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INNOVATIVE WASTE MANAGEMENT FOR A CIRCULAR ECONOMY IN THE NETHERLANDS

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Assessing the potential of a multi-stream waste collection system for the city of Amsterdam

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List of Abbreviations

AEB	Afvalenergiebedrijf Amsterdam, Exploitatie B.V.
BMU	Bundesministerium für Umwelt, Naturschutz, Bau und Reaktorsicherheit
CBS	Nederlandse Centraal Bureau voor de Statistiek
CE	Circular Economy
CWM	Circular Waste Management
DKR	Deutsche Gesellschaft für Kreislaufwirtschaft und Rohstoffe mbH
EEA	European Environment Agency
EC	European Commission
EPR	Extended Producer Responsibility
IWM	Integrated Waste Management
KrWG	Kreislaufwirtschaftsgesetz (Closed Substance Cycle)
MCA	Multi-Criteria-Analysis
MIE	Nederlandse Ministerie van Infrastructuur en Milieu
MSW	Municipal Solid Waste
NVRD	Koninklijke Vereniging voor Afval- en Reinigingsmanagement
PAYT	Pay-as-you-throw tariff
PPW	Plastic Packaging Waste
RFID	Radio Frequency Identification
RVO	Rijksdienst voor Ondernemend
SCM	Supply Chain Management
UBA	Umweltbundesamt
VA	Vereniging Afvalbedrijven
VANG	Nederland Van Afval Naar Grondstof, also called Nedvang
WEEE	Waste Electrical and Electronic Equipment
WRAP	Waste & Resources Action Programme in the United Kingdom
WtE	Waste-to-energy, also called energy-from-waste (EfW)

Abstract

Waste legislation and policy on the EU and national level demand high waste separation rates and the promotion of recycling. However, today's recycling statistics can only partly reflect these ambitions. In the Netherlands, the decision is up to the municipality if waste from households is collected commingled and sorted centrally or if the private consumer has to pre-sort the material. The capital Amsterdam is seeking a new waste collection strategy that leads "Towards a Circular Economy".

The present paper reviews scientific literature delineating the advantages of source separation. In combination with post-separation, the scrutinised Optibag source separation method bears the potential to profoundly increase the separation and recycling yields in Amsterdam, while entailing marginal extra costs. The analysis of practical implementation suggests that the Optibag system fulfils the most important criteria in order to realise innovative waste treatment in a Circular Economy: high quality waste materials and a high educational effect among citizens. Its implementation still requires optimisation in many aspects, e.g. the characteristics of plastic waste bags and the necessary attention to socio-behavioural factors in high-rise building areas. But providing a high level of flexibility, the Optibag system is capable of adapting to changes in waste composition and advancements in research and technology, posing a long-term solution for circular waste management in Amsterdam.

1 Introduction

"Anyone who believes exponential growth can go on forever in a finite world is either a madman or an economist."

- Kenneth E. Boulding, 1973

Today's world economy is unsustainable. If economic growth remains linked to resource consumption the way it was the last 200 years, humanity will need three earths by 2050 to supply the demand of fossil/natural resources. We can either continue this business and hope for the discovery of an alternative planet before it is too late or we can change the functioning of our economic system. In fact, the natural ecosystem has always been sustainable within itself. The business concept of a Circular Economy (CE) that will be introduced in this work is based on a simple idea: learn from natural processes and "get back" to a circular use of resources, inspired by the way it was naturally designed.

In this regard, waste management plays a striking role, determining whether materials are deprived in definite disposal or recovered and reintegrated into the economic cycle. The Waste-to-Energy (WtE) company AEB Amsterdam (hereafter called AEB) is investigating projects and technologies that promote the reuse of waste material. Purposeful use starts with the right collection of consumer waste and, considering this, there is profound room for improvement in Amsterdam.

This scientific research paper shall contribute to the promotion of sustainable technologies and at the same time bring the relevance of household waste separation and recycling for the whole economy closer to public officials and private consumers.

First, the idea that stands behind the term "Circular Economy" is illustrated, so that the following content can be regarded from this very perspective. Then, a short overview of the principles of waste management is followed by the comparison, how distant today's actual recycling rates are from CE ambitions communicated in the political rhetoric and how current recycling practices differ from possible treatment technologies.

The subsequent in-depth analysis concentrates on the topic of source separation as a means to obtain valuable waste materials from private households. The practice of a source separation with "Optibags" in three Scandinavian cities is scrutinised according to its value-adding potential for a CE. Subsequently, the results are combined with the analysis of a pilot in Amsterdam in order to assess whether Optibag is a suitable solution for the uniquely structured city of Amsterdam.

2 Circular Economy and Principles of Waste Management

2.1 CE – implications for supply chain management and urban planning

The term Circular Economy (CE) is a comparably new concept within the sphere of sustainability. The United Nation's Brundtland Commission already demanded a sustainable development of the world's economy in 1987. The UN's definition[1] suggests that present resource consumption and industrial activity shall bear in mind future generations and shall not pose limitations to their own development by excessive exploitation and pollution (UN, 1987). Introduced as the triple bottom line by Elkington, many scholars refer to this idea by asking a wider perspective from companies. They should not only concentrate on their economic interests, but also assume responsibility towards environmental and social concerns, on which they inevitably have an effect.

As broad as the field of sustainable thinking has developed, as divergent are the propositions about how companies can actually realise sustainable business.[2] The CE concept is a vision for the whole economy and at the same time a strategy model for companies how to embed sustainability (Murray et al., 2015).

Circular Economy concept – From the whole economy perspective, the ciruclar economy stands as an antonym to a linear economy that dominates the earth since the Industrial Revolution. In the linear economy as we know it, fossil resources are extracted, used to fuel processes and generate products and afterwards disposed of in a short period of time. Economic development and wealth are reflected in a rise of consumption and waste generation (ibid.). The resource demand is constantly increasing as a consequence of growth in population and wealth. At the same time, the quality and accessibility of these natural resources is rapidly declining due to depletion and pollution. CE advocats see this contradiction as evidence that the linear system is unsustainable in the long run (Andrews, 2015). With the idea of a CE, they suggest a contrasting economic order, which is based on reduced consumption, zero waste, resource efficiency and renewable energy, facilitated by a circular use of resources.

Figure 1: Resource use in a Linear Economy, own illustration based on Murray et al., 2015.

[1] „Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own need." Report of the World Commission on Environment and Development: Our Common Future, 1987, UN Doc A/42/427, New York.

[2] To name a few: Elkington, J. (1999) *Cannibals with Forks: Triple Bottom Line of 21st Century Business*, New York: John Wiley and & Sons; Horrigan, B. (2010) *Corporate social responsibility in the 21st century, Northampton: Edward Elgar;* Lazlo/Zhexembayeva (2011) *Embedded Sustainability*, Sheffield: Greenleaf.

Two scholars who have received large attention in this regard are Braungart/McDonough with the Cradle to Cradle principle and publications by the Ellen Macarthur Foundation. They both remind on the fact that the natural ecosystem itself is a perfectly working cycle. Waste does not exist, minerals flow, since rotten vegetables and animal dung function as fertiliser for the soil they fall onto, mammals and plants exchange CO_2 and H_2O. Only with the onset of industrial production, this equilibrium and the natural metabolism of nutrients were severly disturbed by human activity (Braungart/ McDonough, 2009). The authors further elucidate that all industrial products are a combination of technical/inorganic materials and biological/biodegradable materials. If products remain in this hybrid form at their end of life, they are deemed to end up as waste in the “grave” (ibid., p. 27). Whereas if products are disassembled and materials separated again, technical components can be reused and biological components returned into the biospheres’ metabolism. (Ellen Macarthur 2014, p.15; see *Appendix A).* This shows, while waste prevention and options for reuse are often only ascribed to the disposal stage, that system changes are required throughout the whole life cycle of products.

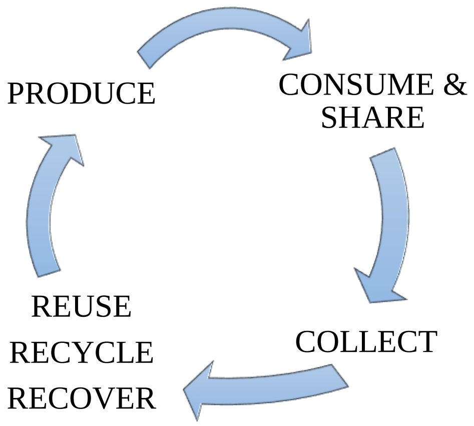

Figure 2: Resource use in a Circular Economy, own illustration based on Murray et al., 2015.

Implications for supply chain management – From a company’s perspective, the CE implications for supply chain management (SCM) and product design are that the value chain also ceases to be linear. The disposal stage is replaced by closed loops where materials from end-of-life products are brought back to the design stage. If the design provides for reuse, materials can be recovered and reintroduced in the next generation of products at the primary production stage (ibid., p. 38f). Hence, the most striking preconditions for remanufacturing are determined at the design stage. The less toxic substances implemented and the more components installed to be replaceable, the more value can be regained at a product’s end of life.[3]

What makes the CE concept attractive for corporations is that organising the supply chain circularly bears profound economic benefits. According to the Ellen Macarthur Foundation (2014), companies can best counter increasing supply risks and rising prices for resources by reusing own outputs and reducing the implementation of virgin materials. This can be

[3] This approach of taking into account which impact the product design has on the life cycle of the product and the environment is called Eco-design or Design for Environment. Cf. Bevilacqua et al. (2012) ‘Integration of Design for Environmental Concepts’ In: Bevilacqua, M., Ciarapica, F. and Giacchetta, G. (eds.) Design for Environment as a Tool for the Development of a Sustainable Supply Chain, London: Springer, pp. 11-32.

achieved by adopting the concept of reverse logistics. By planning the repatriation of their own products from consumption to the production stage in a closed loop supply chain, companies maintain product control beyond distribution. Certainly, the inconsistency in terms of timing and quality of core returns requires diligent planning, but once the logistic chain is synchronised, savings in production expenses have a balancing effect in the long run (Scott et al., 2011).

It is further assumed that if innovation is used to make processes smarter, a circular approach results in higher efficiency, more procurement independence and clear cost reduction for corporations (ibid.). The growing recycling and remanufacturing industry that is settling next to existing manufacturing hubs builds a new labour market and provides employment for people distant from the labour market (WRAP, 2015). Accordingly, the rationale is that a CE not only minimises the negative impact of human activities on the planet, but also holds advantages for all stakeholders. Customers for their part reduce costs by "sharing and consuming" when necessary in the role of a user, instead of owning for the sake of it (Ellen Macarthur 2014, p. 31). The recent rise of concepts like *blablacar.com* car-sharing and *airbnb.com* flat-sharing proof that consumers are willing to forego ownership if they see a financial or social advantage. It is increasingly acknowledged that the value lies within the service and performance of a product not in its production and physical existence.

Implications for urban planning – As much as the CE mandates process innovation in the private economy, it suggests a change in the handling of resource flows within cities. The major flows that have to be considered in the urban metabolism are transports, the inflow of electricity, heat and freshwater required from households and buildings, and the outflow they produce in form of waste and wastewater. Unnecessary imports and exports should be kept to a minimum, substances should be used as efficiently as possible (Geller et al., 2014). The image of closed loops is translated into the urban context, meaning the resources needed in a city should be circulating within its boundaries. Since the primary principle that stands before efficient use is reduced consumption, the built environment and infrastructure should have minimal impact on life and nature. Passive houses are a proven concept by now, but in the vision of a circular city houses become producers instead of consumers (Ellen Macarthur 2015, p. 85). Buildings produce electricity with solar panels, capture heat and gardening on rooftops yields vegetables.

The levers to reach lower consumption are connectivity and the harmonisation of all processes via smart grids (Metabolic 2015a, p. 17). In a smart grid, commonly referred to as the Internet of Things, all buildings, residents and service providers are connected in digital networks. The intelligent IT-system facilitates the exchange of information to coordinate and control consumption. Excess energy from one building can be sent to another where it is needed immediately, air conditioning and lighting are controlled by sensors, residents can share appliances according to use (Ellen Macarthur 2015, p.58).

Likewise, waste prevention is supported by extended communication in a circular city, as building materials can be reused locally if it is shared on a central platform where they are needed. Consumer waste materials are retained from disposal if they are checked for direct reuse or remanufacturing at local waste points. Therefore, another crucial factor for more efficient consumption is increased flexibility.

If the urban metabolism is regarded holistically, synergies can be found between the different flows. The aim is to reprocess outputs locally to serve as new inputs. Organic waste and wastewater treated together can yield energy and nutrients for the urban gardening, captured rainwater can be used in toilets and industry processes, saving freshwater. In contrast, the conventional central discharge of sewage and disposal of waste are linear solutions, because the value that lies in the waste resources is transported away. However, the challenge is to distinguish in which case economies of scale of a central handling would be more efficient than setting up a local cycle (cf. Metabolic 2015a, p. 24).

The concepts and technology to reduce resource and energy consumption are known and proven. The CE crux is that the transition from linear to circular processes requires changes in the whole economic system and, above all, in the systems thinking from all actors in society.[4]

2.2 Waste definition and categorisation

Few things occur so consistently in all areas of private, business and public life and receive comparably little attention at the same time. Waste is such one, as most people only pay attention to it as soon as it begins to entail adverse effects like odour or costs.

Waste is a by-product of civilisation and human activities. A classic definition for waste is the description as objects that are useless and do not have value anymore (McDougall et al., 2001). This definition implies that the object has no value in general, although most of the time it still contains the same materials as originally produced. It is rather that the object does not fulfil its purpose for the holder anymore, but that does not say anything about the performance or value of the item itself. In the course of this paper, many different ways of exploiting the value of materials that are considered as waste will be presented. It is also for

[4] An extensive survey investigating barriers to the implementation of a CE in China recognised the lack of public awareness and lack of legislation as primary concerns and only thereafter the lack of financial support and technology. Cf. Xue, B. et al. (2010) ‘Survey of officials’ awareness on circular economy development in China: Based on municipal and county level’, *Resources, Conservation and Recycling (54),* 1296–1302.

this reason that the European Union (EU) depicts waste as “any substance or object which the holder discards or intends or is required to discard” (Art. 3 (1), 2008/98/EC). This formulation also covers all those substances that have to be officially treated as waste due to legal obligation and therefore have to be disposed of in a regulated way (Bilitewski/Härdtle 2013, p. 47).

Waste is categorised in different ways, depending on the purpose of data collection. Most common categorisations are origin, original use, material composition and physical condition (McDougall et al. 2001, p. 2). Looking into statistical data and reports, waste is mostly distinguished after its origin:

Construction and demolition waste – With 42%, the highest amount of waste generated in the Netherlands stems from the private and public building sector (VA, 2015). Construction and Demolition Waste is debris from infrastructure maintenance work and building renovation. The main waste components are therefore building materials like concrete, brick, wood, metals, insulating and roofing but also soil and granular materials from excavation works. Construction waste is well suitable for recycling as it mostly contains clean wood and drywall, whereas the recycling of mixed concrete demolition debris is more complex (Pichtel 2014, p. 577).

Industrial waste – Industrial waste accounts for about 24% of waste generated (VA, 2015) and can be subsumed as all excess materials that arise from industrial production processes. Next to the same materials that occur in MSW, most industrial residue comes in form of coal ash from power plants, furnace slag from iron and steel industry, red mud and tailings, lime, fertilizer and gypsum (Pichtel 2014, p. 8). In contrast to MSW, industrial waste generally occurs in high quantities per material stream. The fact that these streams are consistent in their composition makes it easier to identify and separate them, which explains higher rates for reuse and recycling (VA, 2015). This is another argument for direct in-house waste treatment by companies. However, most industrial processes exemplarily show that not only the upfront solid waste is generated but that exhaust gases and liquid residues, predominantly contaminated cooling and rinse water, have to be considered under this definition, too.

Municipal solid waste – Under the umbrella of Municipal Solid Waste (MSW) falls residue from private households and gardens (14%), commercial waste from shops and restaurants and institutional waste from schools, prisons and public bodies (9% of total waste generation, ibid., 2015). As the name indicates, it is all solid waste that is collected by the municipality, therewith excluding wastewater and aero emissions. Although it only accounts for a small amount of the total waste generated, it gains comparably high

In this paper, with the term **BIOWASTE** *it is referred to biodegradable garden and park waste, food and kitchen waste from households, restaurants and retail.*

political attention, as its mixed composition requires extensive treatment efforts and poor waste management is directly reflected in citizen’s votes (McDougall et al. 2001, p. 2). In June 2015, protests and outrages in the city of Beirut, Lebanon, showed how far the absence of waste management services can lead (Hubbard, 2015). Due to many different consumer goods converging in this stream, the material composition of MSW is very complex. It mainly contains organic[5], meaning biodegradable fractions from food and yard waste, paper and cardboard from packaging and newspapers, plastic from packaging, bags, bottles or durable goods and fewer parts of glass, textiles, rubber and metal (Pichtel 2014, p. 68f). The following *Table 1* illustrates the prevailing categorisation and average composition of MSW in the Netherlands in 2012.

