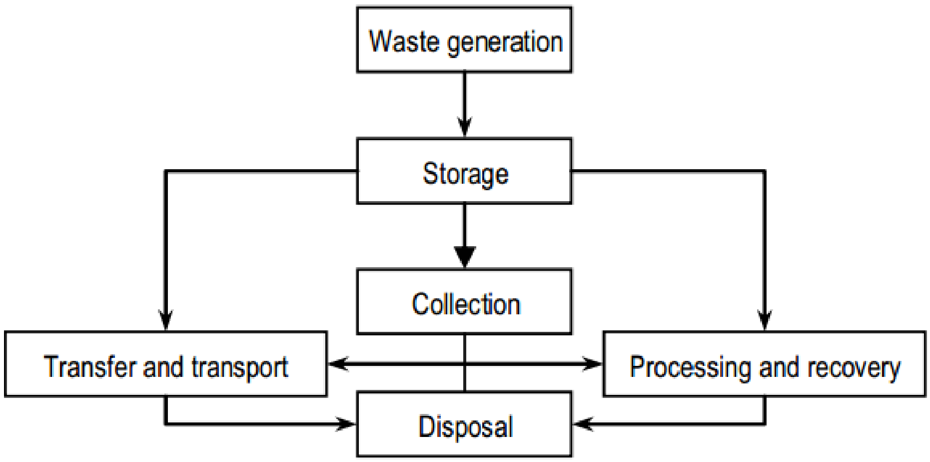

Figure 7: Simplified diagram showing the interrelationships of the functional elements in a solid waste management system (Syed 2006)

Prevention, reuse, recycling, recovery and landfill are the typical methods to deal with MSW. These methods can be categorized as shown in Figure 8. Prevention is the most desirable, which has many benefits regarding reduction in greenhouse gases emission, resources conservation, energy savings, pollutants reduction, and development of green technologies (Cucchiella, D'Adamo, and Gastaldi 2013). However, in many cases prevention are almost impossible; hence, trying to get more out of the more desirable methods can contribute to achieve better results. The aim of RIR is to find better methods to collect MSW according to the hierarchy shown in Figure 8. In fact, an MSW collection system can affect social behavior towards waste, meaning that people may try to sort better which result in better recycling or they even try to prevent waste in some cases. For example, weight-based bailing system can lead to MSW reduction by households.

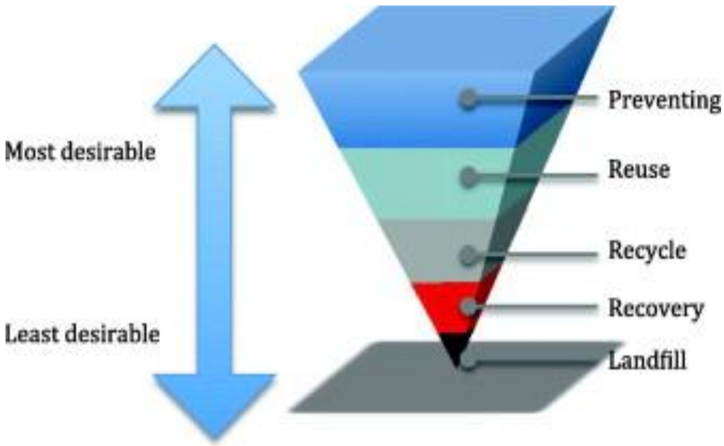

Figure 8: Waste management hierarchy (Cucchiella, D'Adamo, and Gastaldi 2013)

2.2 Key points about different methods of treatment (preventing, reuse, recycling, recovery, and landfill)

Prevention

There are different methods in order to deal with municipal solid wastes, which are mentioned above. The amount of municipal solid waste has shown an increasing trend for years in many countries. Some waste related policies have been established by many governmental agencies and international organizations to reduce the environmental impacts of waste management, including reducing the amount of waste (Gentil, Gallo, and Christensen 2011).Although prevention of waste is generally considered to be good for the environment and society at large, there is little quantitative evidence assessing the environmental aspects of waste prevention. The amount of waste which potentially could be prevented has been an interesting field of research recently (Mazzanti and Zoboli 2008). In the UK, a large research program in waste prevention has been funded by the government including a review of evidence analyzing the behavioral opportunities and barriers in household waste prevention, associated with the effectiveness of various policy measures (Cox et al. 2010). However, literature about the quantitative environmental assessment of waste prevention is scarcely found (Gentil, Gallo, and Christensen 2011).

The key role of waste prevention is of crucial importance throughout the life cycle of a product. Moreover, life cycle assessment helps expanding the perspective beyond the waste management system. This is important since the environmental consequences of waste management often depend more on the impacts on surrounding systems than on the emissions from the waste management system itself (Ekvall 1999); Figure 9 shows a simplified conceptual model for a product's life cycle and opportunities for waste reduction.

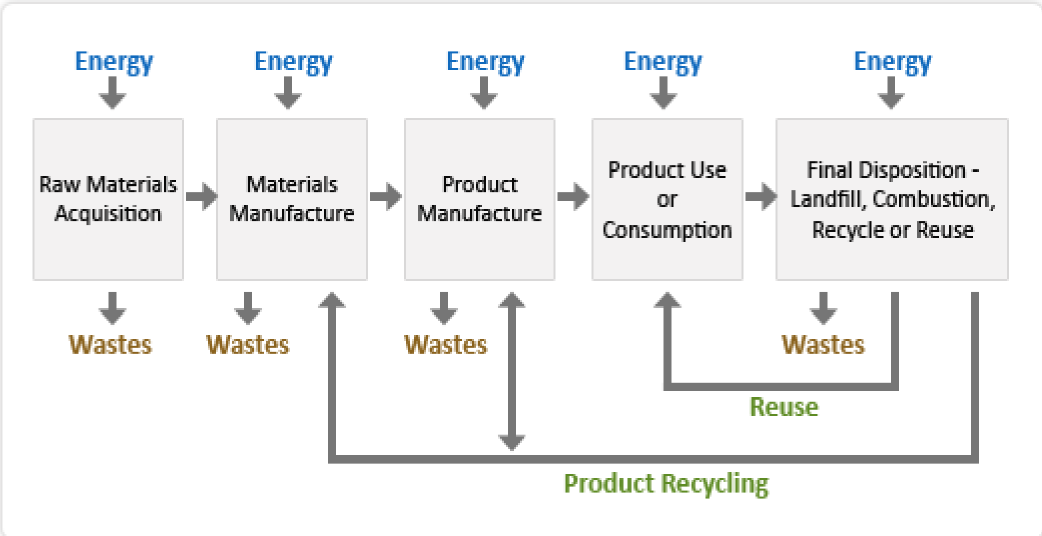

Figure 9: Opportunities to reduce waste throughout a product's life cycle (Associates 2013)

Based on the studies conducted by (Salhofer et al. 2008) about the potentials for municipal solid waste prevention, it can be concluded that the potential prevention of a single fraction could represent up to 10% of that fraction. It was shown, quite remarkably, that although the potential prevention appeared to be small, it was not insignificant, in comparison with the overall MSW produced. Furthermore, it is claimed by Olofsson that prevention of 4% of MSW at national level can lead to greenhouse gas emissions reduction by 5-9% in Sweden (Olofsson 2004).

Prevention of creating waste has many advantages both environmentally and economically, some of these benefits are presented in Table 1:

Environmental benefits	Conservation of natural resources
	Reduced environmental impact from raw material extraction
	Reduced energy usage and pollution from manufacturing
	Reduced burden on landfills and combustors
Economic benefits	Reduced waste management costs
	Savings in material and supply costs
	Savings from more efficient work practices
	Potential revenues from selling unwanted or reusable materials

Table 1: Environmental and economic benefits of waste prevention (EPA 1995)

There are different methods which can be implemented to prevent creating solid waste. Some of them are as follows (EPA 1995):

- Packaging reduction

  Reducing the packaging which are used to transport and contain products and materials, as well as the packaging they receive through shipments.
- Paper reduction

  Paper reduction can be done through activities such as copying on both sides of a piece of paper, using electronic and old-fashioned bulletin boards to distribute information.
- Product and supply reuse

  Replacing disposable items with long-lasting, reusable products can break the frequently expensive cycle of discarding and reordering. Hundreds of items, from file folders to air filters, can be reused.
- Exchange, sale, or donation of unneeded goods

  Through waste exchanges, organizations can trade, sell, or give away goods or materials that would otherwise become waste. Unwanted materials and surplus inventory also can be donated to educational and charitable organizations.
- Hazardous constituent reduction

  Many products are available with few or no hazardous constituents, including inks, glues, paints, solvents, and cleaning products.
- Use and maintenance of durable equipment and supplies

  Long-lasting, high-quality supplies and easily repairable equipment stay out of the waste stream longer. Initially such items can cost more but expenses can be justified by lower disposal, maintenance, and replacement costs.
- “Onsite” composting of yard trimmings

  Leaving grass clippings on the lawn and onsite or backyard composting can contribute to keeps yard trimmings out of the waste stream using compost also returns valuable nutrients to the soil.

Reuse

If prevention is not possible, then we should try to get the most out of reusing items or giving them to someone else that can reuse them (Council). Reuse involves using the items in a different way, when their primary use is finished. For example, a tire of an automobile can be reused as it is shown in Figure 10 or selling it to people who need it. The most important reason of reusing would be reducing waste and decreasing or postponing the garbage sent to, for example, landfills or incineration plants, while at the same time it provides the opportunity to use an item productively and save the money of buying something else. Reduction of waste is considered a crucial means of reducing the environmental impact of global warming and greenhouse gases by The Environmental Protection Agency (EPA). Economically, it inserts office equipment, appliances, furniture, rugs, telephones and many other used products back into the economic stream. These products, equipment and parts can help small business owners and individuals to make money, and put that money back into the economy (reuserecycle.net).

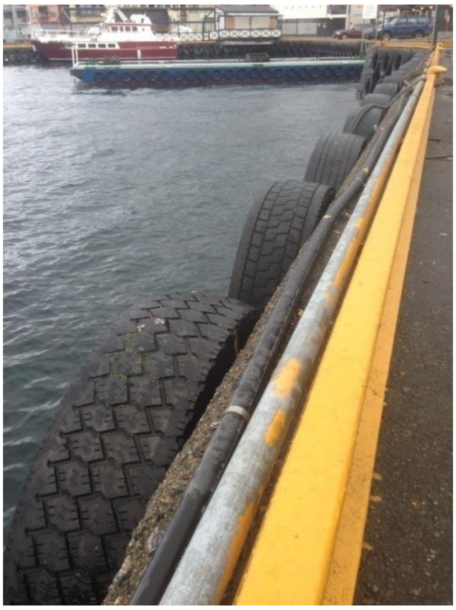

Figure 10: Reusing vehicles' tires in Molde

Community reuse programs are a natural evolution because they require less energy and less labor than recycling, and they help to reduce pollution of air, water and soil. In the following, some other benefits of reusing are presented (reuserecycle.net):

- It extends the life cycle of an item, the initial time and effort which is spent in manufacturing the item.
- The amount of manpower and pollutants can be reduced which would be required to make a new item or recycle old material.
- It supports crucial charitable work and can provide additional money to fund this work.
- It reduces the materials and chemicals that must be recycled and those that might otherwise damage or impact our environment.
- New business models and business opportunities can be introduced.
- It costs less than purchasing a new product or disposing of an old one.
- It does not take dedicated skill and energy to produce a new item, meaning that these skills can be used to manufacture other, more important products.