Waste component		**Composition %**	
Groente, Fruit, Tuin (GFT)	vegetable, fruit, garden = household biowaste	41	
Papier/karton	paper/cardboard	17	7.5
Kunststoffen	hard and soft plastic	13	
Kunststof Verpakking Afval	plastic packaging waste		8.3
Glas	mixed glass, all colours	5	4.7
Ferro & non-ferro metalen	ferrous & non-ferrous metals	4	3.5
Textiel	textile	4	
overig	other (wood/stone/WEEE/diapers)	16	
Verpakking Afval	**packaging waste**	100	**24**

Table 1: waste classification and composition in 2012 in the Netherlands, own illustration based on MIE 2013, p. 7.

Further waste categories of smaller amounts are waste from agricultural activities, medical waste from hospitals and laboratories and waste electrical and electronic equipment (WEEE) (Pichtel, 2014). Rapid technology innovation and planned obsolescence make WEEE to the fastest growing waste stream in the world, adding controversy to improper disposal in developing countries and emphasising the question of corporate responsibility, if companies deliberately incorporate limited life spans in the design of technical devices.[6] In case of ignitability, corrosivity, reactivity or toxicity, waste components of all these origins have to

[5] Biological waste is not defined uniformly and different definitions are used synonymously in literature. While the terms “organic waste” (all waste which originates from plant or animal sources) and “biodegradable waste” (all waste that is capable of undergoing anaerobic or aerobic digestion) include materials like paper, natural textiles and wood per definition; in this paper the term “biowaste” will be used with reference to the European Commission definition for biowaste (see box; IEA Bioenergy, p.50).

[6] A good introduction into the e-waste problem is provided by Widmer et al. (2005) ‘Global perspectives on e-waste’, *Env Imp Assess Rev 25*, 436–458 and Bin Lu, (2015) ‘The environmental impact of technology innovation on WEEE management by Multi-Life Cycle Assessment’, *J Clean Prod 89*, 148-158.

be designated as hazardous waste, requiring increased attention and strict isolation from other waste streams (Bilitewski/Härdtle 2013, p. 65).

The more data is obtainable about the composition and origin of waste, the better its management can be planned (ibid., p.53). At the same time, the fact that waste is categorised differently by different observers impairs the comparability of data sources.

This work is focussing on the category of MSW. Within this, the waste material fractions biowaste and plastic packaging waste (PPW) are of elevated interest as they constitute the highest amounts in the MSW composition and bear most potential for innovative treatment technologies.

2.3 Principles of Integrated Waste Management

While for the consumer, the end of life of a product normally arrives at the point of disposal, in fact, this is where the "waste life cycle" begins (McDougall et al., 2001). The waste life cycle can be described in four major stages: collection, sorting, treatment and final disposal. The alternatives for the handling of waste on each stage are numerous; the basics shall be introduced in short in the following.

Collection & sorting – The prevailing system for MSW collection in Europe is that private households pay an annual fee and can therefore rely on the municipality to organise a proper disposal. One can generally decide between kerbside collection, where the waste is collected directly from individual household containers, and drop-off collection, where residents have to bring their waste to central collection stations. The collection methods are manifold and not consistent within countries, often not even among neighbouring municipalities. While all sorts of materials in MSW are often still collected completely mixed, the direct separation into single streams (mono-streams) that are collected individually becomes more frequent (Bilitewski/Härdtle, 2013). As treatment possibilities for waste material emerge, the condition of waste input and therewith the form of collection become increasingly important.

Treatment – Until the 1980s, however, waste treatment in Central European countries primarily existed in the form of landfilling, dumping waste in the open field, and incineration, volume reduction via combustion, without considering the related toxic exhaust gases and leachate. Sheer elimination was the only concern (ibid., p. 4). With increasing waste quantities, more complex material composition of waste products and rising awareness for the environmental harmfulness of those treatment techniques, alternative processing arose. The focus changed from eliminating "useless" residues to making use of the containing materials again. This is conducted with either mechanical or thermal treatment. Mechanical treatment covers the mechanical sorting of waste to directly gain materials for reuse in their original form, then called secondary raw materials (SRM). This is commonly referred to as recycling. However, the EU definition for recycling is broader, acknowledging "any recovery operation by which waste materials are reprocessed into products, materials or substances" (Art. 3 (17), 2008/98/EC). Hence, the material conversion by shredding, melting and reprocessing waste material into differing outputs for other purposes applies just as well. Often, mechanical treatment is a pre-stage for biodegradable matter to be transformed into recoverable products, for instance fuel, via biological treatment like composting or digestion (cf. *4.2*), summarised as mechanical-biological treatment. With thermal treatment, the calorific value of waste is exploited by either using it as input in Waste-to-Energy (WtE) plants to directly recover energy and heat or by processing the waste into so-called refuse-derived fuel with high-energy value to be burned in Combined Heat and Power (CHP-) plants.

Disposal – The final disposal in form of landfilling also emerged from mere dumping to monitored sanitary landfilling that can capture leachate and landfill gas to reduce adverse environmental effects and use the captured gases for energy production (McDougall et al., 2001).

The increasing knowledge and complaints about harmful effects of improper treatment on the one hand and advancement in treatment methods on the other hand (ibid., p. 8) lead to rising awareness that waste cannot simply be disposed of, but has to be managed from generation to final disposal in a well-structured way. This holistic approach is called Integrated Waste Management (IWM). The four major stages just described should not be considered individually, but synchronised in order to enable effective waste treatment. The way the waste is collected has huge impact on the feasibility of different treatment activities. For instance in Japan, the collection is tailored to separate the waste into combustible and incombustible fractions to prepare it for the main treatment technology of incineration (Japanese Ministry, 2012). While this sounds logical in theory, it is more complicated in practice as a different actor conducts each stage. Often, the municipality responsible for collection contracts a private company for the execution, the local network provider conducts the energy recovery from waste and again other private companies are specialised on the recycling of different waste streams. For this reason, municipalities set up an IWM plan to coordinate the different actors along the waste life cycle (McDougall et al. 2001, p. 18). This shall not be limited to solid waste, but also take aqueous waste (wastewater) and atmospheric emissions into account, acknowledging "multi-media waste" as Seadon (2006, p. 5) puts it.

It is further argued that IWM must include the communication with residents to promote public participation and raise awareness that waste does not simply vanish with its collection (ibid.). Accordingly, IWM should be seen as material flow management that combines all actors and recognises all waste streams in an “environmentally effective, economically affordable and socially acceptable” way (McDougall et al. 2001, p. 16).

2.4 Literature review – comparing source and post separation

Regarding the waste collection, two basic alternatives stand in opposition: source separation and post separation. Source separation of MSW refers to the waste material being already sorted in the household. The different mono-streams are hauled individually and are optimally directly brought to the right processor. With post separation, the household waste material is subject to mixed collection and separated automatically after collection with a central technical sorting machine.

The decision between source and post separation of MSW is an important consideration for municipalities and actors in the waste management industry, as it determines costs and efforts. While in Germany, nearly all municipalities rely on a long established mono-stream source separation, the picture is less clear in the Netherlands (Bilitewski/Härdtle 2013, p. 146). Hasty conclusions are made about the economic, environmental and social superiority of the one or the other system. Generally, mixed collection and subsequent automated separation is associated with lower costs and simple practicability, whereas the quality standard of sorting output is doubted. Searching for scientific evidence, however, the conclusions are highly dispersed.

Material quality – Cimpan et al. (2015) aggregate the current state of research about central sorting of MSW waste. Their analysis of mass balance data from empirical studies in the UK and US indicates that post collection sorting facilities nowadays generally achieve very low residue rates, yielding around 95% recyclable material. However, the sorting accuracy is still highly dependent on the share of contamination in the input streams (Cimpan et al. 2015, p. 188). According to this, preliminary source separation would in any case have a positive impact on post separation results.

For the material classes textile, paper and cardboard the quality requirements for recycling clearly plead for a direct separation at the source. Paper should not get in contact with wet waste fractions. Miranda et al. (2013) investigated that 99% of separately collected paper is suitable for reuse, while commingled collection with other residual waste leads to significantly poorer quality and a total rejection rate of up to 20%.

Reversely, the waste class that is responsible for most of the wet waste content in MSW, the biowaste, should also be kept separate from other waste components in order to enable its reintroduction into a circular utilisation. If the treatment technologies developed in the biobased economy, which are currently conducted with highly homogenous first generation biomass, shall be commercialised with biomass from waste, it has to be obtained with a high degree of organic purity (cf. *5.2*; Wageningen UR, 2012).

Having said that, in the Netherlands, most controversy revolves around the necessity of separate collection for PPW. Regarding quality and usable output, a study by the Wageningen University Research Centre developed different scenarios based on empirical data. The scenarios show that the amount of produced milled goods and agglomerates can be raised to the same level with either increased post or source separation (Wageningen UR 2013, p. 92). In contrast, an investigation by the national Directorate for Sustainability in 2012 shows that the two Dutch post separation lines *Omrin* and *Attero* can process about the same quantity of PPW, but lead to 3kg less reusable material per household per year than source separation in the respective building class. The reported reasons for this are quality losses and complete non-usability of recycled foil from the post separation process (Directorate for Sustainability 2012, p. 13). Hence, the usable output from post separation is lower in the end, as a significant amount has to be sorted out to meet the minimum quality standards for plastic recyclate.

The Dutch studies confirm the findings of Luijsterberg/Goossens (2014), saying that the quality of plastic recycling outputs is above all depending on the technological advancement of the sorting line and reprocessing, rather than the collection method. The performance of the scrutinised Dutch separation lines shows that the technology cannot be constantly updated to adapt to changes in MSW composition and advanced research findings. In this regard, household separation turns out to be more flexible (Cimpan et al. 2015, p. 197).

Costs – In terms of costs, the scholar estimations are even more diverse, depending on which data and collection system is taken as a basis. Further investigation by the Wageningen UR research team concludes that source separation amounts to two times higher costs than post separation. This conclusion is reached because it is assumed that a pressed mixed waste hauler can transport four times more in volume than a separate single kerbside collection of lightweight plastic packaging (Groot et al., 2014).

A German study comes to the same results that a commingled collection of dry mixed waste yields substantial cost savings in logistics and treatment if considered in isolation. However, in their calculation also the costs for new construction of the sorting line are taken into account. As a result, the improved collection efficiencies cannot counterbalance those additional investment expenses (Janz et al., 2011). The latter argument is supported by a UK WRAP study. Within the British waste management sector, it is concluded that kerbside collection is more cost-efficient due to the post separation facilities’ high waste gate fees. In addition, the revenues from the plastic recyclate sales are included in this calculation, which has a positive effect on the source separation balance sheet (Cimpan et al. 2015, p. 194).

The lower collection efforts of commingled collection detected by Janz et al. (2011) are respectively also pointed out as the major advantage in terms of environmental costs if the CO_2 emissions per truck route are counted (Groot et al., 2014). A life cycle assessment of PPW recycling by CE Delft (2011) refutes this hypothesis, if the two collection systems are compared over the long term. The study, which is also based on operational data from the existing Dutch sorting lines, states that until a participation in source separation and a sorting percentage in post separation of 30%, the environmental benefit is the same for both methods. However, exceeding this threshold, the environmental benefit clearly grows faster with source separation. In the long run, the related fossil resource depletion and the harm on ecosystems and humans are estimated lower for source separation (CE Delft 2011, pp. 78, 90).

Summing up, a commingled collection and central sorting only comes into question for dry waste fractions. On a short-term basis, this can lead to a significant reduction of transport efforts and an increase in separated quantities. With the most up to date technology, also the quality of reusable outputs is comparable to source separated streams. Post separation does, however, not contribute to sustainable waste management for the long term. Regarding flexibility, which is indispensable to enable constant optimisation of circular resource reuse, central mechanical sorting is inferior to source separation. This holds even more true, if all costs and especially the environmental costs are taken into account.

Apart from that, each study's conclusion is alternating with the individual local conditions, like collection tariff agreements and geographical distances. Therefore, all the data does not only show that it is impossible to offer generic statements about the benefits of either of the two options. It also explains why decision makers in the private and public sector should be cautious with deriving conclusions for the own municipality by comparing it to other studies. This is even more the case as the citizens' perspective and socio-behavioural factors, which are distinct for each municipality, influence the collection results just as much. Hence, conducting an individual Multi-Criteria-Analysis (MCA) is the only reliable way for a municipality to detect the optimal waste management option for their jurisdiction.

3 Defining Circular Waste Management

Before the status of IWM in reality and the local conditions, which influence the right waste collection in Amsterdam, will be scrutinised, the author establishes criteria that defines Circular Waste Management (CWM). The benefits expected from a CE are translated into claims for the MSW management practice in a city. For IWM to become circular, the criteria that has to be met can be aggregated in the following pillars:

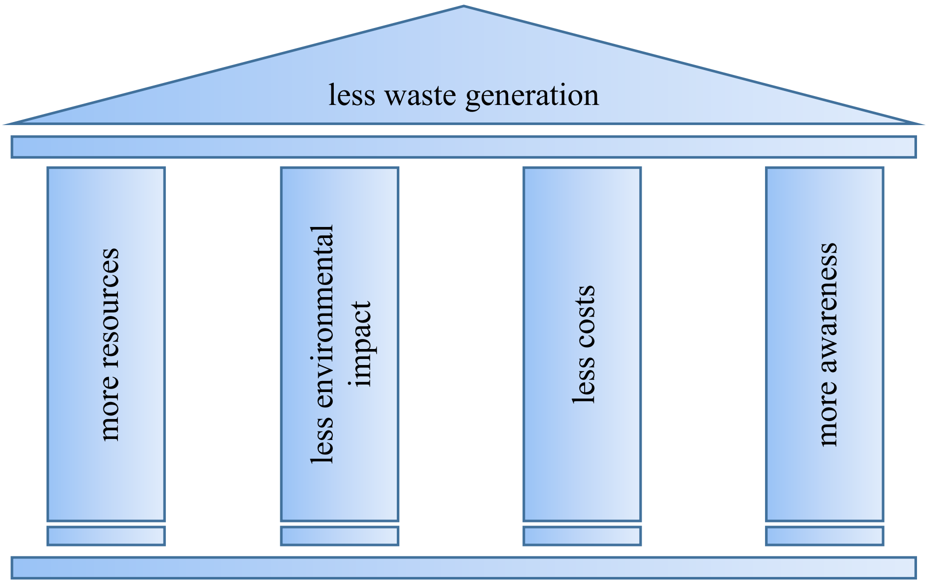

Figure 3: The five major building blocks of Circular Waste Management, own illustration.

First, the premise to minimise the generation of waste is paramount. This responsibility mainly lies with the producing industry and consumers. Although the waste management sector cannot be the prime initiator, targeted waste management can prevent materials from obtaining the waste status at all. In addition, meeting the following four sub-criteria ultimately contributes to the overall goal of less waste generation.

More resources from waste – By maximising the recovery and recycling of materials, waste management has to contribute significantly to minimising primary resource use. The better the quality of resources provided from recovery, the better prepared for reuse, the more likely the producing industry will reintegrate them into the primary production process. However, minimised primary resource use also places demands on the waste management operations themselves. Process efficiencies are demanded, for instance, shifting the vehicle fleet to run on green gas from the own organic waste recovery.

Less environmental impact – Following this example, the waste management-related emissions should be reduced. The treatment hierarchy, which will be elaborated in the next chapter, reflects the related environmental impact. Direct reuse causes practically no environmental harm. The more value retention happens on the upper stages of the hierarchy with recovery and recycling, the less harmful emissions in form of CO_2, other exhaust gases, leachate and extensive land use occurs that are related to waste incineration and landfilling. For the MSW collection in particular, this criteria means that all waste is really handled by designated management, that illegal disposal and local environmental nuisance through litter and odour are avoided.

Less costs – The Ellen Macarthur Foundation has calculated a positive business case with cost savings of up to 350€ billion p.a. for a CE on EU level (Ellen Macarthur, 2012). Likewise, waste management companies can improve their business case with increased efficiency. Smarter collection and more flexibility must lead to shorter transport routes, less processing costs and revenues from SRM sales that yield more than just break even. It is about generating more value for money, more usable outputs without raising the waste charges.