Recycling
Recycling is the process of collecting and processing materials that would otherwise be thrown away as trash and turning them into new products (EPA 2013). For example, if an old automobile tire is recycled, it might become raw material for road surfacing (reuserecycle.net).
There are many reasons why recycling should be considered of crucial importance, some of them are presented as follows (EPA 2013):

- It contributes to reduce the amount of waste sent to incineration plants and landfills.
- Natural resources can be conserved such as timber, water and minerals.
- It contributes to save energy in a general manner.
- Prevents pollution by reducing the need to collect new raw materials.
- The amount of greenhouse gas emission can be reduced.
- It contributes to sustain the environment for future generations.
- Economically, it can contribute to create new jobs in the recycling and manufacturing industries.

Recovery (Energy Recovery from Waste)
Energy recovery from waste refers to the conversion of non-recyclable waste materials into useable electricity, heat or fuel through a variety of processes (such as gasification, combustion, anaerobic digestion, and landfill gas (LFG) recovery). This process can also be called waste-to-energy (WTE) (EPA 2014). It is necessary to explain that the two common processes for recovery of waste are aerobic composting for biological transformation which means using biological process in order to convert the organic portion of MSW to the materials known as *compost* and combustion for chemical transformation (Tchobanoglous, Theisen, and Vigil 1993). In other words, one of the most effective means of dealing with many wastes is incineration which contributes to reduce their potential and often to convert them to an energy form (Tchobanoglous and Kreith 2002).

Landfilling
Landfilling can be defined as the process by which solid waste and solid waste residuals are placed in a landfill (Tchobanoglous and Kreith 2002). Historically, this method of solid waste disposal has been the most environmentally and economically acceptable method for the disposal of solid waste. It is also valuable to explain that even with implementation of waste reduction, transformation technologies and recycling, this method is still considered an important component of an integrated solid waste management strategy (Tchobanoglous, Theisen, and Vigil 1993).

Figure 11: A typical landfill in Great Britain (SmartPlanet 2008)

There are different types of landfills but the principle ones can be classified as conventional landfills for commingled MSW, landfills for milled solid waste, and monofills for designated or specialized waste (Tchobanoglous, Theisen, and Vigil 1993).

2.3 Municipal solid waste management

A holistic management system for multi-sourced solid waste would be one of the best definitions for municipal solid waste management systems. Municipal waste basically refers to household and commercial waste (McDougall et al. 2008), this type of waste is heterogeneous in terms of both physical and chemical composition. During the last 50 years, the composition of MSW has changed; however, it can still be characterized by an accelerated proliferation of waste organic matter, paper, and plastics (Chandler et al. 1997). It is notable to explain that the definition of solid waste can vary between countries. The following definition is prepared by Eurostat:

"Municipal waste is mainly produced by households, though similar wastes from sources such as commerce, offices and public institutions are included. The amount of municipal waste generated consists of waste collected by or on behalf of municipal authorities and disposed of through the waste management system" (Fischer et al. 2013, p. 7).

Table 2 illustrates the amount of separately collected municipal waste from the year 2004 to 2010 in Norway.

	2004	2005	2008	2010
Paper, paper packaging	271	299	335	295
Glass	41	44	49	51
Plastic	8	9	18	25
Metal	53	54	64	68
WEEE	31	39	50	42
Green kitchen waste	156	152	172	172
Wood	113	129	176	191
Garden waste	110	112	140	163
Textiles	9	11	13	14
Hazardous waste	16	23	27	32
Others	45	35	45	58
Total	854	906	1 088	1 110

Table 2: The amount of separately collected waste (1000 tones) from the year 2004 to 2010 in Norway (Kjær 2013) showing growth in each types of waste

In order to plan a regional MSW management system, some factors should be taken into consideration which are presented as follows:

- **Policies and regulations**

  When an MSW management system is planned, the primary considerations are policies and regulations. MSW management system has a long-term impact on the environment, people's health, satisfaction and standard of living. Therefore, it should be consistent with the local policies, regulations and the government's blueprint of development (Yu 2012).
- **Geography and climate**

  Solid waste recycling and disposing facilities can have great impact on the environment. Therefore, geography and climate must be taken into consideration when an MSW management system is planned. In order to minimize the negative effect on populated areas and other important places, trying to place such facilities in proper locations is of crucial importance. For instance, the potential effect of serious air pollution that can be caused by an incineration plant, it means when an incineration plant is planned, some geographical and climate factors should be considered such as, the monsoon of the given region and if there is any possibility, it should be located in the upper location of the minimum wind frequency (Yu 2012).

- **Technologies**

  There is no doubt that technology plays a key role in waste processing, recycling and logistics, and many other sections. Different types of technology can be chosen by considering local policies and regulation, economy, geography and climate, environment, waste composition, etc. For example, economically, the cheapest method to deal with MSW is landfill. However, it is the most expensive method regarding its environmental effects. This method is mainly applied in developing countries where the MSW are rarely classified before treatment (Yu 2012).

- **Cost**

  Generally, cost consists of two major parts, the first part is facility construction cost and the second part is system operating cost. The logistics costs occupy relatively the greatest portion of operating cast, and it is important to disclose that, this logistics costs are quite flexible (Yu 2012).

- **Type of waste**

  The nature of domestic solid waste can differ to a great extent from one region to another, and even between different parts of the same city. For example, in some industrialized countries the residual waste after segregation of recyclables might be much heavier; in other industrialized countries, the waste has a very low density because it consists largely of paper and packaging. In tropical countries where fresh food is plentiful and canned food expensive, there may be large quantities of fruit and vegetable peelings and spoiled food, making the waste dense, wet and corrosive. In arid countries where yards and internal floors are not paved but bare earth, there may be a large quantity of soil in the waste, making it dense and abrasive (Coad 2011).

2.4 Key points and classification of MSW collection systems

Collection of separated and commingled solid waste is one of the most important and complicated components of MSW management system, according to (Tchobanoglous, Theisen, and Vigil 1993) it includes not only gathering or picking up of solid wastes from the various sources , but also the transport of these wastes to the location where the contents of the collection vehicles are emptied. The unloading of the collection vehicle is also part of the collection operation. Methods which are used for gathering and picking up can be different regarding the characteristics of the facilities, activities, or locations where waste are generated and the methods used for onsite storage of accumulated wastes between collections. However, activities associated with hauling and unloading are relatively similar for most collection systems.

A collection system can be regarded as a logistical system in which “products” are taken from the end-consumer into the material flow for production of new products. Logistical system for collecting waste from household can be designed based on a number of principles for deciding where, when, and how activities in production, purchasing and distribution of any products are to be performed (Jahre 1995b).

2.4.1 Shared vs. individual collection

Collection systems for municipal solid waste can be viewed from different perspectives. One would be by its type which can be shared or individual, shared systems refer to those types in which residents can bring out waste at any time, and individual pertains to the systems where the residents need a suitable container and must store their waste on their property until they are collected.

	System	Description	Advantages	Disadvantages
Shared	Dumping at designated location	Residents and other generators are required to dump their waste at a specified location or in a masonry enclosure.	Low capital costs	Loading the waste into trucks is slow and unhygienic - Waste is scattered around the collection point - Adjacent residents and shopkeepers protest about the smell and appearance.
	Shared container (alley collection/drop-off centers)	Residents and other generators put their waste inside a container which is emptied or removed	Low operating costs	If containers are not maintained they quickly corrode or are damaged - Adjacent residents complain about the smell and appearance.
Individual	Block collection	Collector sounds horn or rings bell and waits at specified locations for residents to bring waste to the collection vehicle.	Economical. Less waste on streets - No permanent container or storage to cause complaints	If all family members are out when collector comes, waste must be left outside for collection. It may be scattered by wind, animals and waste pickers.
	Curbside collection	Waste is left outside property in a container and picked up by passing vehicle, or swept up and collected by sweeper.	Convenient - No permanent public storage	Waste that is left out may be scattered by wind, animals, children or waste pickers. If collection service is delayed, waste may not be collected or some time, causing considerable nuisance.

	Door to door collection	Waste collector knocks on each door or rings doorbell and waits for waste to be brought out by resident	Convenient for resident - Little waste on street.	Residents must be available to hand waste over - Not suitable for apartment buildings because of the amount of walking required.
	Backyard collection	Collection laborer enters property to remove waste	Very convenient for residents - No waste in street.	The most expensive system, because of the walking involved - Cultural beliefs, security considerations or architectural styles may prevent laborers from entering properties

Table 3: Basic collection systems (Christiaan, Adrian, and Inge 1998)

Each of the aforementioned systems can have some sub-categories. For example, backyard collection can be divided into two collection services setout-setback and setout, the first one refers to the system in which containers are set out from the homeowner's property and set back after being emptied by additional crews that works in conjunction with the collection crew responsible for loading the collection vehicle. The second one is quite similar to the first one, except for the fact that the homeowners are responsible for the returning the containers to their storage location. Another system which was not explained directly would be drop-off and buy-back centers (subcategory of shared container) (Tchobanoglous, Theisen, and Vigil 1993).

Different types of collection systems can be used for different situations. For instance, in Table 4 appropriate collection systems are recommended for different conditions in which MSW are not separated.

	Classification	Recommended systems
Commingled waste	From low-rise detached dwellings	Curb, alley, setout-setback, and setout
	From low-and medium rise apartments	Curb
	From high-rise apartments	Shared containers

Table 4: Recommended systems for different conditions (Tchobanoglous, Theisen, and Vigil 1993)

According to (Tchobanoglous, Theisen, and Vigil 1993) recommended methods for collecting separated MSW are curbside collection using conventional and specially designed collection vehicles, incidental curbside collection by charitable organizations, and delivery by homeowners to drop-off centers.

Figure 12: A typical curbside collection system in a modern country (Salazar 2010)

Since this study is intended to clarify consequences of collecting MSW for a local cleansing department (RIR), it would be important to dig out more about the current collecting methods used by this company which are curbside and drop-off at specified collection points. In the following, some other benefits and drawbacks of these systems are presented (O'Leary and Walsh. 1995):

Curbside collection

Advantages:

- Crew can move quickly.
- Crew does not enter private property, so fewer accidents and trespassing complaints arise.
- This method is less costly than backyard collection because it generally requires less time and fewer crew members.
- Adaptable to automated and semi-automated collection equipment.

Disadvantages:

- On collection days, waste containers are visible from street.
- Collection days must be scheduled.
- Residents are responsible for placing containers at the proper collection point.

Drop-off at specified collection points

Advantages:

- Drop-off is the least expensive of methods.
- Offers reasonable strategy for low population densities.
- This method involves low staffing requirements.

Disadvantages:

- Residents are inconvenienced.

- There is increased risk of injury to residents.
- If drop-off site is unstaffed, illegal dumping may occur.