More awareness – To some extent, the waste collection method can influence the generation of waste in households. Waste management should aspire to have a social impact and promote education about waste. Public communication must deliver the message that waste is not useless but a resource, by communicating how what actually happens to the waste if certain streams are "recycled". A positive social impact of waste management also means that the disposal and collection is organised as convenient and plausible as possible for the citizen.

Regarded from a holistic perspective, these criteria should be and can be met simultaneously. However, it should be noted that amongst the multitude of stakeholders involved, the interests are conflicting. A high convenience for residents provided by frequent waste collection close to homes is inevitably resulting in higher costs for the service provider. The major concern of reprocessing companies, high-quality SRM streams, are unlikely to result from the most cost-efficient collection method the municipality would choose.

4 Words & Deeds – CE strategies compared to today's reality of recycling rates

4.1 Europe: the German example and manifestation of IWM in law

As the cradle for IWM anchored in law and a nationwide implementation is in Germany, a short digression shall give an insight into the German system. Due to the early developments and economic security provided by legal embedding, Germany became a focal point for the recycling industry. Waste materials from many European countries are exported to Germany for further processing. With 24% of plant and machinery for waste processing located in Germany, the country is world leader (Wuppertal Institute 2014, p. 42).

Already in 1996, more than ten years before the inception of a Europe-wide framework, the overall German Waste Disposal Law was amended. From then on it was called Closed Substance Cycle (Kreislaufwirtschaftsgesetz, KrWG) in order to emphasise a desired circular use of resources in the whole economy (§ 1 KrWG). This national law already manifests all the principles of IWM that are later adopted in the EU Waste Framework

Directive 2008/98/EC. Yet, the actual implications for the waste management practice are laid down in specific ordinances (Durchführungsverordnungen, DVO) and on the federal state level (UBA, 2005). The guidance that is given by the German KrWG and the EU Framework Directive is intended to guarantee that any negative effect of waste on human health and the environment is kept to a minimum. This shall be reached by following the waste hierarchy (Art. 4, 2008/98/EC):

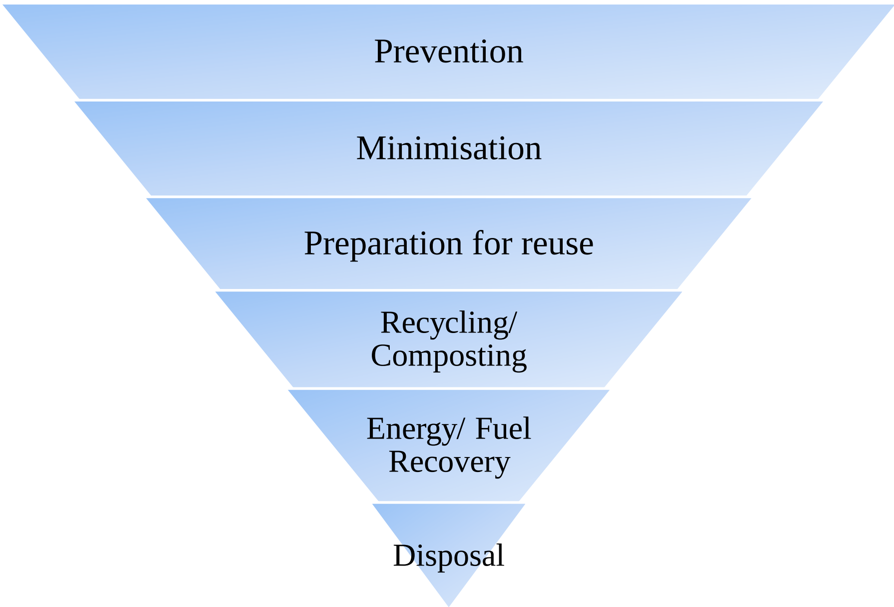

Figure 4: The hierarchy of waste treatment, own illustration based on Art. 4 EU Directive 2008/98/EC.

The most preferred management, prevention and prepare for re-use, is that products do not enter the waste status at all (Art. 3 (13), 2008/98/EC). If this is not possible, waste should be reprocessed into any new material or substance with recycling. The generation of fuels and energy from waste is marked off from recycling as recovery (Annex II, 2008/98/EC). Disposal is regarded as the last resort if no higher treatment is possible. The German legislation went so far as to ban the landfilling of untreated MSW completely in 2005. As an effect, the landfilling, but also the production of harmful landfill gas is close to zero (Stat. Bundesamt, 2015; AbfAblV). In order to prevent products from entering the waste status, special emphasis is put on the responsibility producers have for the products they put on the market. With the Extended Producer Responsibility (EPR) (Art. 8) and Polluter-Pays (Art. 14) principles, companies are held to take back defect products, organise recycling or at least to bear the costs for the necessary waste management deriving from their activities (EU, 2008). With the Packaging Ordinance (VerpackV) the EPR had already been incorporated in a legal regulation in 1991 in Germany. Since then, the subordinate private company Duales System Deutschland GmbH organises a completely separate collection of lightweight packaging (Leichtverpackung, LVP), in order to enable a subsequent sorting for recycling (Bilitewski/Härdtle 2013, p. 147). The quality standards (DKR-Spezifikationen) developed for the sorting of this value stream became the benchmark for plastic recyclate throughout whole Europe (UBA, 2005).

Generally, concerning the controversy about the separation of waste material, the EU policy states a clear preference for source separation to facilitate recycling as early as possible. The EU Framework Directive suggests that a separate collection of paper, metal, plastic and glass within MSW should be implemented in all Member States by the end of 2015 and at least 50% of these materials should be recycled by 2020 (Art. 10 (2), 11 (1), (2a), 2008/98/EC). With its proactive national policy, Germany already yields household waste recycling rates of close to 100% within the long-established mono-stream collection of paper, glass and the Dual System described above (Stat. Bundesamt, 2015).

Correspondingly, the current challenge for countries with an advanced waste management infrastructure is to establish a nationwide separate collection of biowaste. In Germany, this is also required by law from 2015 onwards (§ 11 KrWG). In 2014, 340 of the 400 German counties had a separate collection system for biowaste in place, with about 65% of households connected, half of the biowaste is already collected separately (Bilitewski/Härdtle 2013, p. 161). Despite the German pioneering role, the Dual System is not without its critics[7]. Since recycling rates are stagnating in recent years, the government itself wants to revise the Closed Substance Cycle law again to establish stricter legal obligations[8] (BMU, 2015).

The latest "CE Package" published by the EC in December 2015 shows that the political ambitions to reach a circular resource use are high and that industry players already demand stricter legal regulation (EC, 2015). The realisation among Member States, however, paints a different picture. As the character of EU Directives leaves the Member States freedom about national implementation and budget allocation, the status of waste treatment is highly divergent among Member States. On the one hand, there are countries like Germany, Switzerland, the Benelux and Scandinavia with close to zero landfilling of MSW and high overall recycling and composting rates around 50% in 2013. On the other hand, many Eastern European countries (70-90%), but also Spain (60%), the UK and France (30%) still highly rely on landfilling (Eurostat, 2015; see *Figure 5*). The reason is that, despite the claimed legal ban, without effective landfill fees or financial penalty, mere disposal remains the cheapest option. The EC Vice-President Timmermans claims that the recycling targets[9] were cut back in the CE Package in order to remain ambitious, but to make their realisation

[7] The BDE (Bundesverband der Deutschen Entsorgungs-, Wasser- und Rohstoffwirtschaft e.V.), a German consortium of waste processors, published an open letter to the government, communicating concerns about municipal market power impeding competition in the recycling and waste industry (www.afvalonline.nl/pdf/Offener-Brief.pdf).
[8] The planned obligations include an increased recycling target of 72% for light-weight packaging and an expansion of the EPR separate collection to all plastic and metal waste material instead of only packaging waste (BMU, 2015).
[9] The 2030 recycling target was decreased from 70% to 65% for MSW and 80% to 75% for packaging waste (EC, 2015).

more probable (EC, 2015). While according to Eurostat, the EU average recycling of MSW is 28%, if projected to the use of all raw materials extracted from earth for the whole EU-27 economy, Haas et al. (2015) calculate an overall recycling rate of only 13%.[10] This holistic view reflects an enormous gap between ambitious political plans and the low degree of circularity that is actually ascertainable for the whole economy. The following *Figure 5* gives an impression of the divergence of treatment technologies in Europe.

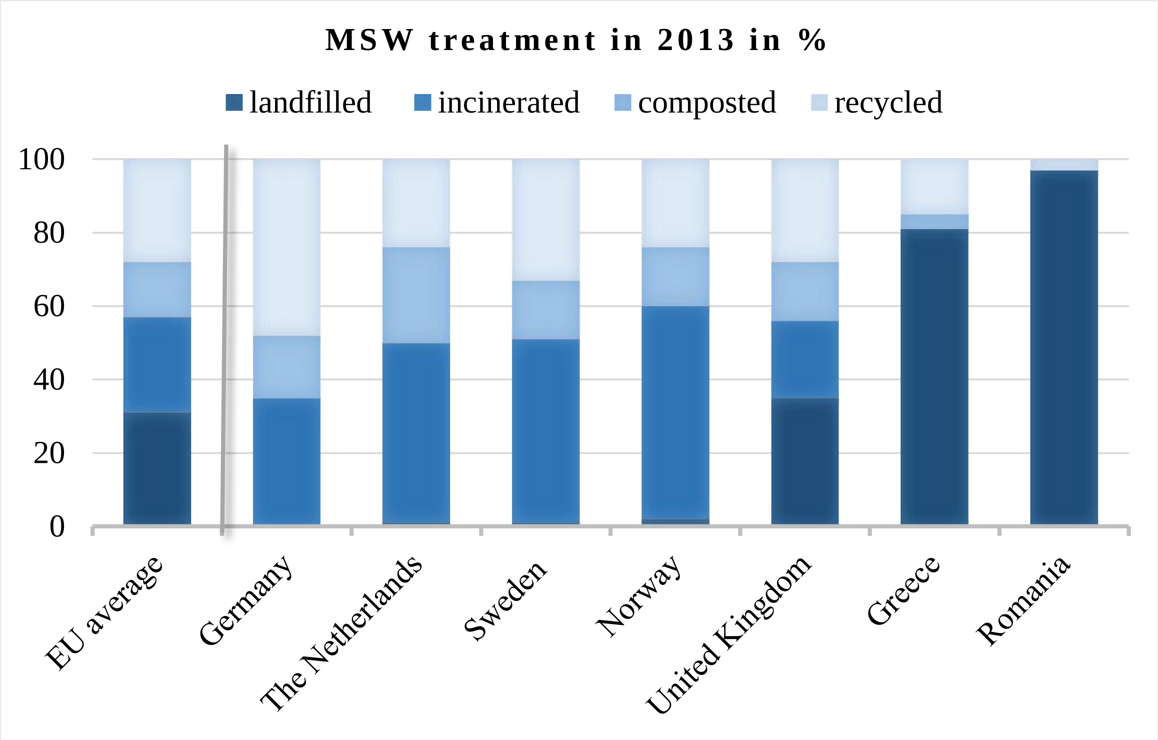

Figure 5: Treatment of MSW in percent in 2013 in selected EU countries, own illustration based on Eurostat, 2015.

4.2 The Netherlands: waste policy and current treatment of PPW and biowaste

According to the EU statistics, the Netherlands are among the frontrunners in IWM and recycling. 99% of MSW is recovered with either energy recovery or a treatment that is located higher on the waste hierarchy. In this way, one of the major targets manifested in the national waste management plan LAP2 (Landelijk Afvalbeheerplan 2, 2009-2021) is already achieved. However, the subgoal of 60-65% MSW recycling could not be reached yet, as the recycling and composting rate is stagnating at around 50% since 2006 (MIE, 2014; Eurostat, 2015). Despite the fact that the reduction of incineration and an increase of separate waste

[10] In 2005, from 7,7 Gigatonnes materials processed in the EU-27, 1 Gigaton was recycled (13%). The major reason why the reuse of resources is still so low is that a large majority, namely 44% of extracted resources, are fossil fuels used for irreversible energy production instead of utilising renewable energy sources (Haas et al. 2015, p. 772).

collection are explicitly declared aims in the Dutch policy program VANG (Van Afval Naar Grondstof) looking into the figures, these goals could not be translated into action so far.

One reason for the slow national progress could be that each communal council is responsible for its MSW collection and treatment, including the decision-making authority how to provide this service (MIE, 1979). Accordingly, each of the 393 Dutch municipalities developed its own individual system, with large differences from container sizes to taxation model (Groot et al. 2014, p. 80). The local authorities also decide over the categorisation for source separation of MSW, the frequency and way of collection. While the large majority of municipalities offers a form of kerbside collection for residual and paper waste, the streams glass and textile rely on a bring system. About 14% of communes resigned from source separation and changed to the reported mechanical post separation[11] (CE Delft 2011; NVRD 2012).

Concerning the largest proportion in MSW, biowaste, the Dutch Environmental Protection Act prescribes a separate collection (Art 10.26 MIE, 1979**)**. Yet, it is often collected commingled with the residual waste for practicality reasons. Just like in Germany, this results in half of the biowaste still being incinerated, but recovery on higher levels is expanding (VA 2014, p. 12). The currently prevailing technique is technical composting. In 14 installations in the Netherlands, 1300 kton biowaste were composted in 2012 by making use of aerobic digestion, which naturally occurs to all organic matter if exposed to oxygen and had been practised in its simplest form by humans for centuries (Pham et al., 2015; VA, 2014). A more efficient but less used treatment is anaerobic digestion under controlled conditions. In the country’s 12 industrial-scale digesters, only 200 kton of waste biomass were divided into a gaseous and a highly concentrated substantial matter. The gaseous matter, called biogas, has a high-energy content and serves as renewable energy fuel, either transformed into bioethanol/biodiesel for vehicles or green gas, the sustainable equivalent to natural gas (Pham et al., 2015). By using the nutrient-rich substantial matter, called digestate, as soil fertiliser in agriculture the fossil nutrients phosphate and nitrogen are reintroduced into the natural environment’s biological cycle (Ellen Macarthur, 2014, see *Appendix A*).

After biowaste, the aggregate fraction of packaging waste accounts for a quarter of the total waste volume (cf. *Table 1*). The producer responsibility for packaging waste suggested by the EU is integrated in Dutch law since 1997 (Staatsblad, 2005). However, only in recent years, several municipalities have introduced a separate collection for PPW (NVRD, 2015). Following a new agreement, producers and importers of plastic packaging are obliged to compensate all the costs that are associated with the separate collection and recycling. The

[11] In 2010, 55 of the 393 Dutch municipalities were connected to one of the three post separation lines in Groningen, Wijster and Oude Haske (Cimpan, 2015, p. 192). A fourth post separation line for the second largest city Rotterdam is currently planned.

charge is collected in a waste fund and distributed to the municipalities, who have to guarantee appropriate sorting in turn (MIE, 2012). With a national recycling rate of 46%, including drinking cartons, the reuse of PPW lies well below its potential, especially considering the relation that two kilos of crude oil are required to produce one kilo of virgin plastic (Nedvang, 2014).

Al-Salem et al. (2009) define four general stages of plastic recycling. The primary stage, direct re-extrusion, is only feasible within the producer cycle where the plastic content and composition is constant and known. Only with the PET-bottle refund systems, this is extended to the consumer stage. While stage four, energy recovery, is not a preferred option anymore and stage three, chemical treatment, like thermal cracking, is not developed on a large-scale yet, mechanical treatment is today's prevailing technique (Cimpan 2015, p. 190). Mechanical sorting means, that the highly heterogeneous PPW is cleaned, shredded and sorted according to the aforementioned German quality standards at only two locations in the Netherlands. These pellets or flakes are used as SRM to produce downcycled products, as Braungart/McDonough (2009) would call them, like grocery bags, door profiles and carpets (Al-Salem et al., p. 2627). Today's most advanced mechanical recycling facilities can basically only recover four different single-polymer types[12] (Cimpan 2015, p. 196**)**. The remaining 50% of sorted material is mixed plastic recyclate (DKR-350), which has practically no market value (Bilitewski/Härdtle 2013, p. 632). The poorer the input quality, the more processing steps necessary, hence, more energy and cost consuming. This confirms, the earlier and better the plastic fraction is sorted, the higher the recycling efficiency.

While the waste sorting can only concentrate on the product's end of life, a major barrier for more plastic recycling is the use of ever more mixed-polymer synthetic materials at the production stage. Biogenic materials should substitute these (Haas, 2015). Speaking of market value, this leads to the second factor that currently impedes the increase of mechanical plastic recycling. Since the chemical composition of recycled plastic polymers cannot be specified as precisely as for virgin plastics, the necessary incentive for producers to choose SRM would have to be a lower price. With the current crude oil price at an historic low[13] this is impossible and poses a serious market disadvantage to recyclers. In addition, it has to be noted, that today's recycling chain does by no means meet the CE claim of material reuse in locally closed loops. Almost half of the European plastic scrap (46%) is sent to China for recycling under insufficiently monitored conditions (Velis 2014, p. 27).

[12] These four different single-polymers are DKR-329 PE polyethylene, 324 PP polypropylene, 325 PET polyethylene terephthalate and 331 PS Polystyrene (cf. Cimpan 2015; http://www.gruener-punkt.de)
[13] On 11 Jan 2016, the price for one barrel Brent crude oil was 0,31 US$/0,28 € (www.nasdaq.com/markets/crude-oil-brent.aspx).

The elaboration shows that there is still a lot of room for improvement for the established treatment of post-consumer waste in Europe. In chapter *5.2* it will be exemplified, which techniques could yield higher-value outputs and bring the economy closer to circularity.

4.3 Amsterdam: the need for a new waste management strategy

The Netherland's good position in the European comparison is substantiated by the many small municipalities with individual and partly innovative waste management strategies. The few major cities, Amsterdam, Rotterdam, Den Haag and Utrecht present significantly lower separation, and therewith recycling rates, than the national average. In Amsterdam, the overall separation rate for MSW did not increase since 2012 and currently lies at 27%. If the large amount of bulk waste is excluded from the calculation, the separation rate for fine household waste is even only 17.7% (Gemeente Amsterdam 2015a, p. 17). The best results are monitored for the glass (58%) and paper (38%) waste streams, since they are collected as separate mono-streams for 35 and ten years (ibid., p. 13). A separate collection for PPW has been introduced in 2013 by adding an amount of 240 containers to the streets, which should serve the whole city. Accordingly, the PPW separation increased from zero to 7.5% within less than two years (ibid., p. 28).

Generally, each of Amsterdam's seven districts is responsible for the organisation and schedule of its own waste collection. Unlike the prevailing Dutch direct kerbside collection, in Amsterdam residents bring all their waste to underground containers at anonymous recycling points in the streets. The container density for the mono-streams in decreasing order is: residual waste, paper, glass, textile, plastic (Hultermans 2014, p. 19). Only in the historic city centre, the waste bags are collected with house-to-house kerbside collection.

Amsterdam's waste authority argues that higher recycling rates and a more tailored waste collection could so far not be realised due to the city's unique structure of multi-storey buildings and canals. In fact, 88% of the city's buildings are classified as high-rise. The population density of 5.000 inhabitants per km² is higher than in Germany's densest city Munich and the average private space in each of the 420.000 households is 70-80 m². Likewise, the open space is limited, as only 10% of households have a garden and the building density is as high as 40% (ibid., p. 16f).

Despite the differing organisation of collection per district, the responsibility for the treatment of MSW is centralised at the single company AEB. Together with residual waste from the whole region and imports from the UK, 1.4 million tons of waste per year are incinerated in the world's largest WtE plant. The mixed residue is used as combustion feedstock to produce renewable energy from the superheated steam. With a net electrical efficiency of 30%, this Waste Fired Power Plant yields the best results on the treatment stage of incineration. Heat is directly distributed with the steam via a district heating network; the electricity is generated and delivered to the city's public transport and households. External processors handle the mono-streams, the little amount of PPW collected separately is sent to sorting in Rotterdam. AEB is also active in recycling before incineration. In this regard, the company concentrates on special wastes until now. It operates six waste points throughout the city where citizens can dispose of bulk, garden waste and 22 other waste materials. On AEB's premises in the Westpoort, WEEE is dismantled and prepared for recycling in the Regional Sorting Centre. A Hazardous Waste Depot provides save disposal for toxic waste material.

Considering CE matters, the city government, who is full owner of the AEB Amsterdam Exploitatie B.V., set up a determined agenda. Together with lobby groups, like *Regio Randstad* and *Amsterdam Economic Board*, the Gemeente Amsterdam rushes ahead with an ambitious policy to transform the Dutch capital into a circular city. Already in 2012, the report "Towards the Amsterdam Circular Economy" outlined the resource cycles within the city and was amended in early 2015 to carry along concrete numeric targets, how to increase this circularity (Gemeente Amsterdam, 2015).

In this regard, one district shall set an example throughout whole Europe by realising the development into a circular city as described in *2.1*. A transformation has started to make a former shipyard on highly contaminated ground to the role model of a "circular, smart and biobased" city (Metabolic 2015, p. 14). The first autarkic houseboats are already in place. They shall lead the way to a completely closed urban metabolism with as low energy consumption and as much local resource reuse as possible. Just like any project in this district called Buiksloterham, new forms of innovative waste collection shall be tested under citizen's involvement and co-creation. There is no central sustainability plan, rather innovation shall sprawl bottom-up by trial and error in this "Living Lab" of a future city (ibid., p. 13).[14]

The two big numeric targets for waste collection that apply to the whole city are to reach 30% waste separation by 2016 and 65% by 2020 (Gemeente Amsterdam 2015, p. 27). Hence, the separate collection would have to more than double in the upcoming four years. In order to reach this goal, the experimentation in Buiksloterham is not sufficient. This is why Amsterdam's overall waste management strategy is under revision. Nine scenarios of different combinations of source and post separation were developed and are currently

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[14] Up to date information about the development and the different initiatives in Buiksloterham can be found in Dutch under: *www.buiksloterham.nl* and *www.buiksloterhamenco.nl*.

scrutinised according to their economic and practical feasibility. The Optibag collection model, which will be investigated in the course of this work, is among them.

5 Optibag collection case study – Assessment of cost factors and practicability

5.1 AEB Amsterdam's mid-term strategy until 2022: business case for PPW

At the moment, AEB is providing a viable solution for the entirety of Amsterdam's MSW with high-efficiency energy recovery. Yet, the imperative to move up the waste hierarchy is communicated on all political levels. Rapid advancement in the research of high-quality recycling opens up business opportunities on new markets. This applies in particular concerning increasing resource scarcity and the fact that 68% of resources and 2/3 of minerals used in the Netherlands are imported (CBS, 2012). Hence, AEB's future has to lie in receiving high revenues for the provision of high-quality SRM, undergoing the strategic change from a waste disposal service to a marketable commodities provider. Thereby, AEB could play an important role for the Netherlands beyond the Metropolitan Region.

For this reason, AEB's declared objective for the 2018 strategy planning is: "AEB is partner in responsibly solving waste problems by recovering more and more raw materials and generating maximum energy from residual waste" (AEB, 2015). As this indicates, a total renunciation of WtE is not considered reasonable. More resource recovery before incineration in Amsterdam frees capacities for imports from countries like the UK, where MSW is still landfilled. This results in an environmental benefit and contractually guaranteed higher gate fee revenues for AEB. In turn, also for the Amsterdam region WtE remains as a necessary sink solution. Today's recycling techniques cannot transform 100% input into 100% output of reusable material. The sorting residues and impurities that arise during the cleaning process have to be disposed of properly. Hazardous organic material has to be isolated from recycling cycles and many can be neutralised with thermal treatment (Brunner/Rechberger, 2015). As long as industries are not producing in the sense of a CE, combustion feedstock for WtE will be guaranteed.

In the short term, AEB's strategic goal is to increase the raw material recovery from 61 ktons in 2014 to 110 ktons in 2016 and 300 ktons in 2018 (AEB, 2015). The primary means to reach such a rise are extending the current recovery operations and building new installations. The budget allocation will incrementally shift towards AEB's recycling activities before incineration. As a first measure, the sludge recovery installation where ferrous- and non-ferrous metals are won from the raw bottom ash that remains after the combustion process will be supplemented by a mineral recovery installation, in order to regain 100% raw materials from the bottom ash (ibid.).

The second installation in the planning for 2016, a digester, is aimed at exploiting a higher energy yield from waste biomass than with incineration. Currently, sewage sludge from the neighbouring wastewater company *Waternet* is co-combusted with the residual waste in AEB's WtE plant. This poses an example of exploiting synergies in waste management, but simply burning the sludge yields close to zero energy. Whereas the anaerobic digestion of this biomass residue into biogas within the digester is expected to produce around 370 TJ sustainable energy per year (ibid.). The biogas will be further enriched into green gas in an additional green gas installation in order to introduce it directly into the city's gas grid.

In light of the 30% discrepancy between the municipality's ambitious waste separation goal for 2020 and the actual separation rate, AEB is working on a business case for the realisation of a post separation line. With this decision, the company is opting for the short-term cost benefits associated with central post separation as described in *2.4*. A capacity of 300 ktons p.a. residual waste that is currently reaching AEB in a mixed stream shall be sorted with different sieve and infrared techniques, so that two-thirds of the input are recovered before incineration. It is expected to achieve an immediate rise in Amsterdam's plastic packaging recycling rate from the current 7,5% to 53%, if the source and post separation are combined (AEB, 2015a).

In terms of separation effectiveness and profitability, the business case is completely focussing, and therewith financially dependent, on the separation of PPW and drinking cartons. The fractions paper, cardboard and textiles are only a by-catch in this post separation scenario due to the high contamination from mixed collection. Paper and cardboard outputs are sold to the recycling industry at zero income, as the price is just sufficient to cover the processing costs. For the quality of metals, in the way they are currently used as SRM, the separation before or after incineration at AEB is indifferent (ibid.). The entire minor sorting residue that remains after separation of the valuable plastic components is subsumed under the term organic wet fraction (OWF). Due to its mixed residual character, it is by no means comparable to source separated biowaste. As a consequence, this low biomass purity makes it unsuitable to be used as input for the prospective innovative treatment technologies that will be presented in the following. Rather, the presently envisaged solution is to co-digest the OWF with the wastewater sewage sludge in the planned digester.

As the one-sided resource yield reveals, this post separation scenario is not a holistic solution, nor a positive example for CWM. First and foremost, it is a way to achieve a quick rise in recycling rates. Thereby, AEB is enabling the municipality, its major customer, to reach its political goals. From AEB's perspective, it is justified as one short-term measure along the company's long-term strategic transition (AEB, 2015; see *Figure* 6). It opens the door for AEB to enter the plastic packaging recycling sector. The revenues in this sector cannot be obtained on the free market but completely stem from the compensations manifested in the Dutch plastic waste fund agreement (see *4.2*). In fact, regarding the low market prices for secondary plastic material, the business case would never break even without this compensation. The legal guarantee that the producers pay compensation to those parties who enable recycling is limited to the short term until 2022. Being owner of the sorting line, this compensation will be fully granted to AEB. As much as this is a form of guaranteed revenue for recycled plastic, it is at the same time the biggest risk factor for the investment. The current compensation amount[15] is already in debate and set to be declining until 2019, exact height uncertain and subject to political negotiation. Despite the fact that the business case is reliant on a single waste fraction, the investment depreciation is calculated with the most optimistic scenario of compensation, implying a high risk-intensity and a comparably low IRR of 5% (AEB, 2015).

With this in mind, it is certain to say that the feasibility of the post separation line is dependent on a sufficiently high amount of plastic packaging material within the residual waste. Therefore, its cost efficiency is clearly competing with efforts to promote source separation. Since the latter advocates the avoidance of PPW ending up in the mixed residual waste stream.

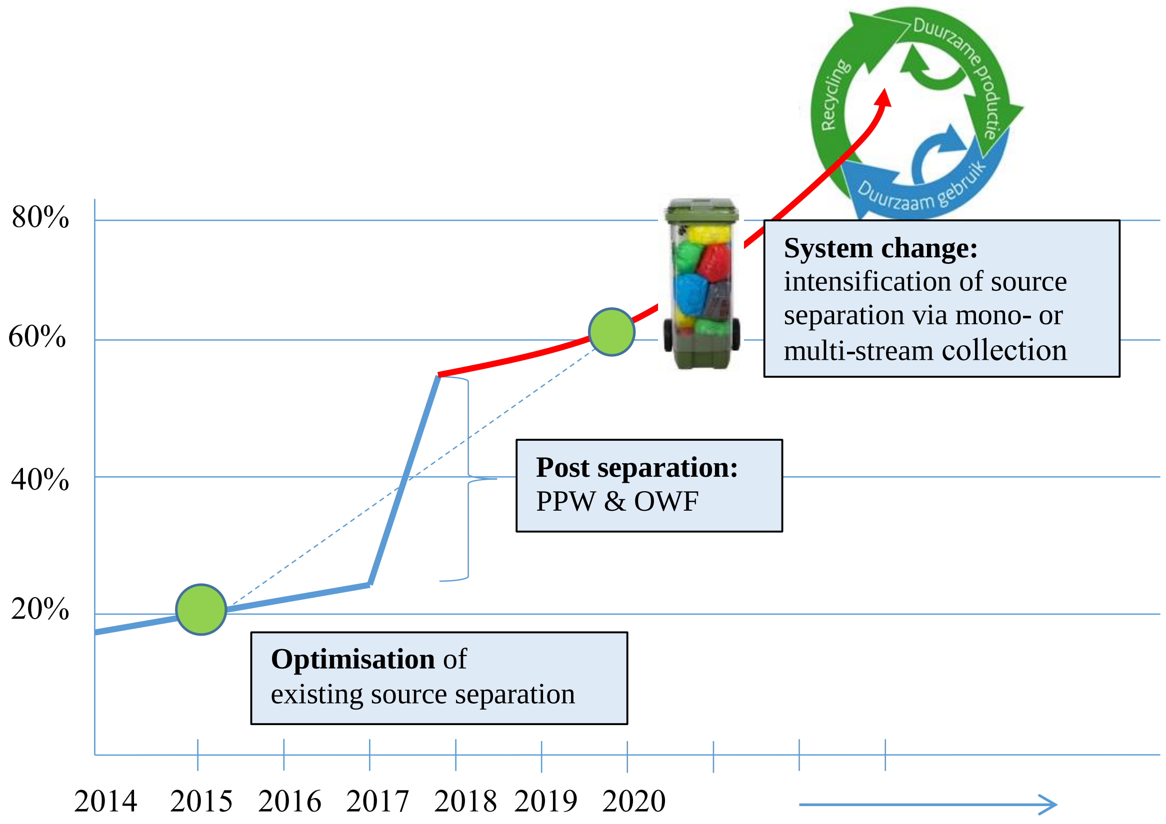

Figure 6: AEB Amsterdam's waste management strategy over time; *source: AEB, 2015c.*

[15] The compensation is estimated for 2017 to be 756 €/t plastic packaging waste and 398 €/t drinking cartons (MIE, 2012; AEB, 2015a).

5.2 AEB Amsterdam’s long-term strategy until 2035: technological innovations

For the long-term, however, AEB is not intending to remain a waste processor but to become a commodities provider. Likewise, AEB’s long-term strategy is defined by its R&D activities that investigate profitable future treatment technologies for different waste streams. Most potential lies in the organic waste material, albeit the research on biowaste stands in close proximity to the category of plastic waste.

Just like the EU hierarchy was established for general waste, AEB prioritises the recovery of biowaste according to a biomass hierarchy, which is supported by Dutch scientists[16] (see *Appendix B*). The hierarchy indicates that waste material is capable of being turned into value-added products, eventually replacing fossil intermediaries that are indispensable in the chemical and food industry.

Ranked on stage five of the biomass hierarchy, the current co-incineration of municipal biowaste adds the least economic and environmental value. With the planned construction of the green gas installation, AEB will reach the fourth stage, fuel recovery, in the short term. The future, however, lies in stages one to three, the processing of waste materials into new marketable commodity products. For that, the waste management sector works closely together with the research field of the biobased economy, which gained especially great momentum in the Netherlands within the last ten years (RVO, 2015). In a biobased economy, techniques from genetic and molecular science are instrumentalised to optimise industrial processes. The main aim is to replace fossil resources with biobased inputs derived from renewable biomass (RVO, 2015). For instance, the generation of bioplastics, a biodegradable substitute for conventional petro-based plastic, is maturely developed. Bioplastics produced from first generation biomass such as sugar or maize starch already enter the market in products like carrier bags and catering items (Razza/Innocenti, 2012).

Material – The key lies in going one step further, advancing the technology that is already proven in the biotechnology research to be feasible with waste materials. Laboratory tests have proven that the precursor for bioplastics, the polymer polylactic acid, can potentially be won from second-generation biomass, inter alia municipal organic waste (Yang et al. 2015, p. 345). For the bioconversion to work with waste material, a stream of pure biowaste input is of utmost importance. This can only be obtained if the household food waste is intercepted directly at the source. Concerning the contribution to a CE, implementing bioplastics from waste in new products would on the one hand make them fit into Ellen

[16] Prof. Dr. Johan Sanders, leader of the chair for Biobased Commodity Chemicals at Wageningen University, promotes the F-ladder, 10 stages of value creation from biowaste: farma, fun, functional chemicals, fiber, fermentation, fuel, fertiliser, fire, flare, fill (VA 2014, p. 13).