2.4.2 Bring vs. Curbside collection

The number of materials[1] separated at the collection level (e.g. by the collection crew or the consumer) can be regarded as an important variable in describing a collection system. Therefore, another perspective toward classification for MSW collection systems can be based on initial transportation which can be performed either by the consumer himself/herself or by the waste manager (Cairncross 1991). "Bring" refers to those collection systems in which the initial transport is performed by the consumer, meaning that the public brings material to specific collection points, while in curbside collection systems the mentioned transportation is performed by someone else in which materials are left on the curbside for collection. However, this classification cannot explain all the existing types of collection systems. The more precise classification criteria would rather be *" the average transport distance for the consumer from point of consumption to point of collection and the number of households covered by one collection point"* (Jahre 1995b, p. 21). In other words, curbside collection systems include a larger number of collection points (e.g. households) in comparison to a bring collection system (i.e. drop-off centers, redemption and retailers centers). It can be logistically noticed that the material flow for curbside collection systems will be more complicated from the collector's point of view considering the number of collection points (Jahre 1995b).

2.4.3 Pay-as-you-throw (PAYT)

Pay-as-you-throw refers to any MSW collection system that makes users pay a variable price based on the amount of waste they produce, rather than a fixed fee. There are two well-known variants of this system; volume-based and weight-based. Volume-based is more typical (Hall et al. 2009). Consumers have greater waste reduction incentive in weight-based systems than volume-based. This is due to the fact that, every pound/kilogram of waste which consumers prevent, recycle or compost leads to direct saving. However, under volume-based system, consumers are charged according to the number and size of waste container (bags, cans, etc.) which they use. Besides, these types of systems are easy to understand and fair from people's point of view (Canterbury 1996). Waste collection is funded by different forms of local tax in many countries throughout the world and people are not aware of the actual cost. However, it is usual for house owners to pay for waste collection by separate billing or directly through e.g. pre-paid waste bags or container tag fee system (Bilitewski 2008). The charge for waste collection can be a flat rate, or based on volume or weight. In weight-based billing systems the householder is charged per kilogram of waste, using collection vehicles equipped to weigh the waste bins at each property. Volume-based billing often means that householders can choose the collection frequency and/or size of the waste bins. These systems can have both some advantages and disadvantages which are presented as follows (Dahlén and Lagerkvist 2010) (Canterbury 1996):

Advantages:

- The pay-as-you-throw systems are generally well accepted by the householders.
- Fair allocation of costs to the users.

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[1] Materials refer to uncollected household waste in a general manner.

- Reducing waste in bins and bags (15–90% reduction reported).
- Ensuring transparency of waste management costs.
- Increasing sorting of recyclables.
- Encouraging home composting.
- Increased interest in waste management issues.
- Less bulky waste in the bins.
- Reduced frequency of collection rounds.
- Reduced waste disposal costs.
- Increased understanding of environmental issues in general.

Disadvantages:

- Increased costs (both investment and operational).
- Encouraging waste tourism (i.e. waste moved to neighboring communities).
- Encouraging illegal waste dumping.
- Increased amounts of contaminants in recyclables.
- Ordinary household waste was inappropriately disposed of at recycling centers.
- Private burning of waste occurred.
- Household waste was disposed of at working places.
- Perception of increased costs to residents.
- Extending direct waste reduction incentives to residents of multi-family housing can present a challenge.

2.4.3 Separation at source vs. separation in a processing facility (centralized separation)

Collection systems can be classified based on whether materials are separated by the consumer (i.e. separation at source) or the materials are centralized (i.e. materials are collected together and sorted separately, usually at MRFs[2]) (Cairncross 1991)
It is important to explain that, separation at source is an interesting issue currently. In Norway, for example, the term "separation at source – systems" is used for the household collection waste, meaning that this is the only feasible way to design systems. It is claimed that the more materials are separated at source, the better. Some of the supporting reasons for claiming that material should be sorted early in the material flow, as opposed to in an MRF are listed as follows (Jahre 1995b):

- Obtaining high quality becomes harder if materials are separated further down the stream.
- Mixing materials which are separated later makes no sense, since it is not a value-adding activity.
- Considering hygienic matters, material for recycling should not be mixed.
- It contributes to cost reduction because more work is done by the consumer.
- Increased contamination in materials which are separated further down the stream may give higher residues and consequently lower quantities of recyclable materials.

[2] MRF is the abbreviation form of Material Recovery Facility which refers to the place where collected recyclables are delivered for processing before being sold (Jahre 1995b).

- The present separation technology is hard to get hold of and very expensive. On the other hand, the working environment for MRFs with manual sorting is relatively bad and poor.

It is noticed that the degree of separation at source will probably decrease when the number of material increases. Some of the reasons for this phenomenon are presented as follows (Jahre 1995b):

- If the number of materials increases while they are still separated by the consumer, the households require an increasing number of storage containers, meaning that this can be difficult to apply in densely populated areas with high rise housing.
- Separation can become more complicated and the feasibility of leaving separation to consumer decreases when the number of material increases.
- Time spent for collection increases which give rise to an increase in collection cost.
- Collection cost increases if the fractions are collected separately because of more transport work.
- Transport has a negative impact on the environment, meaning that by increasing transport work, the negative environmental consequences increases.
- Development in the separation technology (MRF) give continuously better and more cost efficient separation which results in separation cost reduction. Hence, this can be considered less costly compared to the cost of collection.

One issue that can be addressed in this study is as follows:
"A*n increased number of materials, will reduce the degree of separation at source because of requirements for cost efficiency and high service"*(Jahre 1995b, p. 5)

2.4.4 Channels of reverse distribution

According to (Jahre 1995a) collection systems for household waste can be classified by different channels of distribution. However, there are some shortcomings in previous research performed for classifying it. It is important to explain that, the same participants may be involved in both forward and reverse distribution. Figure 13 indicates the major channels of distribution despite the fact that, there is usually a number of actors taking part in reverse channels which are not included in forward channels (Jahre 1995b).

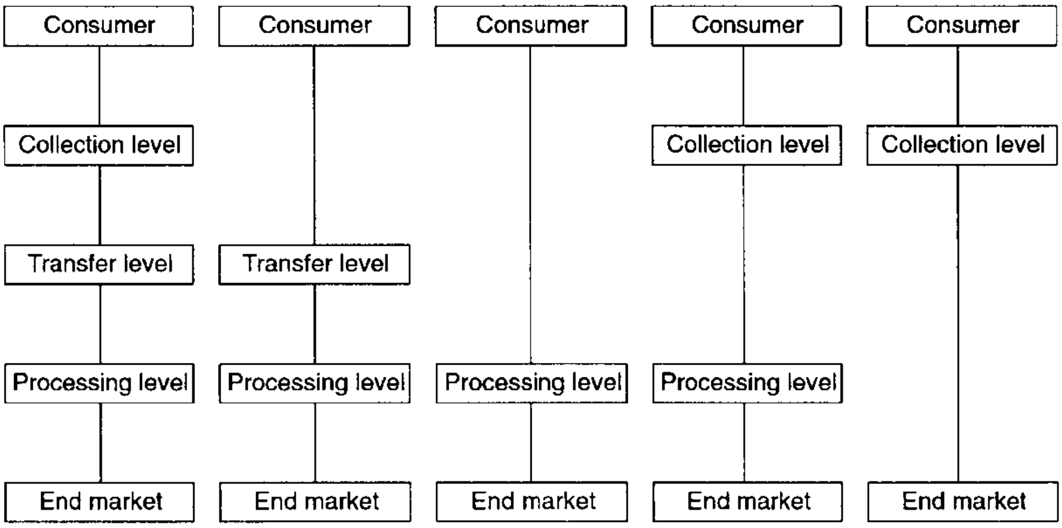

Figure 13: Alternative channels of reverse distribution (Jahre 1995a)

Consumption points and consumers refer to all household waste generated by private households. In collection systems for household waste, the starting point of the channel is the consumer. Collection level can be, for example, drop-off centers if materials are delivered by the consumer to a specific point or if materials are collected at the household, then the household would be defined as the collection level. Collection level in curbside system is the consumer. However, in bring system; there are a number of different collection levels such as drop-off centers, redemption and retailers centers (Jahre 1995b). In some systems for collecting waste from households a transfer level is included which is the next level in reverse channels of distribution. This level includes reloading and maybe some sorting in which collected material are brought for reloading into larger vehicles in order to gain economical transport quantities. These are often called transfer stations or depots. Although a little bit of sorting might take place in these stations, materials are usually taken to the next level which is the processing level for sorting. Processing is done at some sort of MRF which sorts, bales and otherwise prepares materials for reprocessing. In some cases, such sorting may also occur in end-market which can be defined as the recycler or the facility where recyclables substitute primary (Jahre 1995b).

Sorting vs. collection complexity

Sorting complexity is to a great extent determined by the total number of fractions separated at the collection level. Therefore, if recyclables are separated at the source, the collection system will have low sorting complexity. This is due to the fact that there would be less need for further sorting down the stream. On the other hand, collection complexity decreases by having fewer fractions, meaning that there is a negative relationship between complexity of sorting and collection. In other words, "*collection complexity is the number of fractions divided by the number of materials, while sorting complexity is 1 – (the number of fractions divided by the number of materials)*" (Jahre 1995b, p. 23). It is also important to explain that if a collection system includes fewer materials, the degree of complexity for both sorting and collection would be relatively lower than a collection system with a higher amount of materials (Jahre 1995b).

2.4.5 Segregation vs. co-collection

Recent recycling research has started to pay attention on the issue of co-collection. Co-collection refers to the collection systems in which all waste is collected in one vehicle (Brady-Roberts et al. 1996), while in segregated systems all fractions are collected in different vehicles (Platt and Zachary 1992). Collection complexity may be reduced by taking advantage of different methods for collection. The degree of co-collection depends on the number of vehicles used for collecting all waste from a household and the number of fractions separated at the collection level. In a quantitative manner, "*degree of co-collection is 1-(number of vehicles divided by number of fractions"* (Jahre 1995b, p. 25). Complete segregated collection occurs when the number of vehicles equals the number of fractions. For example, one vehicle for glass, one for paper and one for refuse (residual waste). However, complete co-collection takes place when one vehicle is used for collecting all fractions including residual waste. There are different methods for implementing co-collection systems, one would be bagging the different fractions and collecting them in single compartment vehicles and the other one would be using multi-compartment vehicles (Jahre 1995b).

One important factor in order to determine the degree of co-collection is the collection frequency (using alternating schedules) which can be considered the third possibility in addition to number of vehicles and number of fractions separated at source. To be more accurate, using alternating schedules can refer to a situation in which, for example, collecting glass and residual waste in one week and paper and residual waste in the next week, by the aim of reducing the number of vehicles which are used, the most common frequencies would be, weekly, biweekly, monthly and bimonthly. In fact, an effective co-collection system can be achieved by *"collecting more than one fraction at a time in addition to reducing the collection frequency for each fraction"* (Jahre 1995b, p. 26). The degree of co-collection has great implications for logistics. For instance, if the degree of co-collection decreases, the number of operators, vehicles and distribution channels usually increase and consequently give rise to a more complicated logistics model. Generally, a higher degree of co-collection leads to lower frequencies.
Indexes for degree of co-collection can be defined for different collection systems, in curbside collection, the degree of co-collection would be as follows:

"Degree of co-collection = 1 – (number of vehicles incl. refuse used for collection/ number of fractions incl. refuse separated at the collection level)" (Jahre 1995a, p. 97)

However, in bring collection systems; the degree of collection would be defined as follows:

"Degree of co-collection= 1 – (number of vehicles used for collection/ number of fractions separated at the collection level)" (Jahre 1995a, p. 97)

The degree of co-collection is low if the index shows a number close to zero, meaning that collection is performed segregated for the fraction and vice versa (Jahre 1995a).

2.5 Service towards end-markets and customers

In order to have a successful recycling system, the need to pay attention to the fact that the recycled materials should have the possibility to compete with primary materials both in terms of quality and price is of crucial importance. The quality of recycled materials can be affected to a large extent by the way collection activities such as sorting is performed. The price of the recycled materials can be estimated by the cost of collection services. Besides, the best possible recycling system should take the environmental effects as another influential prerequisite (Jahre 1995b).

Service towards end-markets

Service towards end-markets can be regarded as an important factor in terms of demand for secondary materials as compared to substitute inputs. According to (Cairncross 1992), demand will be different for each recycled material. A study in end-market requirements, i.e. specification of materials, indicates that this demand can vary significantly among different countries. It is notable to explain that, one of the main reasons for the shortage of demand for recycled materials and products is lack of information (Freeman 1992). The other reasons for this problem which make companies not purchase more products made from recycled materials are lack of availability of the products, performance (i.e. quality) concerns, and higher price compared to virgin materials. Demand for recycled materials not only depends on service of the collection and processing system, but also on the use of economic instruments in order to control material use and waste disposal. For instance, the price of primary materials may be lower than secondary due to the fact that the production of primary materials has traditionally been subsidized through low energy price. Koplow claims that federal energy subsidies to virgin materials such as primary aluminum slows the expansion of recycling markets, and subsidizing key inputs to the extraction or processing of a virgin material can be equally damaging (Koplow 1994). Another important aspect concerning environment of such policies can be noticed by comparing the pollution and depletion of resources (e.g. renewable vs. non-renewable energy) resulting from not collecting and recycling materials (Barton 1979).

Security can be considered another important service measure. This is determined by what is generated and what is collected. It is suggested by Innazzi and Strauss that in opposition to common belief, supply of recovered office paper will not balance the demand in a long term perspective (Innazzi and Strauss 1994). One convincing piece of evidence to prove this statement is that office paper is not separated from old newspaper in household waste, meaning that the higher grade of paper will not become available for recovery. Moreover, the most of office paper is generated in offices in which waste is often collected by commercial haulers over which the municipalities have little or no power. Furthermore, the end-user of office paper are much more diverse and numerous than the small group of publishers which control the newsprint usage.

There will be no demand if there is no supply, meaning that the importance of the balance between supply and demand should be taken into consideration. It is important to explain that in traditional business you “should” not have supply if there is no demand. This balance is difficult to reach in reverse logistics systems and there has to be an understanding that it might take some time. From a German experiment, it can be concluded that without market demand, investments in recycling technology are less attractive (Burt and Dillion 1994).

The most important dimensions in order to measure a MSW system for the provided service towards end-market are presented as follows (Jahre 1995a):

- Recyclability

  This refers to the way in which it is possible to recycle the sorted and the collected materials. Recyclability depends also on how well the materials are sorted and the products are designed.
- Quality

  Depends on the contamination by other materials of the materials which are to be recycled, e.g. paper packaging contaminated by food would not be regarded as high quality.
- Flexibility

  It refers to the degree to which processing and collection can make collected waste suitable to fit end-markets concerning the number of sorts and how materials are sorted. A very high flexibility towards end-markets would suggest customer order production as in traditional distribution.
- Price

  The price per ton processed materials. This dimension can be different from one area to another as well as over the years and even throughout a year.
- Stability of supply –short term

  Variations in quantities which are collected and processed per month or whenever the end-market wants it delivered.
- Stability of supply – long term

  The situation in which the end-market can be sure that processing and collection have the possibility to take place on long-term basis.

Service towards consumers

Braton claims that collected quantities can be different with respect to collection system service levels defined by *where*, i.e. collection points and *when*, i.e. collection frequencies, materials are collected (Barton 1979). Watson describe different collection systems and their convenience form consumers' point of view (Watson 1991). In the U.S. during the 1980's, three tiered containers were commonly used in which consumers would leave separated recyclables and take out to the curb at collection day. However, it was found expensive and inconvenient to store and cumbersome to transport to the curb by the consumers. Therefore, another system in which consumers commingle recyclables using the single bin and bag were developed. Although the commingle method is found convenient for consumers, it leads to contamination of materials which may significantly reduce the recyclables volume because sorting technology is not yet satisfactory (O'Brien 1991). Besides, it is also claimed that a commingle bag system has another contamination problem meaning that consumers frequently include materials which are not recyclables or marketable. To tackle the problem of contamination "separation at source" was introduced. This is due to the fact that materials which are held segregated during collection are less likely to become contaminated. However, there may be limits to how many materials can be included since consumers are not able or do not want to sort a large number of materials. Hence, there would be a limitation in the number of materials, and subsequently it can lead to some reductions in total quantities (Jahre 1995b).

Based on experience from a pilot bag project in Chicago it is revealed that, the bag was preferred by 90% of the respondents to a consumer survey. This is due to the fact that it was cleaner, requires no separate collection and had more capacity. It was also noticed that consumers like the convenience of a bag that could be hung or stored in the kitchen, using the same method for disposal. The image problem caused by recyclables which are placed in the same truck as refuse did not exist – acceptance by the public was very good and gave the same pressure effect as the blue bin. Therefore, collected quantities were not lower than for a segregated bin system (Robinson, Eubanks, and Treager 1992)
The service level can be determined when the total packet of service is included, meaning that in order to find the service level we need to consider the mix of the amount of work which have to be carried out by consumers, the price of the container, convenience and the collection frequency altogether. If there are many different systems, i.e. curbside collection of refuse one day and of recyclables another, bring system for glass, all the systems should be included to determine the service level, this may reduce the service as perceived by the consumers. In the following, important dimensions for measuring the service towards consumers are provided (Jahre 1995b):

- Collection point density

  The number of households which share one collection point. In curbside collection system this number will be high (one point per household), and in bring system this number is lower, meaning that customers need to transport their materials by foot or car.
- Number of sorts and other work

  This dimension includes the number of sorts which a consumer has to do. It can be discussed what is the most work: sorting out recyclables from other refuse and commingling them into one box (number of sort is one) or sorting three different colors of glass (number of sorts is three). Accordingly, the types of materials to be sorted also matters as do other operations which have to be performed by the consumers such as flattening and cleaning containers or bagging, bundling other materials.
- Cost

  Cost of the services which should be paid by consumers. This can also include the cost of transport and the time spent for sorting and so forth.
- Collection frequencies

  This dimension pertains to the frequency by which recyclable and residual wastes are collected. In a bring system frequency of collection is not important for the consumer, as long as containers are not full when consumers come to deliver. However, in a curbside system this has a direct impact on service.
- The amount of waste management services

  This dimension depends on whether the program is integrated which means recyclable and residual waste are collected in the same system, or collection of recyclables take place on the same day as residual waste. This also depends on the number of materials which are collected for recycling. A large number of different systems (e.g. glass igloos, paper containers curbside collection of other recyclable and other system for residual waste collection) may be confusing for the consumers.

2.6 Cost analysis

Costs include all the logistical activities such as storage, transport, separation, cleaning, handling and administration (Katan 1987, Cairncross 1992, Pohlen and Farris 1992). Costs regarding investment and maintenance in collection and processing facilities should also be included. Moreover, if recycling performance is measured, it would be important to include manufacturing cost in addition to collection costs (Reeves 1993, Smith and Baetz 1991) and finally costs concerning monitoring and promotion would have to be added (Smith and Baetz 1991, Katan 1987).

There are many different approaches towards calculating costs of recycling and collection programs – operating expense, full cost and true cost. Most communities calculate operating expense at present (Crampton 1993). However, a number of communities have not been required to calculate waste disposal costs isolated from other types of public service (Jahre 1995b). Most of the time, the mentioned accounting is limited to direct costs including collection and transport equipment, wages, and landfill fees. However, full cost accounting (FCA) includes all corresponding services which are performed by the local governmental unit and true-cost accounting (TCA) covers even more elements by including socio-economic and environmental impact of alternative.

It is claimed by Crampton that despite the fact that the objective of true cost accounting is worthy, few towns and cities are capable of calculating it at present (Crampton 1993). It is also claimed by Burt and Dillion that internalizing external effects (such as pollution and depletion of resources) of traditional disposal methods into the cost of traditional refuse disposal is the only way which would make a system appear cost effective (Burt and Dillion 1994). Such avoided costs are often used to defend the cost of collection for recycling and there are many misunderstandings with respect to what these costs include (Gershman 1992).

An analysis is conducted by Siegler about the cost effectiveness of adding plastics to recycling programs shows that by collecting solid waste which contribute to remove a high-volume material, we can reduce the costs associated with keeping them in landfills. It would be important to take into consideration that material such as plastics takes up a lot of space in a landfill (Siegler 1994). Another study conducted by Stevens shows that calculation based on either cost per household or cost per ton can result in large differences concerning which systems are more cost efficient (Stevens 1994).
Other important aspects of the cost of collection and processing are scale and scope economies (Economies of scale are factors that cause the average cost of producing something to fall as the volume of its output increases. Economies of scope are factors that make it cheaper to produce a range of products together than to produce each one of them on its own (Tim 2008)). Economies of scale are mostly discussed in production literature. Less literature focuses on this aspect in distribution or transport, i.e. collection in reverse channels. However, There are some exceptions (Porter 1980, Bruning and Olson 1982, Daller, Chicoine, and Walzer 1988). Most of this literature is related to the size of the carrier and they do not consider the size of the trucks which is more important in this study.

An extensive cost measurement methodology for monitoring full cost has been developed by the European Recovery and Recycling Association (ERRA) which includes cost of collection, processing and transfer. In this study economic costs are distinguished from environmental consequences. Some important measures in collection systems for economic cost are provided as follows (Jahre 1995b):

- Collection cost
  This dimension includes staff in collection and administration, vehicles, containers and other equipment.
- Processing cost
  This dimension includes buildings, equipment, staff in processing, administration and disposal cost of residue.
- Total cost
  This cost can be calculated by summing the two aforementioned costs and the cost of operating a transfer station and the transport cost for taking materials from station to MRF or another reprocesser or recycler.
- Collection cost per collected ton
  It can be used for comparison with refuse collection and with other programs.
- Total cost per recovered ton
  All costs per ton processed, which can be used for comparison with refuse collection and disposal and with other programs.
- The consumer total cost per household
  This type of cost can be used for estimating fees which consumers have to pay.
- Total cost per inhabitant
  This type of cost can be used for estimating fees which consumers have to pay.
- Total cost per recovered ton per diversion rate
  This measurement is defined to show the cost of taking away a specific number of tons from refuse. (Diversion rate is tons recovered divided by tons generated)

2.7 Potential environmental impacts from solid waste management activities

Collection of materials for recycling is considered one of the positive environmental consequences through less depletion of resources and less pollution. One of the important aspects of this study is to evaluate different collection system in order to identify their corresponding environmental consequences. It is notable to explain that, some environmental effects such as deprivation of recreational facilities, dissipation of energy, and depletion of recourses in addition to pollution are extremely difficult to measure and include (Barton 1979, Sushil 1990). However, in the following some measurements for environmental consequences are presented (Jahre 1995b):

- Pollution from collection activities
  This dimension refers to the transport distance in collection allocated to on-route (while collecting) and off-route (driving between route and MRF, transfer station or yard plus driving between transfer station and MRF).
- Pollution from processing
  This pollution is caused by processing facilities and equipment (incl. vehicles) for processing.
- Use of resources for collection activities

This dimension depends on the transport distances in collection allocated to on-route (while collecting) and off-route (driving between route and MRF, transfer station or yard plus driving between transfer station and MRF).