Macarthur's biological metabolism and on the other hand mitigate the controversy of using first generation biomass for other purposes than food.

Bioplastics can also be won by converting post-consumer plastic packaging itself instead of biowaste. This chance of closing the loop even tighter by staying in the same material category is investigated by the RWTH Aachen. In an EU-funded research project, they focus on reprocessing plastic waste into new bioplastics via biosynthesis (RWTH, 2015). Likewise, in Amsterdam, AEB is cooperating with the TU Delft to investigate the potential of implementing shredded PPW as raw material for a 3D-printer in the Living Lab Buiksloterham. Locally recycled plastic granulate shall be inserted in a prototype for 3D-print large-scale building components (AMS, 2015). This approach constitutes a form of upcycling as suggested by Braungart/McDonough (2009), as the plastic material will be part of a higher value product than before recycling.

Notably, there is also a solution underway to overcome the major impediment to more plastic recycling, the fact that the reuse of PPW is currently not economically attractive for producers. If chemical markers were inserted in plastic packaging at the production stage, waste management companies like AEB could help producers to trace back their own packaging material with the specific polymer combination before it is mixed with other plastics in the conventional disposal process (Pilon et al., 2015). In this case, not only PET bottles, but all plastic packaging could be reintegrated directly in the production process with substantial savings in cost and effort.

Food and feed – Returning to the biomass hierarchy, AEB launched two research projects to make progress on the second stage, the generation of new feed and food from biowaste. The current main protein source for pigs and poultry is soy. The rationale behind an AEB cooperation with the Wageningen UR is again to replace this first generation biomass by feed that can be won through the exploitation of waste biomass. Small-scale experiments have proven that using food waste to rear housefly larvae yields highly aggregated amounts of animal protein in the form of insect larvae (Wageningen UR, 2012). In the Netherlands, insects are already fed to exotic animals on a commercial basis. The insect larvae processed into protein flakes are seen to have potential to extend this into the livestock industry.

Another way of obtaining new usable protein is to produce a substitute for animal protein. In this sense, the objective of the investigation "power2protein" is to generate a single-cell protein via bacterial conversion that has an amino acid profile, which is comparable to animal proteins. Here, it is not the biowaste used in its original form, but the products that can be obtained with further processing after the biowaste digestion. The rationale for AEB is that the major input needed for the bacterial process, carbon dioxide CO_2, ammonia NH_3

and hydrogen H_2, can be obtained from the own on-site digester that is due to be constructed (AEB, 2015b).

Those proteins gained from organic waste processing shall serve as animal feed in a first instance and potentially substitute animal and plant proteins for human food in the future. Concerning not only population growth and the fact that 45% of the worldwide farmland is occupied for livestock and cattle feedstock, but also that the livestock industry is responsible for 18% of total greenhouse gas emissions (Thornton et al., 2011), this protein source is a relevant alternative for sustainability. However, public acceptance and legal foundations take more time to adjust than the technological development. Currently, EU regulations 1069/2009 and 142/2011 prohibit insect protein to be used as animal feed; for food multiple rigid health regulations, toxicology and allergenicity issues will have to be addressed before realisation (Wageningen UR, 2012).

Pharma & fine chemicals – Finally, the most valuable recovery of biowaste revolves around the production of fine chemicals for the pharmaceutical industry. The process under scrutiny is to transform the sugars that are naturally contained in organic waste into furans, which in turn are the precursor for aromatics. Aromatics are ubiquitous as 40% of chemicals used in all kinds of industries are aromatic of nature, nowadays predominantly derived from crude oil (VA, 2014). Considered this, for the owner of biowaste a large economic potential opens up with the possibility to render resources, which have a high market value beyond the recycling sector. The market value of furan intermediates is estimated at more than 750 €/t (AEB, 2015c). This constitutes a profound revenue boost, regarding that the current income from biowaste composting or digestion lies between 50 and 75 €/t. AEB is active in this field as part of the research consortium *Biorizon*, investigating the business case for the biowaste to be processed into furans with several biotechnological and chemical steps on a laboratory scale (ibid.). Additionally, in the sense of efficiency optimisation, the biowaste can be exploited several times in succession. After gaining the high-value biochemical products, sorting and process residues can still serve as energy source on a lower stage of the biomass hierarchy (ibid.).

Apart from the strategic significance for AEB, this chapter makes clear that accurately obtaining waste materials and preparing them for reprocessing is not merely an important issue for the waste management industry alone. The presented technologies on the rise indicate that "waste as a resource" is not a political catch phrase but a business model that will affect multiple industries from chemicals to nutrition.

5.3 Advantages and disadvantages of the Optibag source separation

An active separation of waste material into valuable streams is a prerequisite for the realisation of the business perspectives just described. One collection systems scrutinised for optimisation in Amsterdam is the Optibag source separation. This method works with different coloured bags, the Optibags, and subsequent optical sorting. It is currently in operation in several municipalities in Finland, Norway and Sweden. First put on the Scandinavian market by the Swedish company *Envac Optibag AB* in 1994, the multi-bag collection aims at combining the transport efficiencies of commingled collection with the quality achievements of source separated waste streams (Nilsson, 2014).

The typical source separation method assumed in the scientific studies analysed in *2.4* is kerbside collection with individual containers and transport schedules for each mono-stream. Thereby being relatively time, labour and cost consuming. On the contrary, the Optibag rationale is collecting multiple waste fractions separately with only having the management effort of one mono-stream. The citizens have to sort their waste into different coloured bags at home according to material type but can dispose of them together in a single container (multi-stream). This method shall ensure contamination prevention and a full exploitation of waste hauler capacity. The bulk of commingled bags is then brought to the waste management company's optical sorting line. It optically detects and automatically sorts the waste bags according to their colour, so that the valuable streams can be sent directly to their optimal recovery (ibid.). In all cases that will be scrutinised in the following, biowaste is separated for digestion and residual waste is incinerated in a WtE plant.

The main reasons for AEB to choose this system to be tested in Amsterdam are the expected low modification efforts and high flexibility. Existing containers, transport vehicles and collection routes can be carried on. Thus, the operational costs should not differ significantly, while the commingled collection of bags even bears the potential of increased logistic efficiencies. The existing treatment facilities can be maintained and extended by an upstream optical sorting line. *Envac Optibag* estimates its investment costs at 100-140€ per ton waste processed, depending on the amount of sorted fractions (Envac Optibag, 2015). Scaling up the cost estimations given by *Envac Optibag* to the waste input capacity assumed by AEB for the post separation line, investment costs for the two options range on the same level if costs for the waste bag distribution are included (Envac Optibag, 2015; AEB, 2015a).[17]

In contrast, the optical sorting system is more flexible in the long run. While the post separation line is technically tailored to sort specific existing waste materials, in the AEB

[17] Because AEB's investment in the post separation line is in the middle of the tender process at the time of writing, the exact investment estimations are subject to confidentiality obligation.

scenario plastic packaging, the optical sorting is tailored to colour detection. Hence, the hardware can be maintained and the material streams that are separated within the coloured bags can be adapted according to changes in MSW composition or advancements in research about optimal recycling. To post an example, AEB is investigating the recyclability of diapers. The Optibag system would make it technically easy to obtain a single diaper stream, once the treatment technology is mature. More practically speaking, the system provides flexibility to start with only two or three fractions and scale the number up incrementally. In fact, the variety of fractions in Scandinavian municipalities currently ranges between two, separating organic waste from residual waste, and six different streams (Nilsson, 2014).

Regarded from the consumer side, the reported benefits for the residents should be higher convenience, as all bags can be disposed of in one container, and increased, as all fractions are strictly isolated in sealed bags. Furthermore, it is arguable whether the task of home separation triggers the citizens' feeling of responsibility for managing their own waste accurately, as opposed to post separation. The multi-bag collection system exemplifies the fundamental question of disposal responsibility.

The strong involvement of the citizens into waste management is the backbone of the multi-bag collection and can be its biggest drawback at the same time. The functioning of the system is completely dependent on the resident's sorting activity and accuracy at home. In this regard, the intended rise in positive awareness for waste management is at risk to have the opposite effect, if advantages are not communicated accurately and people perceive the coloured bag separation as an extra burden.

In any case, compared to the technical establishment of a mechanical post separation line, introducing the Optibag home separation requires a lengthy process. This is not only due to the citizens' need for accommodation time (Midden 2015, p. 20) but also because the waste management operations have to be optimised by individual experience in the designated area. This holds especially true if considered that a multitude of factors influence the success of source separation. Dahlén/Lagerkvist (2010, p. 579) distinguish between factors that cannot be influenced by waste management strategies (property type, household size, employment rates, network in the neighbourhood) and fewer factors that can be controlled (technical design of collection, education programme, taxation, provision of equipment). The fact that so many factors lie beyond control makes it even more important to analyse and customise those factors that are manageable (see *Appendix C*).

5.4 Optibag in Scandinavia – results from Oslo, Linköping and Eskilstuna

In theory, the Optibag collection method holds advantages for all stakeholders. The author's personal observation revealed that within discussions about the right waste management, the Optibag municipalities were often highlighted as role models. It shall now be scrutinised whether these advantages apply in reality and where the supposedly positive figures come from. *Table 2* provides an overview of the findings, which will be subsequently explained in detail. The practice in three Scandinavian municipalities is observed to find out if the Optibag system is capable of meeting the demands of CWM as outlined in chapter *3*. Subsequently, it is to be seen whether this system is applicable to the circumstances in Amsterdam.

Criterion	**Eskilstuna, SE**	**Linköping, SE**	**Oslo, NO**
System introduction	January 2011	May 2012	June 2012
Households covered	22.000	108.000	340.000
No. of separate streams	6	2	3
Fractions collected separately with Optibag (bag colour)	Food waste Residual waste Plastic packaging Metal packaging Cardboard packaging Newspapers	Food waste Residual waste	Food waste Residual waste Plastic packaging
Other collection system Drop-off stations:	PET bottle refund Glass; disposal of all Optibag fractions still possible	PET bottle refund Glass, plastic, cardboard, paper, metal packaging	PET bottle refund Glass, metal, textile, hazardous waste
Manned recycling centres:	WEEE, hazardous, bulk waste	WEEE, hazardous, bulk waste	all other fractions
Kerbside collection:			Paper
Taxation	Individual PAYT for residual waste	Individual PAYT for residual waste	Fee p.a. based on container size
Less waste?			
Overall waste quantity	Same	Same	Declined
Biowaste quantity	Declined	Declined	Declined
More resources from waste?			
Overall recycling rate	54%	62%	37%
Biowaste sorting rate[18]	50%	70%	40%
Sorting purity[19] – Biowaste	96%	94%	98%
Sorting purity[19] – PPW	93%	-	95%

[cont.]

[18] biowaste sorting rate = Amount of biowaste that is collected in designated green bags in comparison to total amount of biowaste generated.
[19] sorting purity = Amount of correctly sorted pure waste material in designated bags for this stream in comparison to amount of contamination through other fractions within the stream.

Criterion		Eskilstuna, SE	Linköping, SE	Oslo, NO
Less environmental impact?				
Less incineration		✓	✓	✓
Energy recovery	Heat	External company	1630 GWh/p.a.	900 GWh/p.a.
	Electricity		676 GWh/p.a.	125 GWh/p.a.
Biowaste recycling	Biogas	1060 kWh/t	1440 kWh/t	since 2014
	Fertiliser	244.920 m^3 p.a.	14 Mio. m^3 p.a.	254.850 m^3 p.a. possible
Reduction in CO_2 emissions		4.400 t p.a.	9.000 t p.a.	6.400 t p.a.
Less cost?				
Investment costs		< alternative	no alternative	= alternative
Efficiency	Operational costs	Same	Same	5-10% rise in transport effort
	Optical sorting precision	> 90%	> 90%	> 90%
More awareness?				
Participation today		99%	86%	81%
"Optibag is a convenient system"		47%	-	56%

Table 2: Comparison of Optibag waste collection in Eskilstuna, Linköping and Oslo, own research based on: personal consultation with Reiner Schulz, Executive Director Waste Collection, Eskilstuna Energi och Miljö AB; Johan Böök, Head of International Relations, Tekniska verken i Linköping AB; Håkon Jentoft, Senior Executive Officer, Oslo kommune Renovasjonsetaten; Stefan K.A. Nilsson, Marketing Manager, Envac Optibag AB (see Appendix D).

Before analysing the bare figures, it is reasonable to scrutinise the waste collection system that prevailed before the change to Optibag collection. Since 1994 in Sweden, the EPR for packaging waste is mandatory and acted out by a designated service organisation called "Förpacknings- och Tidningsinsamlingen" (FTI) (Packaging and Newspaper Collection). The FTI runs local recycling stations with separate containers for all packaging materials, predominantly glass, plastic, cardboard and metal packaging. The costs for maintenance and recycling are incorporated in the consumer prices for packaged products (Fråne et al., 2014). The citizens have to bring their packaging waste to the drop-off stations, only residual waste is collected via kerbside collection. Hence, residents are used to a bring-system for recyclable waste, which turns out to have a high public acceptance (Golush 2008, pp. 307ff). In Norway, the EPR is on a voluntary basis. In the Norwegian structure of many small municipalities, the majority of PPW is collected with mono-stream kerbside collection and forwarded to handling under the Swedish FTI system (Fråne et al., 2014). Apart from that, the bring system for other recyclable waste materials via unmanned recycling stations and fewer big recycling centres is also established there.

Waste generation – The overriding goal for waste management in a CE is that less waste is generated. In the examined cases, the Swedish municipalities estimate no significant change of *MSW quantities*, while the waste generated per capita in Oslo decreased from 379kg in 2010 to 347kg in 2014 (REN Oslo 2015a, p. 11). However, it cannot be concluded that this positive effect can be ascribed to the Optibag collection. Generally, the household waste generation is very volatile and stands in relation with private consumption patterns. Long-term monitoring shows that waste quantities linearly increase with the economic growth and increasing income per household within European countries (Mazzanti, 2008). Like the figures from Oslo, the European average MSW generation per capita is following a declining trend since 2007 (Eurostat, 2015a). In light of the 2007 outbreak of the global financial crisis, the monitored decreasing waste generation is rather evidence for the correlation of household waste generation with economic fluctuations than with the collection system.

Yet, that does not mean that a different collection system cannot have an impact on waste generation patterns at all. For instance, the contact persons from all three municipalities emphasise that the amount of *biowaste generated* decreased with the introduction of separate collection. Johan Böök from Linköping observed that a separate bin for green waste in the household makes the citizens aware of the large volume of biowaste they produce and leads to efforts to reduce this amount (Böök, 2015).

Recycling – If the new Optibag and the former system are compared in terms of how many resources are recovered, it is certain to say that with Optibag, the resource yield has improved in terms of both quantity and quality of outputs. Before, all mixed MSW was sent to energy recovery via incineration. The separate collection caused biowaste to be sent to higher-energy efficient digestion and the amount of plastic packaging prepared for recycling to multiply. For instance, in contrast to the rest of the country, in Oslo there had been no plastic packaging separation from household waste established at all (Jentoft, 2015). Consequently, the *recycling rate* for the Optibag-covered fractions PPW and biowaste rose fourfold from 2010 to 2014 (REN Oslo, 2011 & 2015). The strongest increase in recycling rates explicitly stemming from the Optibag collection was reached in Eskilstuna, as it covers all main waste fractions with the six different bags. The percentage of residual waste for incineration could be reduced from 60% to 46% within four years, resulting in 54% of waste materials that are directly sent to the right recycling stream (Schulz, 2015).[20] With this in mind, it has to be noted that the comparably high overall recycling rates for Linköping and Oslo include the MSW that is brought to the recycling stations. In Linköping, 49% of the 62% recycling rate in 2014 is achieved via the long established bring system (Böök, 2015). In Oslo, almost half of the recycled materials derive from the separate kerbside collection for cardboard and paper waste that was established before (REN Oslo, 2015a).

[20] Of the 54% waste that is not incinerated, 30% is assigned to organic waste which is recovered in the digester and 24% is assigned to material recycling from newspaper, metal, cardboard & plastic packaging. The latter could therewith be doubled with the Optibag introduction as the recycling rate was 12% in 2010 (Schulz, 2015).