- Use of resources for processing activities

  This dimension depends on use of fuel in processing facilities and use of other equipment. For example, bags for transport of aluminum material.

- Use of landfill space and pollution from landfills

  This usage depends on the quantities of materials recycled which are then diverted from landfills.

2.8 Program ratios

Program ratios can be measured by different methods such as recycling rate, return rate, collection rate and so forth. Having a general understanding about program ratios can be of crucial importance in order to evaluate the performance and compare different recycling programs.

One of the performance measures for evaluating recycling program is recycling rate which is defined as the quantities recycled in relation to quantities consumed or generated (Habersatter and Widmer 1991). Recycling rate can be also defined as the relationship between the amount of specific material recycled from generators served and the total amount of the specific material available in the waste stream of the generators served. If the end-market is defined as the recycler, then recycling rate is measured after the end-market. If the end-market is defined as the raw materials user, then recycling rates are measured before sale to the end market. Recycling rates concern recycling performance and not the collection system performance (Jahre 1995b).

Return rates can be considered one of the relatively important elements in order to evaluate studies on existing systems. It can be defined as *"returned units (or number of tons) in relation to the potential, expressed as the number of units or quantity consumed or generated"*(Jahre 1995b, p. 39). It is not clear whether the amount of material returned is measured before or after the materials are taken to the MRF. Therefore, it is also important to differentiate between two return rates; recovery rates and collection recovery rates. The first one is measured at the end of the final process prior to sale to the end-market; they are defined as the amount of specific material recovered from the generators served in relation to the total amount of the specific material available in the waste stream of the generator served. In other words, it refers to the total quantity in each container compared to the potential which could be in the container if everything was sorted correctly, including targeted and non- targeted materials as well as targeted material put in the wrong bin. Collection recovery rates can be defined as the quantity of specific material collected from generators served in relation to the total quantity of the specific material available in the waste stream of the generator served. It is important to explain that, collection recovery rates are measured after collection but before the materials which go to the MRF. To be more accurate, this rate refers to the sorting efficiency of the consumer or the collection crew (Jahre 1995b).

Residue ratios can be defined as the amount of materials sent to final disposal from the MRF in relation to the amount of material received at MRF. They are measured at end of the final process prior to sale to the end-market. This is a specification of the quantity which cannot be recovered from that which was collected; either because of bad sorting earlier in the channel or due to lack of efficiency in the MRF, e.g. absence of the equipment to sort all usable materials in the MRF. In systems where there are no residue, recovery rates and collection recovery rates are the same (Jahre 1995b).

Participation rate can be defined as the relationship between the number of generators which are participating at least once in a four week period and the total number of generators served by the program in the same period. To simplify, this rate refers to the number of households participating in relation to the number covered by the program. Set-out rate refers to the number of households setting out on collection day in relation to the number covered by the program (not the number participating). It is important to explain that both set-out rate and participation rate have impacts on other performance measures, e.g. collection cost and collection recovery rates (Jahre 1995b).

There is another common measure which is called diversion rate. This rate is often used to measure the total performance of all recycling activities in an area. This is the amount of material which is recovered from generators served in relation to the quantity of available waste from generator served. It would be important to explain that, the more materials being collected and recovered, the higher would be the diversion rate. Finally, the last measuring program ratios would be effectiveness which can be defined as actual diversion on potential diversion. For example, the total recovery rate for all targeted materials (Jahre 1995b).

2.9 Previous research about collection of MSW

2.9.1 Comparison of different collection systems for sorted household waste in Sweden

An analysis has been conducted in six municipalities in southern Sweden with similar socio-economic conditions but with different collection systems, concerning composition and quantity per person of municipal solid waste. During 26 analyses that took place from 1998–2004, samples of residual waste have been sorted, classified and weighed in 21 categories. The overall objective is to contribute to decision support in planning and development of MSW source sorting systems (Dahlén et al. 2007).
The term *source sorting* refers to when the householders handle and dispose of different waste materials separately. *Residual household waste* is used to describe bagged, mixed waste in the ordinary waste bin, for example, the waste left when the householders have handled any source-sorted materials separately. *Dry recyclables* refer to newsprint and packaging materials included in the ordinance on producer responsibility in Sweden and with established collection and recycling systems. This study is designed to answer the following questions (Dahlén et al. 2007).

- What are the effects of a weight-based billing system?
- What are the effects of curbside collection of recyclables compared to drop-off systems?
- How can different MSW collection systems be compared?

2.9.1.1 The six municipalities and their waste collection systems

The six municipalities are denoted A (Bjuv), B (Åstorp), C (Helsingborg), D (Höganäs), E (Ängelholm) and F (Båstad). Due to some differences in the household waste collection, the mentioned municipalities can be divided into three main groups which are as follows (Dahlén et al. 2007):

- The first group consists of municipalities A and B, with extended curbside collection of sorted recyclables including biodegradables.
- The second group is only municipality C, with curbside collection of dry recyclables.
- Group three is comprised of municipalities D, E and F, with mainly drop-off (bring) systems for sorted recyclables.

Municipality	Newsprint	Packaging materials					Biowaste	Residual waste
		Glass	Paper	Metal	Plastic film	Plastic hard		
A	*	*	*	*	*	*	*	*
B	*	*	*	*	*	*	*	*
C	*	*	*	*	□	*		*
D	*	*	□	□	□	□		*
E	*	□	□	□	□	□		*
F	□	□	□	□	□	□		*

Figure 14: * marks curbside collection, in addition to drop-off points, □ marks collection at drop-off points (bring system) only, and empty space in the table means no separate collection (Dahlén et al. 2007)

Considering the fact that this study was done in the period between 1996 until 2004, there has been some changes which are important to explain (Dahlén et al. 2007):

- Extended curbside collection was introduced in 1996 in municipality C and gradually during 1999 and 2000 in municipalities A and B.
- Drop-off points for dry recyclables were present the entire period in all six municipalities.
- With no curbside collection there was approximately one drop-off point per 400–1000 households. However, with curbside collection there was one drop-off point per 2000–2500 households in municipalities A and C, with the exception of municipality of B which kept the system with about one drop-off point per 400 households, in parallel with curbside collection.
- Municipality A was the only municipality in the study with weight-based billing (In the year 2000, the weight-based billing was introduced with a low fixed fee of 50 euros/year and the weight-based fee of 0.4 euros/kg residual waste, plus 0.1 euro/kg sorted biodegradable waste. There was no weight-based fee for dry recyclables. Two years later in 2002, the billing system was revised to a higher fixed fee (130 euros/year) and a lower weight-based fee for residual waste, now 0.25 euros/kg, while the cost of leaving biodegradable waste was unchanged)
- In the other five municipalities, which did not have weight-based billing, there was some variation in the refuse collection charges, though a usual fee for a family in a residential home was on the order of 170 euros/year in 2003.

2.9.1.2 The impact of weight-based billing in municipality A

As it is explained above, municipality A is in the first group and it is the only municipality in the study which uses weight-based billing. In the following, the different aspects of this municipality are presented (Dahlén et al. 2007):

- Delivered amounts of source-sorted materials such as biowaste and metal, paper and plastic packaging per person appeared to be more in municipality A. However, the amount of source-sorted glass and newsprint per person were 50% and 30% respectively less than the average of the other five municipalities. It is also notable to explain that, in the residual waste from municipality A, there were also smaller amount of glass and newsprint found, compared to the other municipalities.
- When all dry recyclables were added up, fewer kg dry recyclables/person had been delivered by the households in municipality A, compared to the other five municipalities. However, it is important to refer that the highest sorting ratio belongs to municipality A.

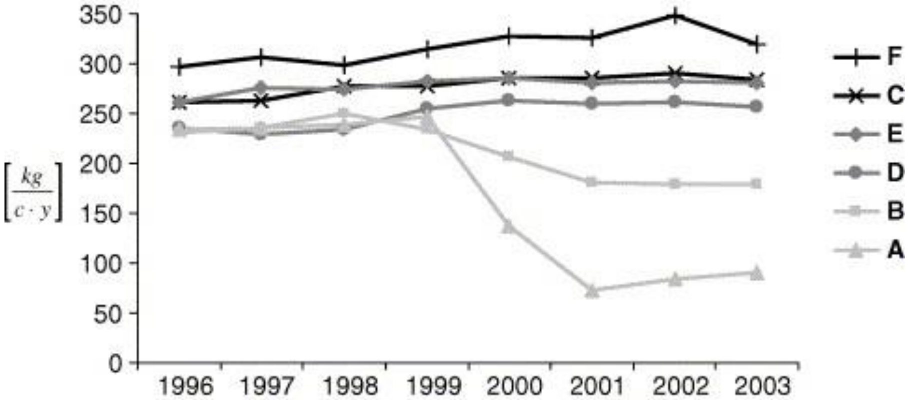

Figure 15: The amount of residual household waste in the municipalities A–F 1996–2003, based on waste amounts collected and delivered to treatment facilities each year (kg/capita year). Extended curbside collection was introduced in municipalities A and B in the years 1999-2000 (Dahlén et al. 20)

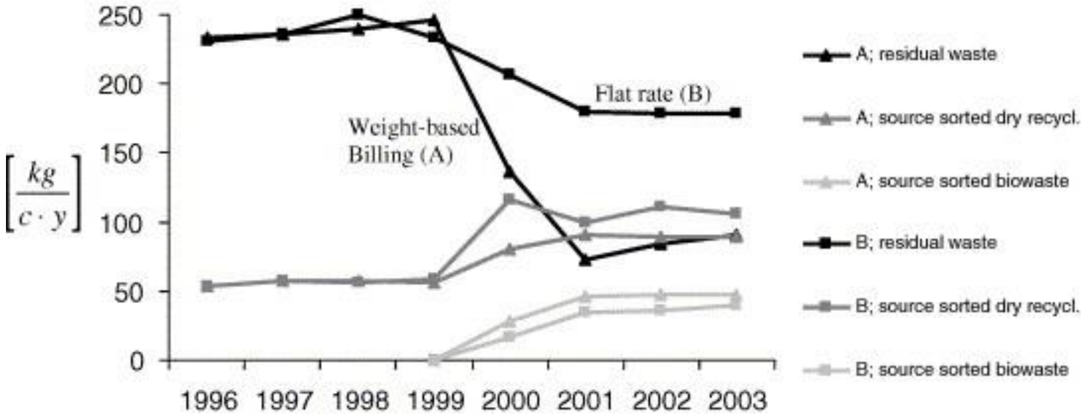

Figure 16: Household waste materials in municipalities A and B (kg/capita year) based on amounts collected and delivered to treatment facilities each year. Extended curbside collection was introduced in both municipalities in the years 1999–2000 (Dahlén et al. 20)

Figure 15 indicates that only half as much residual waste (90 kg/capita year) was collected in municipality A, compared to municipality B (180 kg/capita year) during the year 2003, while in Figure 16, it is shown that the amounts of delivered source-sorted materials were about the same. It can be possibly concluded that the weight-based billing can be used as a powerful instrument in order to promote both reducing the total waste generation and further engagement in sorting out recyclables. It is also important to explain that, the weight-based billing might tempt some people to burn waste in fireplace or to dump them illegally (Dahlén et al. 2007).