As already indicated, in order to facilitate circular material reuse, the quality within obtained waste streams is even more important than mere quantities. In this regard, the concept to avoid contamination with the multi-bags is proving successful in reality. The *sorting purity* of PPW and biowaste lies above 90% in all cases and makes these streams highly suitable for high-value recovery options. The *sorting rate* and *purity* represent how well the residents understand the system and actually sort their waste at home. What is also apparent from the figures is that with 70%, Linköping reaches by far the highest biowaste sorting rate, indicating that if residents only have to concentrate on one fraction, their performance is best.

However, the PPW purity results were not satisfactory in Oslo at the beginning. Likewise, Reiner Schulz from Eskilstuna reported that the citizens needed a lot of explanation on which materials exactly belong in the PPW stream. The increasingly mixed and complex composition of plastic packaging makes it harder for consumers to distinguish, how to dispose of it correctly.[21] Consequently, the 95% PPW sorting rate in Oslo was only reached in 2014 by installing an additional weight detector[22] at the optical sorting line (Jentoft, 2015).

Environmental impact – The question, which effect the Optibag system has on the environmental impact of the local waste management, is harder to quantify in exact figures. Rather, several positive effects are derivable in principle. First, if the amount of residual *waste incinerated* is reduced, because more waste is diverted to recycling, this can be rated positive for the environment. The higher the treatment on the waste hierarchy, the *less CO_2 emissions*. Furthermore, the large increase in Eskilstuna and Oslo of plastic that is directly forwarded to recycling can be translated into savings of fossil resource use. Every product that is made from this recycled instead of virgin plastic avoids the CO_2-intensive exploitation of crude oil. The biggest improvement can be ascribed to a change in transportation. In all three cities, not only the waste vehicle fleet but also the public transport buses were transformed to run on renewable *biogas* from the local biowaste digestion. As a result, a reduction in transport CO_2 emissions from 1.2 to 0.4 kg/km was observed in Oslo (REN Oslo 2011 & 2015, pp. 28, 30). Likewise, farmers in the immediate vicinity implement the *biofertiliser* that is won in the digester. This posts an example for local closed loop recycling.

Despite these fundamental coherences, it is impossible to distinguish which of the results are particularly related to the Optibag system. On the one hand, the results cannot be kept apart. For example, the digestion yields in Linköping are so high because the household foodwaste only makes up half of the input. The other half derives from slaughterhouse waste products

[21] Typical examples are yoghurt pots or Nespresso coffee capsules comprising plastic, mixed metallic, light-weight cardboard and residual organic material, each belonging to a separate waste stream.
[22] The weight detector sorts out all blue plastic bags that weigh more than 700g. The likelihood for those bags to be filled with wrong and residual waste materials instead of lightweight plastics is extremely high. This measure increased the purity of plastic output but simultaneously reduced the output quantity substantially.

(Böök, 2015). On the other hand, neither of the three waste management companies compiles a designated Life Cycle Assessment for their operations, let alone measures the CO_2 emissions with a consistent approach. Correspondingly, the average yearly CO_2 savings reported in the table are an aggregation of different measurements that were made accessible.

Cost – Likewise, the contact persons stated that it would be difficult to determine exact figures about the costs related to the Optibag collection. Apart from that, simply asking for *less cost* turns out to be the wrong question. If the resource yield from waste shall be raised significantly, investments in innovations are indispensable. Their profitability will manifest if over the long term more value can be obtained for money. Hence, at the decision point for a new system, it is more reasonable to compare investment alternatives, instead of new costs to the old inefficient system. Håkon Jentoft explains that in Oslo, opting for the Optibag system was a political decision in 2005. Initially, they concluded that the costs were similar to an alternative system with additional separate containers for biowaste and PPW. The Optibag collection prevailed in the end, thanks to its substantial space savings, which are necessary in the densely populated city centre. The investment costs for the optical sorting line turned out to be 54€ million in 2010. The sorting line's operational costs were with 10€ million in 2014 lower than budgeted due to the lower separation performance of citizens at home (Jentoft, 2015).

In Eskilstuna, the Quattro Select system was considered as an alternative to Optibag. Quattro Select works with containers with four different compartments for loose waste streams. This would have required not only the acquisition of new containers for each household but also new waste haulers and the reconstruction of parking spots (Schulz, 2015), hence entailing significantly higher investment costs. In Linköping, no modifications of the collection infrastructure were necessary at all to introduce the separate biowaste collection, (Böök, 2015). In this regard, the Optibag system's low transformation effort is proven in practice as all three waste management companies could continue to implement the same waste haulers and disposal system as before.

Regarding the *operational collection costs*, the envisaged concept of combining high efficiencies from commingled collection with high resource yields from separated waste streams seems to work out. According to the reports, in Linköping and Oslo the waste quantities collected with the same load did not change. Only their arrangement within the transport vehicle did, as the streams are now isolated in the Optibags. As a result, no significant change in transport efforts is reported. In Oslo the monitored "5-10% rise in transport is a lot lower than expected" and stems from the lower compression within the haulers to prevent the Optibags from bursting (Jentoft, 2015). If it is considered that the resource yield is further guaranteed by the high *precision of the optical sorting line*,[23] it can be concluded that the overall efficiency rose with the introduction of the Optibag system.

Social awareness – What remains is the question of a social benefit. Can the Optibag system trigger the individual's awareness for the necessity of proper waste management for a CE to function? Is the new collection rather perceived as an extra burden or do residents find it more convenient?

The public impact can be measured by the *participation rate*. All three municipalities managed to raise the average participation on a high level of over 80%, regardless of the housing type. This required extensive communication efforts in all cases. In the first place, the recycling activity is linked to the fee for waste collection. Except for Oslo, the participation in the Optibag collection is on a voluntary basis, but it is incentivised by differentiated taxation. In Eskilstuna, the waste collection fee is twice as high for a household that insists on the old mixed waste collection. The exact fee is further differentiated according to household type, container size and pick-up interval. For a 190-l-container collected every two weeks a single-family house pays 600€ for commingled collection[24] and about 280€ for the colour sorting (EEM, 2015).

In terms of communication, a first measure in all three cases was to equip each household with a starter package, containing a first range of coloured bags, an explanatory guide how to separate waste, FAQs and contact details for further questions. In addition, in Eskilstuna it was taken advantage of the fact that the Optibag system was introduced in the rural areas outside the city centre, addressing single-family houses and holiday cottages. The introduction of the new system was prepared in cooperation with the local neighbourhood association (Schulz, 2015a). The Optibag promotion was synchronised with the annual spring garden festival, streets were decorated with the colourful waste bags. An immediate participation of 97% gives evidence for the fact that drawing the system change into the context of traditional habits pays off.

In the bigger municipalities Linköping and Oslo, where five or 15 times as many households had to be addressed, the concentration lay on extensive mass communication. A comprehensive marketing campaign was developed, including all traditional media, such as banners on public transport and waste haulers, billboards in public places, newspaper advertisement and cinema clips. In Linköping, the mass marketing was combined with emotional appeal. On the one hand, a green mascot incorporating the separated biowaste was

[23] The practical results show that with a precision of close to 100%, in Oslo it is estimated at 98%, the only purity errors within the Optibag system can stem from the residents' sorting performance. In contrast to a post separation line, no additional human sorting is necessary.
[24] Even with commingled collection, the separate collection of organic waste is mandatory In Eskilstuna in any case. In this regard, households can choose between having only the biowaste collected separately or replacing the green bags or biowaste collection by an own private composter (EEM, 2015).

invented and recurs on every related document. On the other hand, local ambassadors report in magazine articles how easy it is for them to separate their waste at home, attaching the motivational slogan “Du och vi gör skillnad", meaning "you and we make a difference together" (Böök, 2015).[25]

In Oslo, the unsatisfactory separation of PPW led to a substantial extension of communication on a personal level. To date, 15 employees are engaged in door-to-door communication every evening. They act as waste coaches, mainly addressing residents in multi-storey apartment buildings, to exemplify how easy it can be to organise the waste separation even with limited space at home. Moreover, it is made use of personal reinforcement by openly communicating results that have already been achieved via information booths in shopping malls and mailing (REN Oslo, 2015a). The necessity of those extensive communication measures led Håkon Jentoft to conclude that in relation with the Optibag introduction “10% of efforts are technical and 90% communicational” of nature (Jentoft, 2015).

Further information about the social impact is given by the quantitative monitoring data *sorting rate and purity*. If the sorting rate is 100%, all participating residents put the totality of their biowaste in the designated bin and prevent every kind of other material from it. Thinking of leftover food in packaging or the already indicated mixed-material yoghurt pot, this is currently impossible in practice. Hence, the 70% sorting accuracy monitored in Linköping has to be understood as 70% of the amount of the actual realistic potential. With this in mind, it is a lucrative result and indicates that the biowaste separation is easy to understand and to implement. This is further confirmed by the fact that the immediate sorting rate in the first year of introduction of the green biowaste bag was 60% (Böök, 2015). At the same time, this poses the question how the sorting accuracy could be further raised to significantly higher results in the future at all.

It would be an oversimplification to translate the achieved sorting results directly into the individual’s personal conviction that the Optibag sorting is reasonable and necessary. In order to gain an insight in the personal awareness it is useful to collect qualitative data in from surveys. In light of the Optibag collection’s high dependence on the consumer’s sorting accuracy and the multitude of influential factors (cf. *2.4*), this is even more important. Yet, it has to be stated that this public inquiry was not conducted in a sufficient manner by the investigated municipalities but rather on a sample basis. A mail-based survey was conducted in a pilot area in Eskilstuna before the adoption of the system on a larger scale. It shows that the results for extrinsic and intrinsic motivational forces are very close to each other. While

[25] Further illustrations of the communicational and educational material distributed in the investigated cities are provided in *Appendix E.*

47% of respondents say it is easy to organise the sorting at home and with simple changes they could sort more in a *convenient way*, 37% respond that they only separate their waste because the municipality wants them to do so (Schulz, 2015). On the contrary, comparative surveys in Oslo revealed that only 11% rated the prevailing waste management a "convenient system" in 2010. In 2013, one and a half years after the Optibag introduction, this percentage had risen to 56% (Jentoft, 2014). This indicates that those residents who engage in waste separation welcome a coherent citywide system that gives guidance how to sort the own waste in a correct and easy manner. In fact, 59% of respondents believe that their contribution at home makes sense because the waste is recycled after collection (ibid.). From the little data available, it can be concluded that in the course of implementation, the rationale of the multi-bag source separation is more and more understood and supported. However, with the statistical results revolving around 50%, it cannot be stated that the implementation at home is immediately perceived as convenient.

One important aspect to mention is that the reported high participation rates likewise stem from empirical surveys. A comparison with the factually measured separation accuracy indicates that the citizen's own declaration of commitment is highly divergent from the real action. If 81% of all residents in Oslo were really separating their waste as they state, the sorting rate of biowaste would certainly have to be higher than 40%.

Limitations – This investigation does not claim to be exhaustive. The scope of research is personal consultation of employees from the waste management companies, the municipalities and the company *Envac Optibag AB* in conjunction with official publications. The results are based on the waste management company's own monitoring and reporting. Accordingly, the data is not verified by an independent party and is not tested to fulfil the scientific survey quality standards.

Furthermore, as the three cities changed to the Optibag system in 2011, its evolvement and all developments took place in the timeframe of maximally five years. Regarding the fact that it is principally hard to discern clear trends in waste generation and collection participation due to the high volatility that is substantiated by many different factors, this period is too short to derive general statements. Similarly, it makes a difference whether results are considered in isolation or compared to the separation history of other waste streams. For instance, the establishment of glass and paper separation in the Netherlands took about 20 years to reach the recycling rates of 60-80% that can be observed today (Nedvang, 2014).

Yet, for the first time, this comparison provides substantial insight in the implementation of the Optibag system and therefore enriches the discussion about the practical implications of source and post separation. Although the explanations above indicate that one should be cautious with deriving conclusions from the bare figures, the overall question about the Optibag system's CWM performance to date can be answered with:

Less waste?	generally no, biowaste yes
More resources?	definitely yes
Less environmental impact?	yes, both concerning treatment and transport
More value for money?	yes
More awareness?	little research, rather yes

5.5 Optibag in Amsterdam – results from the pilot in Zuidoost

One insightful method to scrutinise the practical feasibility of a new waste collection system in the whole city is to conduct a pilot project on a small scale. If prepared and implemented elaborately, such a test gives indications about complications and citizen's reactions that cannot be anticipated in a calculation model but only reveal in real life implementation.

Context – The Optibag pilot in Amsterdam took place within the framework of the EU-funded research programme *WASTECOSMART* under the theme "Optimisation of Integrated Solid Waste Management Strategies for the Maximisation of Resource Efficiency". Within this frame, a MCA and a subsequent sensitivity analysis were conducted to determine, which of four different waste collection scenarios from complete mono-streams to different multi-stream combinations would be most beneficial and worth to be tested. Based on this data it was decided that the cheapest and most effective alternative would be a combination of the existent mono-streams with an additional multi-stream for the separate collection of recyclables. After a site visit in Oslo and consultations with the company *Envac Optibag*, the choice fell on the Optibag system.

Intention – Neither own quantitative targets were determined beforehand, nor the city's ambition of 65% waste separation by 2020 should be directly transferred to the pilot. The declared aim was to gather qualitative data. Accordingly, the following questions should be answered (Vringer, 2015):

- What are the main reasons for participation and non-participation?
- How many different streams are practicable and accepted by the residents?
- How do the residents organise and perceive the separation at home?
- Do the assumptions made in the MCA proof in reality?

Considering that the four big cities in the Netherlands clearly lag behind in waste management recycling, the pilot should furthermore help assess whether this multi-stream collection is a feasible system for densely-populated urban areas (ibid.). For this reason, a challenging area was chosen for the pilot, the so-called T-Buurt.

In these four streets in the Zuidoost district of Amsterdam, about 740 citizens live in 350 small flats within four-storied multi-family apartment buildings without a lift. The proportion of foreigners compared to Dutch natives is estimated at 70%, which is well above the Amsterdam average of around 50%, the diversity of nations is high (O+S Amsterdam 2013, p. 27). The amount of residents with a high education is exactly half as high as the Amsterdam average (18% compared to 36%, O+S Amsterdam 2013, p. 142). Apart from that, the separation rate of recyclable waste in this district is the lowest of all areas in Amsterdam. In 2012, it was measured to be 18% in Zuidoost. A pre-analysis in the T-Buurt resulted in again half of that, namely 9% (CREM, 2015). Hence, the motto was ‘if we can do it there, we can do it everywhere’.

Set up – A steering committee was founded to execute the pilot. The committee consisted of officials from the district Zuidoost, the waste management company AEB, the sustainability research bureau *CREM* and the consultancy *Onsburo*. The latter was involved in order to facilitate a third qualitative target that was agreed on within the framework of *WASTECOSMART*. The project should be realised with co-creation and direct citizen participation (Reus/Steenhuisen, 2015). For that, ten citizens of the neighbourhood were selected to form the “Klankbordgroep”. A “resonance group” of active residents who participate in the steering committee’s consultations about organisation and implementation of the pilot. Most importantly, they should act as ambassadors, providing help, guidance and motivation for the rest of the neighbourhood (ibid.).

The pilot was scheduled to run for six months, from May to November 2015. Six underground containers for residual waste and each one container for the mono-streams paper and glass provided the former waste disposal in the test area. For the Optibag pilot, six additional “value containers” were placed next to the residual waste containers. Unlike the approach in Scandinavia, the recyclable material should be collected completely separated from the residual waste on purpose. This should point out the value that is incorporated in the recycling streams. All 350 households were equipped with a similar starter package (see *Appendix F*). The four separate Optibag streams were:

- green: kitchen waste
- orange: plastic packaging & drinking cartons
- blue: newspaper & cardboard packaging
- red: textiles & small household items like electronics, kitchenware

Monitoring – The results from this *Optibag* pilot derive from an in-depth analysis on a small scale. Waste quantities were monitored in the dimension of waste bags collected per week and the sorting was conducted by hand at the district's local waste point. For this reason, the assessment is not incorporated in the comparison of the city-wide systems in *5.4*.

The quantities collected separately within the value containers developed in a slightly declining trend. Starting with around 200 bags and a total weight of 400kg per week in June, in the last weeks 120-150 value bags were collected in the designated containers. From the average 400kg "value waste" per week, one third have to be subtracted due to wrong sorting. The monitoring revealed that not only the coloured bags landed in the value containers but also random plastic bags, residual waste bags and completely loose components, like pizza cartons. Whereas no value bags were found in the residual waste containers (CREM, 2015a). This suggests, that the residents did not internalise the idea that the value containers should not be seen as waste dumps but as a repository for reusable materials.

Just like the results from Scandinavia, the quality of those waste materials that were collected in the separate bags was excellent. In week ten of the pilot, an in-depth analysis of the bag content was conducted. The purity of biowaste in the green bags was 95%, the blue bags were to 90% only filled with paper and cardboard items. The correct separation of plastic packaging and drinking cartons likewise turned out to be the most challenging task for residents. Around 80% of components in the orange bags were suitable for PPW recycling, the rest was hard plastics or other materials. Thus, the pilot proves Optibag's main assumption of obtaining high-quality waste streams to be true.

The separation rate, here the amount of separately collected recyclable material compared to the total amount of fine residual waste collected from the households, is 13%. Compared to the 9% that were measured initially in the T-Buurt, this is an increase of 45%. However, in this investigation it was also scrutinised, which of the components within the household waste could possibly be recycled with this particular system at all. A pre-analysis showed that if all fractions are considered, including those that would have to be brought to the waste points, 81% of the T-Buurt's MSW can generally be recycled. If only those fractions that are collectable with the Optibags are considered, the following diagram *Figure 7* shows that 65% of those are recyclable (ibid.).

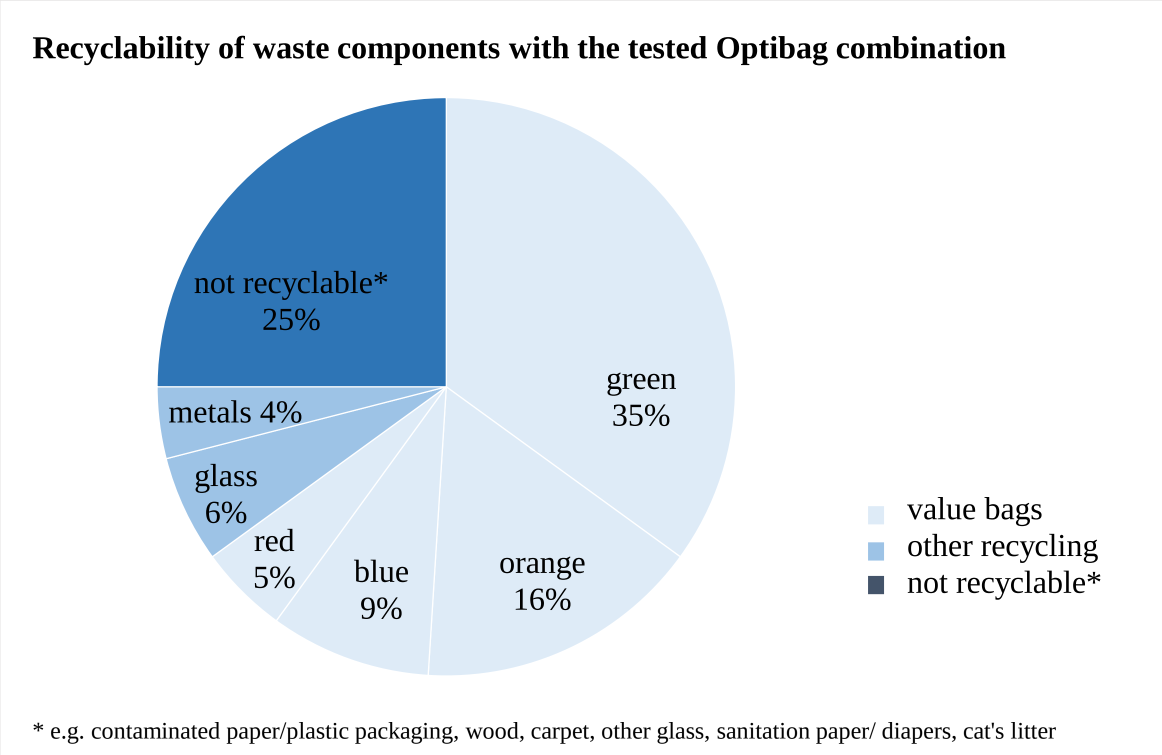

Figure 8: Recyclability of waste components with the Optibag combination tested in Amsterdam Zuidoost, own illustration based on CREM, 2015a.

If this is taken into account, the sorting rate of separately collected material compared to the total of actually recyclable material is 20%. Hence, only one fifth of recyclables is collected with the piloted Optibag system. That does not mean, however, that the remaining four fifth completely land in the residual waste. Direct consultation with the residents revealed that, resulting from the formerly limited recycling opportunity in the street, many residents developed a routine to bring packaging waste, textiles and batteries to the nearby shopping mall (CREM, 2015a). The magnitude of this factor cannot be estimated, as these quantities were not included in the pilot monitoring.

Participation – Several factors indicate that the overall awareness for the pilot project was low. About 10% of residents took part in the introductory meeting that was set up in form of a neighbourhood festival in May. A weekly question-and-answer-hour in the beginning phase was not frequented by a single person. The offer to pick up a biowaste bin free of charge at the local DIY market, where also new coloured bags could be attained, was accepted by 77 people. An analysis of the biowaste quantities, a stream that equally arises in all households, suggested that the overall participation rate lay between ten to 15% (Reus/Steenhuisen, 2015).

In a similar manner, the feedback gathered from a survey was limited. One month after the start of the pilot, a mail-based questionnaire was sent out to all 350 households. 31 responses came back for evaluation. Accordingly, the following survey results are not representative but rather indicative. The respondents estimate their participation three times higher than the figures monitored for the whole neighbourhood. 60% of the respondents say they participate in the Optibag collection, 22% of those at least partly. It was further asked whether the residents had already been active in waste separation independent from the pilot project. For each of the three streams paper, PPW and biowaste more than 50% of the respondents say they separate these materials completely from their residual waste (CREM, 2015a). This discrepancy speaks for the high probability that the same people who are motivated to participate in the separation trial are also willing to answer the questionnaire.

Concerning the question, why one should participate in such a trial that promotes source separation, the most frequent motivation factors are to separate waste "for the environment" or because it is "a moral imperative". The finding of exactly these two major reasons is statistically confirmed by a comparative study about waste management behaviour in private households (Midden 2015, p. 3). On the contrary, the reasons for non-participation are very diverse. A majority says they had not been informed or they do not have enough space to organise the separation at home. Further arguments are "I cannot engage more in waste separation because of health reasons" or "too much work" (CREM 2015a). Apart from that, a lot of remarks were given about the practicability: The red textile stream is not deemed necessary, the blue bags should be bigger in size, more guidance is needed on how to sort the waste.

In essence, while the perceived convenience in relation to the coloured bags is questionable, one clear result of the citizen's consultation is that the residents find it the most convenient, the closer the waste containers are located to their homes (ibid.).

Communication – Due to the substantially lower participation than expected, the steering committee launched several communication measures during the pilot. A related webpage[26] should inform about separation achievements and provide a platform for exchange. Following the starter package, monthly newsletters with reports and updates about the project were sent to all households (see *Appendix F*). One of them included a lottery, incentivising the residents to attach a sticker to a value bag with the chance to win a 15€ voucher. Moreover, a personal door-to-door visit by the ambassadors in October should trigger increased participation. Despite the extensive communicational efforts, the statistical data indicates that these did not lead to an increase of participation throughout the pilot.

Limitations – The course of the pilot project lead to limited validity of results. While the crux of the matter clearly was the low participation, it is impossible to draw unequivocal conclusions why the resonance in the neighbourhood was so low. It can be stated, however, that several structural and executional errors negatively affected the pilot's success. The

[26] https://www.amsterdam.nl/reigersbos/afvalproef/

project was delayed by internal discussions about the usefulness of co-creation, as well as operational complications with the design and provision of the Optibags. One possible reason for the ineffectiveness of communication efforts is that measures were taken reactively, instead of having a proactive strategy for motivation in place prior to the start. Apart from that, the engagement of ambassadors did not result in the intended raised motivation. This can be explained by the fact that the ambassadors were not assigned by choice of the residents, but volunteered. Hence, they did not have a wide communicational reach as they were not acquainted before and were not recognised in their ambassador role.

Further impairment of results stems from the weighting activity of the value container content at the waste point. The workers in charge did not deliver entirely continuous data. Consequently, the statistical monitoring had to be corrected with extrapolations. Again, recalling the multitude of influential factors, in order to derive general conclusions from a waste collection pilot that highly depends on the participant's behaviour, the test period has to be at least one year.

Still, regarded from a meta-level, the absence of these managerial shortcomings alone would not have improved the participation substantially. Rather, the pilot reveals how difficult it is to trigger active involvement in a neighbourhood with the initially elaborated characteristics. In internal discussions, the low resonance was primarily explained with a low social cohesion among the residents of the T-Buurt. However, this argument is hard to measure, especially as no own empirical data was collected and analysed beforehand to support this hypothesis. While the statistical results for a correlation between socio-economic status and waste separation activity are not straightforward, evidence is given for a correlation of the latter with the accommodation type. Residents of single-family houses are more active in waste separation than those in apartment blocks, home owners separate more than tenants (Midden, 2015, p. 20). Despite the fact that the steering committee implemented many of the communicational and psychological measures that are recommended by Midden[27] (2015), in order to create motivation in a high-rise building area, the communication strategy was of little avail. In this regard, the personal consultation with the residents clearly showed that the factors, which influence their motivation, are highly diverse and therewith harder to stimulate than expected.

While the pilot delivered some quantitative and Amsterdam-specific insights, this complexity impedes to answer all questions that were raised in the beginning. This inevitably begs the question of what the use of choosing a challenging area is if then exactly this

[27] For instance, these measures are: give clear instructions and background information (starter package, in Dutch and English), give feedback (newsletters and updates on homepage), provide financial reward (sticker lottery), provide active role models (Klankbordgroep ambassadors) (Midden 2015, p. 36.

circumstance is pointed out to be the major influence factor for not achieving meaningful data from the pilot.

6 Conclusions from the case study – working out a scenario for Amsterdam

Optibag contributes to CWM – Returning to the meta-level, the case study shows that the Optibag source separation is a collection system that positively contributes to the ambitions of a CE. Its practical success, however, is not implicit but highly dependent on the right managerial realisation.

Many of the expected advantages delineated in chapter *5.3* and demanded by CWM prove true in practice. The amount of MSW quantities diverted from incineration and separated for targeted recycling are significantly increased in all cities. As the contact persons report, this high increase in recycling is achieved with comparably low extra costs. With little modification effort, compared to the introduction of alternative mono-stream collection systems, a reliable separate collection could be established for waste streams that were formerly not separated at all. With 62% overall recycling and a 70% biowaste sorting rate, Linköping yielded the best results by concentrating solely on biowaste separation. In Oslo, the system is running in large dimensions for PPW and biowaste, covering 340.000 households. Thus, Optibag is a potent method to improve recycling activities quickly in cities like Amsterdam, where the waste management system is still mainly designed for mixed residual waste collection.

At the same time, the fact that the technology used, the optical sorting line, concentrates on colour detection instead of material specialisation leaves room for future alterations. The low current quality yields from the Dutch post-separation lines show that this flexibility is an indispensable asset if the provision of usable waste material shall keep pace with the scientific progress. This is an important message for waste management companies like AEB if long-term investments are considered.

It also became apparent from the case study that the Optibag system cannot be appraised as the panacea for CWM. First, the quantity of waste generated in private households is subject to too many factors beyond the collection, like the overall economic development and consumption patterns, and could therefore not be affected by the system change. Then, the related positive environmental effect was not measured comprehensively. The fact, that the environmental impact is positive, is evident, but it cannot be pointed out with clear results from an ecological footprint analysis. Lastly, it would be presumptuous to claim that the change to Optibag was responsible for the generally high recycling rates in the Scandinavian cities. These stem from the long established bring system for recyclable waste, which embraces a comprehensive infrastructure of maintained recycling stations. Looking at it from the other side, however, it is difficult to further improve recycling amounts significantly with the old known bring-system. In this regard, the introduction of Optibag provides potential to take recycling yields to the next level. For instance by including new waste streams, as it happened with biowaste.

Notwithstanding the preceding elaboration, according to the author’s assessment, the Optibag system constitutes an enhancement towards CWM for the following two reasons. The major contributions for a more circular economy that have to be pointed out are the material quality of the obtained streams and the educational effect. While the actual costs and organisation of infrastructure have to be examined individually for every case, these two factors can be concluded as Optibag’ general advantages.

After all, what is most important for CWM is that waste materials are obtained in such a high quality that they are suitable for purposeful reuse. The one constant that was monitored as high and satisfactory from the beginning was the sorting accuracy within the Optibags. The purity was above 90% in all cases, even in the short-term pilot project. Regardless of the participation and actual amounts of recyclables obtained, this shows that those people who do participate, immediately do it in the right way. This is an important finding as it proofs that the system as such is effective. Knowing this, efforts can be concentrated on the question, how to reach the people. The Optibag system has the biggest effect on biowaste. While this fraction did not exist as a separate stream in former collection systems, the sorting purity was immediately close to 100% with the green Optibags. Even the generation of biowaste was reported to be declining, as smaller and separate bins in the kitchen made the residents aware of the food waste volume they produce. The high purity of the waste biomass captured with Optibag makes it highly fitting for the innovative treatment options that AEB plans to realise in the future. The earlier and the more quantities of waste biomass the waste management company can obtain itself, the better the business case looks for the realisation of one of the investments delineated in chapter *5.2*.

Within the course of this investigation, it was concluded that the aim of getting high-quality secondary resources could better be reached via source separation than post separation. In the same manner, Optibag demonstrates the superiority of source separation with regards to an educational effect. Since the ultimate aim of a CE is to eventually eradicate waste completely, the first step is to make normal citizens cease to see their post-consumption products as waste. Post separation encourages people to carelessly throw every material in one bin; it is irrelevant what happens with it afterwards. The expression “to throw away” literally underlines the image of getting rid of things that are from then on useless. On the contrary, if citizens “sort” their waste, this only makes sense if a purpose stands behind this action. By deploying the Optibags, citizens get the impression of preparing the contained materials to become new commodities. The private consumer is one active member, a secondary resource provider, in the economic cycle. The idea of circular use of separate streams is transported right into people's kitchens. In this sense, the Optibag system fits perfectly into the picture of a future CE. Further developing this idea, the simple system with hygienic brightly coloured bags especially has an educational effect on children. If they internalise the rationale in early years, a lot is won, as they will be the enablers of smart circular resource use in the future.

With this in mind, the bags' characteristics bear a lot of room for improvement. The resident's responses in the case study revealed that the disposal of paper and organic material in one-way plastic bags causes irritation and does not comply with the idea of strict recycling. The bags have to be further optimised, for example using reusable jute sacks for paper waste and completely biodegradable bags that can be digested with the biowaste. Again, the Optibag system provides flexibility to be improved and tailored to local conditions incrementally.

In essence, the Optibag system's big advantage is that it covers different factors at the same time, which are just as important for the realisation of a CE, as for the development of waste management companies: high flexibility, high practicability with low costs, high-quality resources and a social educational effect.

Convenience and additional enforcement – It is further demonstrated with the case study that all those effects only turn out positively if the new waste collection system is properly implemented. Especially the pilot project in Amsterdam Zuidoost showed that the Optibag method stands or falls by the participation of the people. In fact, the trial turned out to be rather a social study, without having been primarily designed for that. The participation did not exceed the first 16% of early adopters, who actually engage in innovations on their own accord as explained by Rogers' diffusion of innovation curve (Rogers, 1995). Although allegedly similar and multiple communication measures were implemented in both cases, only in the Scandinavian municipalities the large majority was reached.[28] In either way, the formerly described high claim of educational effect requires high initial efforts of communication from waste management. In the following, it shall be presented what it takes to make the Optibag source separation work in Amsterdam.

First of all, waste management should concentrate efforts on those factors that are influenceable with a local strategy at all. The Scandinavian cities managed to address these major factors[29] with a holistic strategy. First, preparation before the introduction of the new

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[28] It has to be stated, however, that so far none of the scrutinised cities succeeded in engaging the entirety of residents, including the laggards. Therefore, it requires long-term observation to derive an ultimate conclusion about the Optibag collection's universality.
[29] See *Appendix C*, Dahlén/Lagerkvist 2010, p. 579.

system is key. In Oslo and Eskilstuna, the message of the Optibag source separation's usefulness was brought into the citizen's subconsciousness already years before, by appealing advertising and related disguised messages in public places (Schulz, 2015a). Accordingly, in Oslo, 94% of the people knew the system before its implementation, which lead to high initial participation (Jentoft, 2015). Subsequently, the large-scale communication has to be accompanied by personal addressing. Thanks to the combination of an elaborate technological infrastructure and the prevailing accommodation type, in Eskilstuna communication was advanced to targeted customer-relationship-marketing. The disposal activity of every single-family household is monitored with RFID-tags on each private container and accessible via an online database. Residents receive direct feedback about their waste separation performance via messages that the waste collectors attach to the private containers (Schulz, 2015a). This mutual feedback leads to quick efficiency improvements and a feeling of involvement among the residents.