It is pointed out by a sociological research review that the economic incentives can be regarded as an important factor which affects waste sorting behavior (Dahlén et al. 2007).Based on a questionnaire which is conducted by Sterner and Bartelings in a residential area, it is shown that seventy percent of the households are in the opinion that the design of the refuse collection charge can affect sorting behavior directly and households seem to be even more motivated and interested in waste sorting than can be explained only by savings on the waste management bill (Bartelings and Sterner 1999). To sum up, *"weight-based billing showed clear effects with up to 50% reduction of delivered residual waste/capita, but it is unknown to what extent improper material paths had developed"*(Dahlén et al. 2007, p. 1305).

2.9.1.3 The effect of curbside collection of recyclables in municipalities A, B and C, compared to drop-off systems in municipalities D, E and F

As it is shown in Figure 17, the amount of dry recyclables left in the residual waste for municipalities with curbside collection (A, B and C) had been less than the municipalities with mainly drop-off systems (D, E and F).

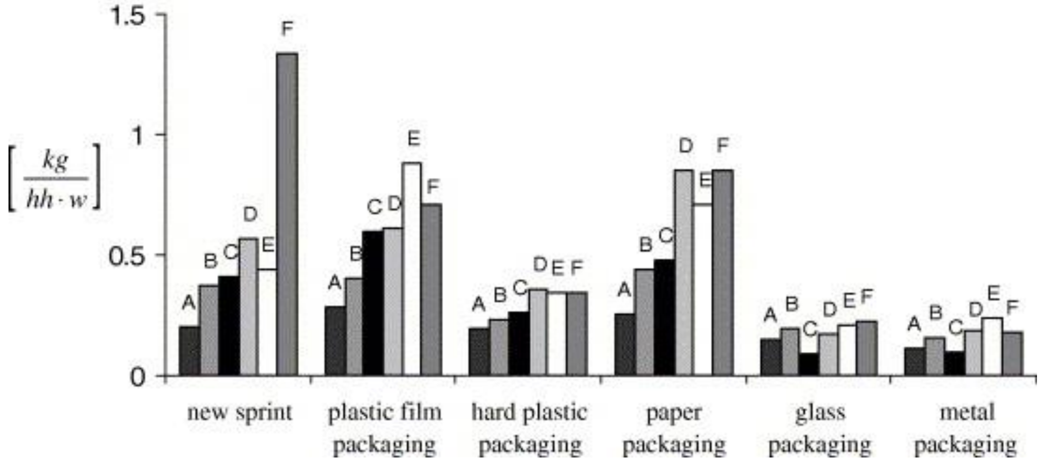

Figure 17: The amounts of six categories of dry recyclables left in the residual waste. Municipalities A, B and C had complete curbside collection of recyclables; D, E and F had mainly drop-off systems, with the exception of curbside collection of newsprint (D, E) and glass (D). Results are averages from single-family houses 2002-2004 (kg/households week) (Dahlén et al. 2007)

Figure 18 indicates that households with complete curbside collection of dry recyclables (A, B, and C) sorted out approximately twice the amount per person of plastic, metal and paper packaging materials (average 28 kg/capita year), compared to municipalities D, E, and F with drop-off systems (average 14 kg/capita year). In other words, with curbside collection more metal, plastic and paper packaging were separated and left for recycling.

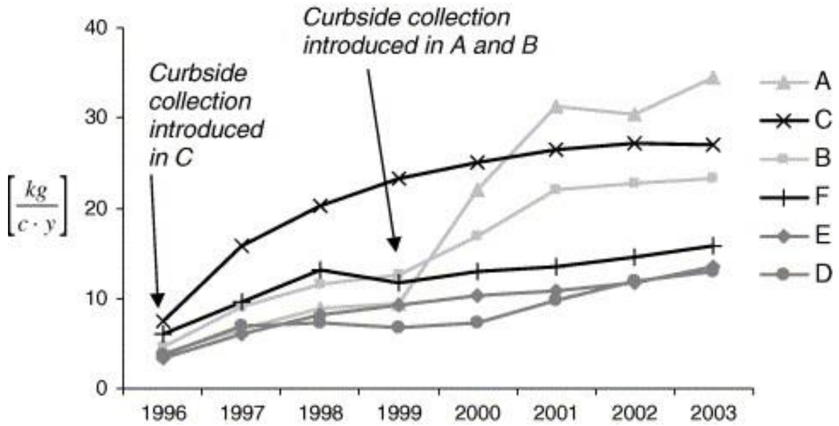

Figure 18: The combined amounts of source-sorted plastic, metal and paper packaging materials from the households in the six municipalities from 1996–2003 (kg/capita year), based on amounts collected and delivered to treatment facilities each year (Dahlén et al. 2007)

The highest overall source sorting ratio was in municipalities A and B, with extended curbside collection. Whereas, the lowest source sorting ratio was in municipality F, with no curbside collection of recyclable. Considering the fact that the biodegradable fraction represents a high proportion of weight, it was expected to find the source sorting ratio higher in the municipalities with separate collection of biodegradables. However, the dry source sorting ratio (biodegradables excluded) was also higher in these municipalities. Figure 19 shows that there were not only less biodegradables in the analyzed residual waste, but also less dry recyclables when separate collection of biodegradables was available. A possible explanation, apart from the convenience of curbside collection, could be that handling biodegradables separately facilitates the sorting of dry recyclables.

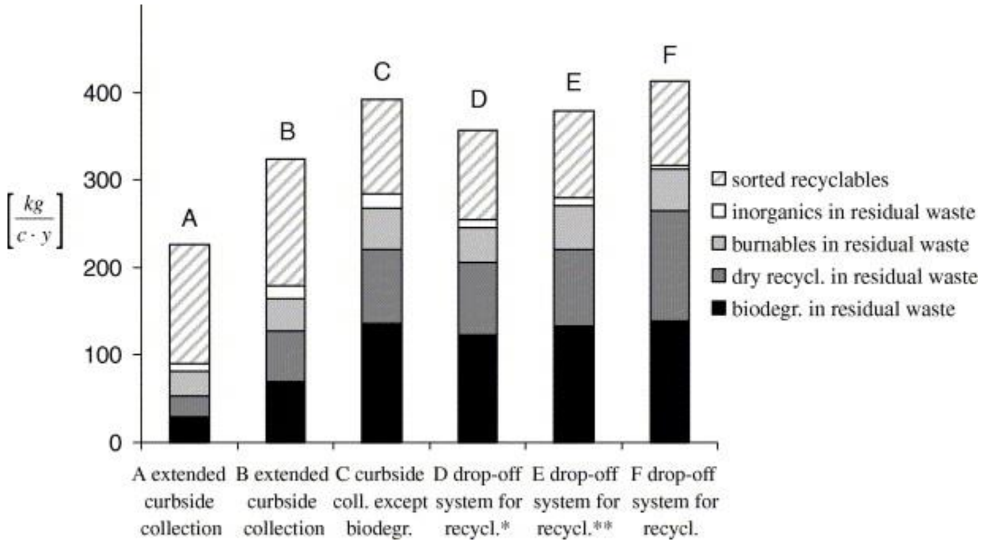

Figure 19: The total waste flow from the households in municipalities A–F (kg/capita year), based on quantities collected and delivered to treatment facilities 2003, and the composition of the residual waste based on the weighted average of analyzed samples 1998– 2004. Only municipality A had weight-based billing. * D had curbside collection of glass and newsprint. ** E had curbside collection of newsprint (Dahlén et al. 2007)

It is pointed out by a sociological research review of waste sorting that the most influential factor for sorting behavior is accessibility (nearness) and it can be possibly concluded that if the goal is to stimulate as much sorting of waste materials as possible, curbside collection seems to be the best choice (Dahlén et al. 2007).

Chapter 3: Collecting data and introducing new municipal solid waste collection systems for RIR

This study is intended to introduce new MSW collection systems and find the consequences of applying different MSW collection system for a local cleansing department (RIR). Therefore, this section is designed to first introduce the best possible systems and then discussing their outcomes concerning different aspects by taking advantage of existing literature and interview.

3.1 Introducing new collection systems

There are many different collection systems used all over the world but considering the fact that Norway is a leading country in terms of waste disposal systems, most of the systems which will be discussed in the following are not very different from the current system. However, in the context of less developed countries this issue can be very different and subsequently introduced systems may not be similar to the existing systems.

3.1.1 Using existing system but applying different pattern (first collection system)

The first system is using the current system but applying different pattern. Basically, the current system is a combination of two systems; bring system (drop-off centers) for glass/metal packaging, clothes/textiles and curbside collection system for residual, paper, plastic packaging, biowaste. The new pattern will add glass/metal packaging fraction to curbside collection. Hence, each household needs to have four suitable containers for biowaste, paper, glass/metal packaging and residual waste and one sack for plastic packaging which must be kept in their property. Table 5 shows the current pattern of collecting MSW from households.

Containers	Collection frequency
80 l rolling bin for biowaste	Weekly
140 l rolling bin for paper	Monthly
140 l rolling bin for residual waste	Biweekly
140 l sack for plastic packaging	Monthly

Table 5: Current pattern of collecting MSW from households by the company RIR

In order to introduce the new pattern, some basic information is needed such as fill rate. This rate represents the percentage of used volume in collection trucks. Table 6 indicates this rate for different fractions. Trucks which are used to collect MSW have two compartments, the smaller one is only for biowaste and the other one is used for the other types of waste. Figure 20 shows a typical truck in RIR.

Type of waste	Fill rate
Paper	95%
Residual waste	85%
Biowaste	60%
Plastic packaging	40%

Table 6: Fill rate of different waste collected by RIR

As can be seen in Table 6, the only fraction which can be modified in the given collection frequency is plastic packaging (40%). Furthermore, paper and residual waste can be regarded as the bottlenecks with 95% and 85% respectively. Therefore, changing their pattern can cause serious problems. For example, collection trucks become full before collecting all the assigned rolling bins from households and need to come back to empty collected waste and return to collect the rest of MSW again which is very costly. Fill rate for biowaste is around 60%, meaning that there is some space for modifying and changing the collection frequency but it is found out by the interview (RIR company) that biowaste can create bad smell which may annoy residents. Therefore, it must be collected every week irrespective of other factors.

Figure 20: A typical two-compartment truck that collects household waste in RIR (Langmyren 2011)

There can be many different patterns which may fit this system. One possible pattern would be as follows:

Containers	Collection frequency
80 l rolling bin for biowaste	Weekly
140 l rolling bin for paper	Monthly
140 l rolling bin for residual waste	Biweekly
140 l sack for plastic packaging	Bimonthly
140 l rolling bin for glass/metal packaging	Bimonthly

Table 7: Introduced pattern of MSW collection

Adding this new fraction does not mean omitting drop-off centers. Therefore, residents who have produced more waste before collection time, he/she can throw the extra glass/metal packaging in the drop-off centers. Moreover, Table 6 indicates that fill rate for collected plastic packaging is less than half, meaning that this type of waste can be collected in a longer period. By applying the suggested pattern, the operating cost for collection of MSW would be the same as before, since plastic packaging can be collected in one month and glass/metal packaging in the other month.

Generally, the new system can almost be considered curbside collection; since almost all the fractions are collected by curbside system and one (clothes and textile) by bring system, meaning that it is an individual collection system which is one of the most convenient MSW collection systems in consumers' point of view. However, consumers are responsible for placing containers at the proper collection point in front of their houses so that collection crew can collect them as easy and fast as possible. The degree of co-

collection is not very high since MSW are collected by two-compartment trucks, meaning that only two fractions are assigned to be collected at the collection level (channels of reverse distribution). However, this system tries to get the most out of collection frequency to reduce the number of trucks assigned to collect the MSW from household. It is explained in Section 2 that by collecting more than one fraction at a time as well as reducing the collection frequency for each fraction, an effective co-collection system can be reached.

One of the best characteristics of this MSW collection system is that sorting complexity is low which results in cost reduction both in terms of investment and resource usage in MRFs. This is due to the fact that almost all the recyclables and biological materials are separated at source. This MSW collection system can also have a great impact on service towards end-markets since the quality of collected household waste is quite high compared to other types of MSW collection systems in which MSW are not separated at source. Moreover, the price of collected materials is rather low because of the fact that most of the separation work is done by households. It was explained earlier that this MSW collection system is relatively more convenient than other systems such as bring system (drop-off centers), this means that the service which is provided for households are quite high in terms of collection point density (one point for each household). However, the number of sorts which are done by each household is high, since they are required to sort their waste into six fractions (glass/metal packaging, residual waste, paper, plastic packaging, biowaste and clothes/textiles) (clothes/textiles is not considered in this study) and each household needs to store four rolling bins and one sack in their properties, this may cause some space problem.

In terms of collection and processing costs, it is important to explain that in this MSW collection system collection cost is relatively high compared to bring system. This is because of the fact that collecting MSW from the door of each household requires more vehicles, containers and other equipment in addition to staff assigned to collect MSW. However, processing costs in this MSW collection system is relatively low compared to other MSW collection systems in which most of the sorting job performed in MRFs. Besides, one basic cost which the company RIR would consider is the number and distribution of rolling bins which will be added to the existing fractions collected form households.

The most important operating factors in measuring environmental consequences of an MSW collection system are pollution and resource usage which are caused by collection and processing activities. However, there can be many other factors which are important to consider. For example, lack of an efficient MSW collection system can lead to collecting less recyclables which can affect the environment in the long run; in Section 2 some of the supporting reasons for this issue were provided. Although the suggested MSW collection system produces relatively much pollution in terms of collection activities (collecting MSW from each households), the amount of pollution caused by processing activities in MRFs is low. This is because of the fact that separation is mostly done by households which leads to less processing activities in MRFs.

3.1.2 Applying pay-as-you-throw system (second collection system)

This type of MSW collection system is mostly designed to improve the sorting efficiency applied by consumers. Moreover, it can lead to an increase in the rate of waste prevention and reuse. However, some illegal dumping may occur. The collection system would be the same as the first one, except for one difference which is weighing each fraction at the households. In other words, each fraction would have different price with the aim of reducing waste and increasing the rate of sorting and recycling.

To implement weight-based billing system, some major cost would occur, since some special equipment is needed and it is necessary to have more staff to handle the more complex billing system. Startup costs include truck-mounted scales for weighing waste and some type of system such as bar-coding on waste cans in order to entering required information into a computer for accurate billing. Furthermore, some of the equipment used to record the data, weigh the waste, and bill the customer is still experimental (Canterbury 1996). However, operating cost in terms of collection density will be the same as the existing system.

People who participate might have different perspective toward introduced systems. For instance, it is claimed by one of the managers in NIR[3] that systems such as PAYT may look less appealing to consumers.

3.1.3 Using different color bags (third collection system)

Collecting MSW can be done by different methods; RIR uses rolling bins for three fractions and a sack for one fraction. Using one container with waste which is separated by different color bags is an alternative to the existing system. According to one of the managers in NIR, some fractions cannot be collected together due to service towards end-market problems. For example, glass should not be compressed when they are collected or collecting biowaste along with other fractions can cause some contamination if some of the bags are torn. However, from logistics perspective, increasing the degree of co-collection can reduce the transportation costs to some extent and increase efficiency of the system.

According to the problems concerning service towards end-market, there is one possibility which is collecting residual waste and plastic packaging together and by considering the fill rate which is shown in Table 6, they can be collected biweekly with a filling rate of 95% since the filling rates for residual waste and plastic packaging biweekly is around 85% and 10%, respectively. This means these two fractions are merged together. Fill rate for paper is 95% which is quite high; therefore, using bags with different color in order to co-collect paper with other fractions is not possible. Finally, the pattern of collecting the rest of MSW would be the same as System 1.

Despite of the fact that this system can reduce the MSW collection costs, it increases the costs regarding sorting of MSW in MRFs. For example, some equipment is required to sort the waste in MRFs such as an optical sorting machine. Which one is less costly? Merging two fractions and sorting them in MRFs or collecting them separately as before?

[3] NIR (Nordmøre interkommunale renovasjonsselskap) is an intermunicipal waste management company which manage MSW in 9 municipalities; Aure, Averøy, Halsa, Kristiansund, Oppdal, Rauma, Smøla, Sunndal, and Tingvoll (NIR 2012).

Generally, there is almost always a balance between investment and operating costs (Jahre 1995a). This system leads to higher investment but less operating costs. Environmentally, this system causes less pollution in terms of collection activities. However, it increases the pollution caused by processing MSW in MRFs.

The collection equipment of households will be the same as the current system, meaning that they use one sack for plastic packaging and one rolling bin for residual waste. However, this system requires that consumers use two different color bags. For example, black bags for residual waste and white bags for plastic packaging.

3.1.4 Applying two different MSW collection systems simultaneously (fourth collection system)

Consumers may have very different opinions about how to sort their waste. For example, some consumers prefer to use bring system for glass/metal packaging and some prefer to use curbside collection system. Bring system is less costly for RIR to run; therefore, consumers who feel convenient with the current system, in particular, consumers who live close to drop-off centers or those who have difficulty to store an extra rolling bin for glass/metal packaging can have this option and pay less fee for the collection activities. A system can be designed in which consumers have two different alternatives, some would use drop-off system for glass/metal packaging and pay relatively less money and some would use rolling bins. This can increase the complexity of the system in terms of administration. However, this provides consumer with higher level of service. These types of systems can increase the participation rate and efficiency of sorting which is done by consumers.

3.2 Cost analysis of introduced MSW collection systems

Finding and classifying consequences of the systems which are introduced can be considered the main purpose of this study. In the following, some of the important costs will be estimated and discussed.

3.2.1 Cost analysis of System 1

The first system is basically similar to the existing system except for the fact that the pattern of collecting plastic packaging is changed from monthly to bimonthly and a new rolling bin is added to the current system for collecting glass/metal packaging which will also be collected bimonthly. This means, the main operating costs for the System 1 are transportation and reloading which is occurred in RIR plant (Årødalen), and collecting MSW from households and drop-off centers. In addition, investment or startup cost should be taken into consideration. There are only two main startup costs which are purchasing and distributing new rolling bins among households. This is important to explain that, one major cost which cannot be neglected is the costs associated with residual waste disposal. This is due to the fact that in NIR, this cost is estimated around 290,000 NOK which is more than the sum of the costs for collecting MSW from drop-off centers (97,000 NOK) and reloading and transportation (Syklus) (124,000 NOK) in NIR. Therefore, one of the most important reasons for adding this fraction (glass/metal packaging) to the existing system is not only to get the advantage of collecting more and subsequently having better income of selling them but also to reduce the amount of non-recyclable waste. So far, costs associated with MSW collection system have mostly been discussed. In this study, the main objective is to estimate operating costs and investment costs which are as follows:

Operating Cost						
Collecting MSW from households		Number of bins/sacks	Frequency	Price per collection	Numbers of collections per year	Annual Cost
	80L Biowaste	17 000	Weekly	20	52	17 680 000
	140L paper	17 000	Monthly	22	12	4 488 000
	140L residual waste	17 000	Biweekly	22	24	8 976 000
	140L glass/metal	17 000	Bimonthly	22	6	2 244 000
	240L plastics	17 000	Bimonthly	8	6	816 000
	Total					**34 204 000**
Collecting MSW from drop-off centers						
	Glass/metal					**50 000**
Transportation and reloading (Årødalen)						
	Reloading in Årødalen					Annual cost
				FTE (Full Time Employee)	Annual cost per employee	
				4	600 000	2 400 000
				Wheel Loader	Annual cost per unit	
				3	300 000	900 000
				Total		**3 300 000**
	Transportation from Årødalen					
		Biowaste	Linköping, Sweden			3 100 000
		Paper	Heimdal, Norway			900 000
		Residual Waste	Norrköping, Sweden			4 400 000
		Glass/metal	Onsøy, Norway			N/A
		Plastics	Germany			N/A
		Total				**N/A**

Table 8: Operating costs for System 1, wheel loader costs include depreciation, fuel, and maintenance. N/A is the abbreviation form of "not available"

As can be seen in Table 8, almost all the costs can be estimated except for the two transportation costs which are transporting glass/metal packaging and plastic packaging from Årødalen to Onsøy and Germany respectively. All the figures are estimated by RIR while transportation is authorized by another company which means estimations for transportation costs are quite imprecise.

Investment (startup costs)				
Distributing new rolling bins/plastic sacks		Number of rolling bins/sacks		Total Cost
	Rolling bins	17 000		566 666
	Plastic sack			300 000
	Total			**866 666**
Purchasing new rolling bins/ plastic sacks		Number of households	Price per unit	Total investment
	140L glass/metal	17 000	600	10 200 000
	140L plastic sack	17 000	1.5*6	-153 000
	240L plastic sack	17 000	2.5*6	255 000
	Total			**10 302 000**

Table 9: Estimated startup costs for System 1

Table 9 indicates estimated costs for both purchasing and distributing of new plastic sacks and rolling bins. It is discussed that plastic packaging collection frequency can be changed from monthly to bimonthly (6 times in a year). This requires changing the size of plastic sacks from 140 liter to 240 liter so that households could store twice as much as they store monthly.

Annual costs

- Operating costs
  - Collecting MSW from households 34 204 000 NOK
  - Collecting MSW from drop-off centers 50 000 NOK
  - Transportation and reloading (Årødalen) N/A
- Investment (startup costs)
  - Distributing new rolling bins/ plastic sacks 866 666 NOK
  - Purchasing new rolling bins/ plastic sacks 10 302 000 NOK

3.2.2 Cost analysis of System 2

PAYT system can be implemented by two major methods which are weight-based billing and volume-based billing. The advantages and disadvantages of these two methods are discussed in Section 2 and it was concluded that weight-based billing is more effective in terms of reducing non-recyclable waste. The collection system would be the same as the first one, except for one difference which is weighing each fraction at the households. This means, operating costs associated with this system are quite similar to the System 1, which are transportation and reloading in RIR plant (Årødalen), and collecting MSW from households and drop-off centers. However, in this system the time spent for collecting MSW from households may increase. This is due to the fact that a new task is added which is weighing rolling bins at households. The major investment which should be taken into consideration is equipping collection trucks with scales for weighing and some type of bar-coding system for rolling bins for entering required information into a computer for accurate billing (bar-coding system is currently used by RIR). This is also important to explain that this system increase the administration costs because more staff is needed to handle the more complex billing system.

Operating Cost						
Collecting MSW from households		Number of bins/sacks	Frequency	Price per collection	Numbers of collections per year	Annual Cost
	80L biowaste	17 000	weekly	20,5	52	18 122 000
	140L paper	17 000	monthly	22,5	12	4 590 000
	140L residual waste	17 000	biweekly	22,5	24	9 180 000
	140L glass/metal	17 000	bimonthly	22,5	6	2 295 000
	240L plastics	17 000	bimonthly	8,5	6	867 000
						35 054 000
Collecting MSW from drop-off centers						
	Glass/metal					**51 250**

Table 10: Estimated figures showing operating costs in System 2

As it is shown in Table 10, weighing each fraction at households increase the time assigned to collect MSW by approximately 5 seconds. Therefore, the price per collection is increased by 0.5 NOK. It is also estimated that the price of collecting MSW from drop-off centers will increase by 2.5%. This is due to the fact that consumers may use drop-off centers more often in order to reduce the weight of waste they produce.

Investment (startup costs)				
Distributing new rolling bins/plastic sacks		Number of rolling bins/sacks		Total Cost
	Rolling bins	17 000		566 666
	Plastic sack			300 000
	Total			**866 666**
Purchasing new rolling bins/ plastic sacks		Number of households	Price per unit	Total investment
	140L glass/metal	17 000	600	10 200 000
	140L plastic sack	17 000	1.5*6	-153 000
	240L plastic sack	17 000	2.5*6	255 000
	Total			**10 302 000**
Adding scale to collection trucks		Cost per truck	Number of trucks	Total cost
		300 000	8	**2 400 000**
Adding bar-coding system for rolling bins(registration system)		Number of bins	Cost per bin	Total cost
		68 000	15	**1 020 000**
				Total costs
Additional annual administration costs	Billing		20% FTE	120 000
	Maintenance per truck		20 h per year	16 000
		Total		**136 000**

Table 11: Startup costs associated with System 2

System 2 includes not only the costs which are explained in System 1, but also includes costs concerning registration system (around 1 020 000 NOK), adding scales to the collection trucks (estimated cost is not available) and additional administration costs (136 000 NOK).

Annual costs

- Operating costs
  - Collecting MSW from households 35 054 000 NOK
  - Collecting MSW from drop-off centers 51 250 NOK
  - Transportation and reloading (Årødalen) N/A
- Investment (startup costs)
  - Distributing new rolling bins/ plastic sacks 866 666 NOK
  - Purchasing new rolling bins/ plastic sacks 10 302 000 NOK
  - Adding bar-coding system for rolling bins 1 020 000 NOK
  - Adding scale to collection trucks 2 400 000 NOK
  - Administration costs 136 000 NOK

3.2.3 Cost analysis of System 3

Using bags with different colors for sorting MSW can be considered one of the most effective methods in collection systems since it contributes to a great extent to reduce the frequency of collecting MSW and increasing the degree of co-collection. However, due to some problems associated with contamination and lowering the service towards end-markets. This system cannot be applied for all fractions. In this study, it is offered to use this system only for collecting residual and plastic packaging together. For instance, consumers may use blue bags for residual and black bags for plastic packaging and finally put them in sacks and rolling bins they already have. However, at collection time, these two fractions will be collected together. Operating costs associated with this system is quite similar to the existing system while one fraction is omitted at the collection level. This means, the costs associated with the collection of plastic packaging is omitted since it is co-collected with residuals. However, a new task will be added in MRFs which is sorting residual waste and plastic packaging bags according to their colors. This requires either machinery such as an optical sorting machine or some manual job which can be done by some workers. In addition, distributing bags with different colors should be considered which can be done either by collection crew or grocery stores in which people can buy them themselves.

Annual costs

- Operating costs
  - Collecting MSW from households N/A
  - Collecting MSW from drop-off centers N/A
  - Transportation and reloading (Årødalen) N/A
  - Distributing bags with different colors N/A
  - Sorting residual waste and plastic packaging bags N/A
- Investment (startup costs)
  - Distributing new rolling bins 866 666 NOK

– Purchasing new rolling bins/ plastic sacks 10 302 000 NOK
– Purchasing optical sorting machine N/A

“Applying this system cannot be justified economically “claimed by RIR. Estimating costs associated with System 3 can be considered illogical. This is due to the fact that the number of households which are served by RIR is relatively low and required investment for this system is quite high. Such systems can be economically accepted and applied in MSW collection companies which have higher number of consumers. For instance, in Oslo this system is used.

3.2.4 Cost analysis of System 4

Applying two different MSW collection systems at the same time basically refers to taking advantage of using the existing system and System 1. This is due to the fact that, some consumers would prefer to sort their glass/metal packaging using the current system. Therefore, this possibility should be provided for them. It also results in more efficient collection system by reducing the number of collection spots which should be served. Operating costs will decrease to some extent because less number of households will be served for collecting glass/metal packaging. However, it can increase the administration costs in RIR to manage both systems simultaneously.

Operating Cost						
Collecting MSW from households		Number of bins/sacks	Frequency	Price per collection	Numbers of collections per year	Annual Cost
	80L biowaste	17 000	weekly	20	52	17 680 000
	140L paper	17 000	monthly	22	12	4 488 000
	140L residual waste	17 000	biweekly	22	24	8 976 000
	140L glass/metal	3 400	bimonthly	22	6	448 800
	240L plastic	17 000	bimonthly	8	6	816 000
	Total					**32 408 800**
Collecting MSW from drop-off centers						
	Glass/metal					**800 000**

Table 12: Operating costs associated with applying two different systems for collecting MSW from households

Investment (startup costs)				
Distributing new rolling bins		Number of rolling bins		Total Cost
	Rolling bins	3 400		113 333
	Plastic sack			300 000
	Total			**413 000**
Purchasing new rolling bins		Number of households	price per unit	Total investment
	140L glass/metal	3 400	600	2 040 000
	140L plastic sacks	17 000	1.5*6	-153 000
	240L plastic sacks	17 000	2.5*6	255 000
	Total			**2 142 000**
Additional administration costs				
			5 % FTE	**30 000**

Table 13: Startup costs for MSW collection System 4

Annual costs

- Operating costs
    - Collecting MSW from households 32 408 000 NOK
    - Collecting MSW from drop-off centers 800 000 NOK
    - Transportation and reloading (Årødalen) N/A
- Investment (startup costs)
    - Distributing new rolling bins 342 500 NOK
    - Purchasing new rolling bins/ plastic sacks 2 142 000 NOK
    - Additional administration costs 30 000 NOK

In this study, it is assumed that 20 percent of consumers would choose to have their own rolling bins for glass/metal packaging (3 400 out of 17 000 consumers) and the rest of consumers would prefer to use the existing system.

Chapter 4: Discussion and conclusion

In this chapter, the results from the previous sections will be interpreted and discussed. It was explained in Section 3 that there can be many different methods for collecting MSW from households. However, in this study, some of them are only discussed. Each of the introduced systems can be interpreted in many different ways. For instance, costs, environmental impacts, social participation, service towards end-markets, service towards consumers and so forth. However, in this study, it is intended to consider only three main factors.

The most important aspect which should be discussed is the corresponding costs. Table 14 shows the associated costs for each MSW collection systems:

	System 1	System 2	System 3	System 4
Collection costs	34 254 000	35 105 250	N/A	33 208 000
Investments	11 168 666	14 724 666	N/A	2 514 500

Table 14: Summarized costs of introduced systems

As can be seen in Table 14, the highest collection cost belongs to System 2, and the lowest is for System 4. This means that the fourth system can be considered economically the best method for collecting waste among the introduced systems since it provides the company with the lowest operating costs in collection of MSW from households. Moreover, required investment for System 4 is far less than other systems. This can easily concluded that System 4 economically is the most efficient one.

Pollution and use of resources associated with collection activities in System 4 and System 3 are less than other systems. This is due to the fact that, the rate of using drop-off centers is relatively high in System 4 which result in less collection activity, and by taking advantage of different color bags in System 3, two fractions can be collected at the same time. However, pollution from processing activities for System 3 can to a great extent affect the environment. Moreover, by considering the fact that, System 3 is by no means justifiable economically. Therefore, this can be concluded that environmentally, the forth system can be regarded as the best possible option for RIR.

Rate of social participation cannot be estimated precisely for each MSW collection systems. However, it can be roughly discussed that, System 2 would increase the participation rate in which the households reduce the amount of waste they produce. According to (Dahlén et al. 2007, p. 1305) *“weight-based billing showed clear effects with up to 50% reduction of delivered residual waste/capita, but it is unknown to what extent improper material paths had developed”*. The first introduced system might have the highest participation rate after the second system, since almost all the households get a new rolling for glass/packaging. According to NIR’s experience, by implementing this system the volume of collected glass/metal packaging increased by 42% (from 214 metric tons to 304 metric tons) which means the participation rate for sorting glass/metal packaging has considerably increased.

So far, the main questions of this study have been answered and from the author’s point of view, it can be concluded that the fourth system would be the most efficient system with regard to the corresponding consequences. This is due to the fact that, this system has the lowest corresponding costs both in terms of operating and investment. Moreover, environmentally, this system contributes to serve fewer households for collecting glass/metal packaging. However, it would be difficult to estimate by how much this system can increase the social participation.

4.1 Limitation and further research

The main limitation of this research can be considered time. It was intended to conduct a survey to gain the data for the estimation of participation rate for each introduced systems. However, executing a survey by using regular mail would be both slow and costly. Therefore, this part of the study can be regarded as further research for those who are interested in this topic. In addition, by the evolution of this project, it was noticed that one of the main goal of sorting MSW is reducing residual waste. Hence, the next step might be analyzing the content of this type of waste produced by households in order to find some space for improvement. For example, there might be some stuff in this fraction which potentially could be sorted in other fractions. Finally, from author's point of view, more research for finding efficient methods to collect MSW should be conducted by the aim of increasing co-collection degree and reducing frequency of collection. This is due to the fact that, in many cases, huge investment cannot be economically justified for MSW collection companies. Therefore, an interesting area for the further research would be changing the pattern and in some cases increasing co-collection degree to achieve better result.

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