If furthermore several basic findings about the psychology of household waste separation behaviour are considered, large amounts of budget can be saved by targeted communication. Based on the extensive review of different scientific studies, Midden (2015, p.15) concludes that the individual separation activity arises from a combination of personal attitudes and social norms. In order to form the personal attitudes, the waste management authority should develop programmes for education about waste recycling and provide information in the starter package about what will happen with the waste after separation. For instance, 72% of the respondents in the T-Buurt state, now that they know about its recyclability, they are motivated to separate more of their plastic waste in the future (CREM, 2015a).

In order to reach a persistent change in awareness, it holds most potential to take the children as starting point. The aforementioned educational effect is achieved via school initiatives in Oslo and by introducing the waste separation guide in form of an ABC-learning book in the kindergarten in Eskilstuna (Schulz, 2015a). Fittingly, Hage et al. (2009) claims that residents will not prepare recycling at home if they are not aware of the problem. Their self-ascription has to be activated with targeted measures. One way of achieving this is using the force of normative influence, e.g. by instrumentalising peer pressure. The way the ambassadors in Linköping report about their own advantages from participating in the Optibag source separation and the open communication of achieved sorting benchmarks provide the necessary assurance that the own efforts are not in vain but that the collective is working towards a common good (Hage et al. 2009, pp. 157, 162).

However, regardless of moral norms and intrinsic motivation, several sources confirm that high convenience is the most effective factor to trigger the household separation activity. As the feedback from the T-Buurt pilot illustrates, especially in high-rise apartment blocks, the primary task that has be performed by the waste management company is providing a convenient infrastructure. More representative studies exemplify that reducing the distance to recycling containers can improve the disposal frequency by up to 50% (Midden 2015, p. 28; Hage et al. 2009, p. 162). In a Swedish experiment, the effects of education versus facilitating practicability are compared directly and it is shown that convenience prevails. While a first sample group provided with information about biowaste treatment did not change their behaviour, the separate food waste collection rose about 45% in a second sample group that was equipped with biowaste bins and guidance how to integrate them in the kitchen (Bernstad 2014, p. 1320).

In Sweden and in the city of Oslo, further convenience is provided by the design of the disposal sites. Other than the anonymous street containers in Amsterdam, most apartment blocks have a waste room, called “miljöhus”, which is right in the building and under supervision of the janitor (Fråne et al. 2014, p. 55). In rural areas, the waste haulers deliver new coloured bags home on demand. Hence, it proofs successful to bring the system’s utilities into the resident’s comfort zone.

Despite the success in the Scandinavian cities, all contact persons likewise perceive reaching all residents in multi-storey buildings as the biggest challenge. In that case, communication alone is not effective. This finding compels the implementation of hard factors like financial enforcement or legal obligation. The first step is to link the source separation system to the waste taxation via individual pay-as-you-throw tariffs (PAYT) for residual waste as applied in Sweden. More effectiveness can be expected from additional mandatory regulations. For example, the obligation to install a multi-compartment waste drawer in the kitchen counter can be incorporated in the lease contract for an apartment. Another idea is that if tenants within one apartment block pay together for the management of their waste, the interest for the neighbour’s separation behaviour and resulting group enforcement improves participation. In Amsterdam, it should be taken advantage of direct cooperation with the housing corporations, which maintain more than half of the apartment blocks in the city (CBS, 2011).

Summing up, the added value that is guaranteed over the long term by collecting high-value waste streams for marketable waste treatment outputs with the Optibag source separation outweighs the marketing and communication expenses that are necessary to get the system running by far, especially if certain behavioural patterns are analysed beforehand.

The next steps for Amsterdam – Which implications can now be drawn for the City of Amsterdam, regarding the currently ongoing revision of the waste collection system? Considering all factors that were discussed in the course of this paper, the best solution for the next step towards CWM in Amsterdam is a combination of source and post separation with Optibag.

This conclusion arises above all from the fact that the whole political strategy and municipal scope of action is geared for reaching the supreme target of 65% waste separation by 2020. Despite the positive effect of concrete numeric goals on the political agenda, a short glance in the practical case for Amsterdam shows, which actions such a goal requires in reality: If only about 73% of MSW from households is suitable for recycling with source separation, the participation would have to be as high as 90% of all residents separating their waste with 100% precision in order to reach the 65% separation goal. The case study in Scandinavia shows, that an increase of maximally 15% can be expected in the exact course of four years. Albeit the fact that the prior recycling infrastructure there had been even more elaborate than in Amsterdam now, the results indicate that such a drastic increase is not achievable with a source separation system alone, where behavioural and habitual factors play a decisive role.

The empirical data illustrates that the home separation of PPW requires most education and time and thus has the flattest growing curve of separation and sorting rate. In Amsterdam, the source separation for PPW in form of separate street containers is far from being mature, as the average separation lies at 8%. This means that the large majority of PPW still lands in the residual mixed waste. Consequently, the biggest leap forward towards higher-scale waste treatment is to capture this plastic material with a post separation installation. The existence of the waste fund remuneration financed by the packaging industry is a strong argument for realising PPW separation as soon, and in as large quantities, as possible. Further regarded from an economic perspective, for AEB as a waste management company the on-site post separation line guarantees to retain the waste ownership until then. This constitutes an important lever to maintain the strong market position in an industry that is more and more shifting to recycling before incineration.

The plastic post separation ensures to make the most of currently available material and revenues. Notwithstanding, in order to provide the highest possible secondary resource quality in the future, AEB's investment in the post separation line should be considered as a transitional solution from the beginning. The sorting mechanism should be designed in such a way that it allows subsequent modification into a flexible optical sorting line. Since over the long term, the subsequent introduction of more and more source-separated streams bears the greatest benefits for all stakeholders. In this regard, the Optibag system's flexibility should be exploited by developing a customised strategy for subsequent upscaling to multiple streams and the introduction of a PAYT tariff. Instead of overexerting the resident's sorting willingness with many streams at once, they should be triggered with one plausible stream first.

Henceforth, the concrete next step in Amsterdam has to be the introduction of a separate biowaste collection. The fact that all factors tested in the case study proved to be highly successful with biowaste constitutes a strong imperative to exploit this option as a guarantor for immediate success. Furthermore, as the building design in the inner city circle prohibits alternative separation methods like private composting in the backyard, the Optibag method offers the best solution. Concerning opportunities in waste treatment, obtaining source-separated biowaste enables AEB to upscale the described research projects along the biomass hierarchy into large-scale proofs. At the same time, if the wet organic matter is isolated from the residual waste fractions, this will substantially improve the quality of the dry materials yielded with the post separation line. This way, the disposal method would resemble the highly cost-efficient concept of the “dry container” (Trockene Tonne) tested in the German case study (cf. *2.4;* Janz/Bilitewski, 2011).

All the conducted research and monitoring signifies that in order to introduce a new system successfully, waste management has to consider economic and social influence factors in combination. Hage (2009, p. 164) suggests to deliver the new policy in a “package”, combining economic enforcement with the creation of moral obligation. This applies even more, regarding Amsterdam’s particular challenge to launch communication measures among its 88% high-rise apartment buildings. Thus, for Amsterdam it is a promising approach to combine the motivational force of ambassadors with the mandatory inclusion of waste separation in new buildings in the area of Buiksloterham. The pilot in Zuidoost exemplifies that efforts in a challenging area yield suboptimal results. Therefore, it makes sense to exploit the dynamic of innovation and green thinking that lifts off in Amsterdam’s Living Lab (cf. *4.3*). In Buiksloterham, new buildings are built with sustainability focus. Separate waste bins in the kitchen drawers would only be one among many innovative measures and would make the long accommodation times related to a change of personal routines obsolete.

Scaling up the ambassador function, Buiksloterham could become the role model for the whole city. The new resident’s intrinsic awareness for the relation between waste disposal and resource recovery can be assumed high. In the way it is already happening with other sustainability initiatives, a citywide communication campaign could focus on illustrating how effortless waste separation at home can be included into daily routines. After the word is spread, the extension of the source separation to further districts can begin.

7 Résumé

This paper confirms that the Optibag source separation generally contributes to waste management that promotes circular resource use. Furthermore, Optibag constitutes a viable solution for waste collection in the densely populated city of Amsterdam if certain important factors are considered with its implementation.

The practical cases in Scandinavia and Amsterdam Zuidoost yielded less numeric data records to serve for extensive calculations than expected. Consequently, the rather empiric depictions lead to the fact that the conclusions and recommendations of this work are likewise of a contextual character. Surprisingly, also the data collection on the European level is not regulated with a uniform model, but is a result of each country's individual measurement. For instance, in Dutch reports, waste separation rates are equated with recycling, regardless of which kind of treatment actually follows. Likewise, the way in which differing data processing can distort results is illustrated by the variation of Amsterdam's separation rate depending on whether bulky waste is incorporated in the calculation or not.

In addition, during the research it became apparent that scholars who develop waste collection models either focus on financial/technical or on social/psychological aspects. In this regard, the research field would be enriched by a scientific investigation and the development of a model that shows how all relevant factors can be addressed holistically.

This elaboration shall contribute to the learning curve of companies and municipal bodies in the sector on how to develop waste management into a circular future. In particular, it can be used as a knowledge base and a guideline by major cities like Stockholm and The Hague, who are currently considering a systems change to Optibag for the near future. Similarly, for Amsterdam the process is ongoing. The next pilot should investigate the effect of combining participatory Optibag collection with financial or legal enforcement.

Ultimately, the present analysis on a small scale leads back to general questions that will have to be addressed in the future. Taking up the idea of private consumers being a link in the resource chain – would not the certainty of direct remuneration motivate the individual to deliver cleanly sorted waste material instead of a punishment with higher waste fees for non-compliance? How would such a system be harmonised with central waste management services? Before posing these questions, the impressive multitude of purposeful waste treatment technologies that lies ahead has to be brought to the public knowledge in order to achieve sweeping understanding of the purpose that stands behind MSW separation.

After all, closing the loop of this work, all the progress on waste separation and material processing can only substantially contribute to a CE if legislation and producers acknowledge the added value of SRM.

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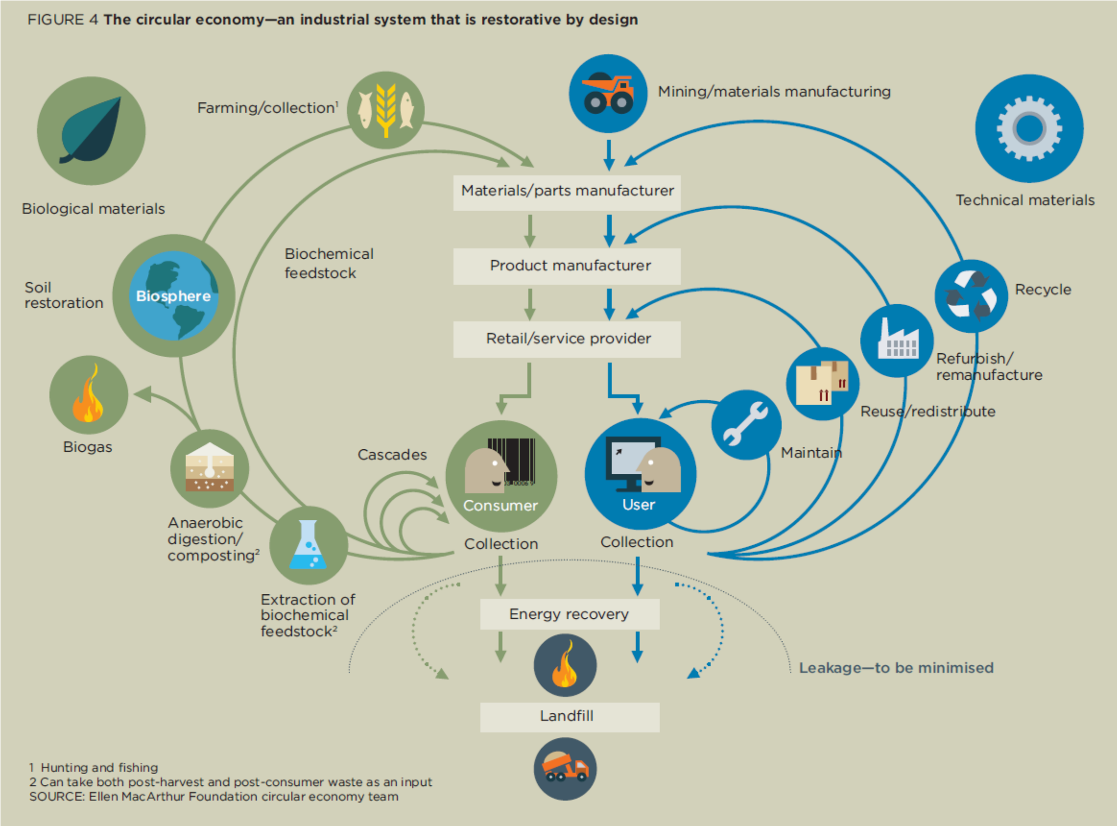
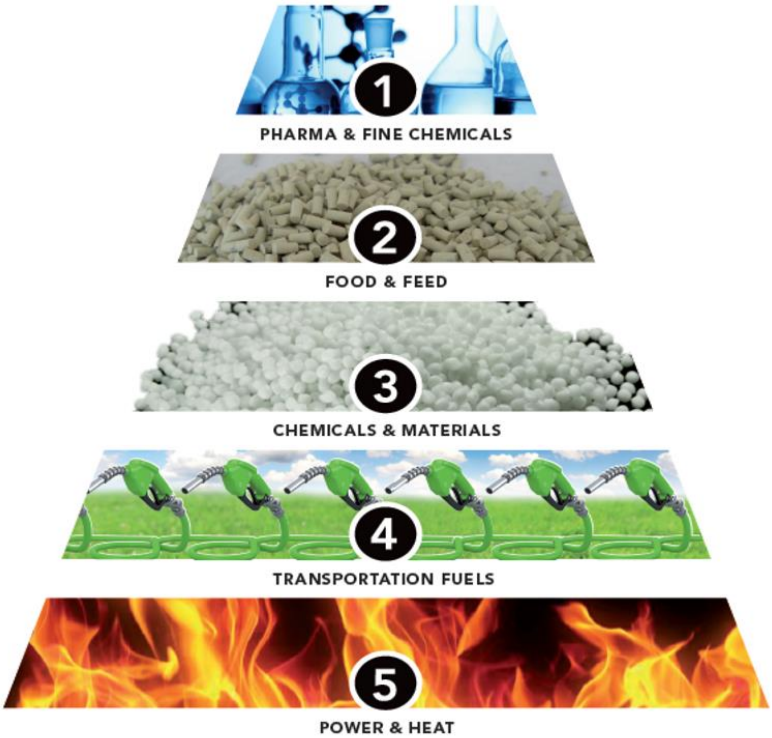
9 Appendices

Appendix A: Ellen Macarthur's model of a technical and biological resource flow, Ellen Macarthur 2014, p.15.



Appendix B: The AEB Amsterdam biomass hierarchy, prioritising the value creation in relation to different recovery and treatment alternatives for biowaste.



Appendix C: Factors that can and cannot be controlled by a local waste management strategy; the factors underlined in grey have direct influence on waste sorting activities, Dahlén/Lagerkvist, 2010, p. 579, Table 1.

Factors that can be controlled by local/regional waste management strategies	**Factors that can be controlled by national waste management strategies**	**Factors that are beyond the control of waste management strategies**
Accepted level of operating costs	Level and type of financing that is accepted and legal	Production and consumption rate (GDP)
Waste management objectives	Legislation (*e.g*. producer responsibility)	Household economy; employment status of adults
Technical design of collection equipment and vehicles	National economic incentives (*e.g*. waste taxes)	Residential structure:
Types of waste materials collected separately	Environmental objectives (*e.g*. recycling targets)	• household size
Mandatory or voluntary recycling program	Levels of public education and awareness of waste issues	• property type (*e.g*. single-family, multi-family, size and type of yards, *etc*.)
Design of collection charges; economic incentives		• tenure • urban/suburban/rural areas
Information strategies and clarity of sorting instructions		• heating system (solid fuel used for private heating) • stability and networking in the neighbourhood
Education program (*e.g*. school programs, media)		Family life cycle; age of household members, number of household members at home daytime, number of males/females
Provision of indoor equipment for sorting (*e.g*. bins under the kitchen sink), and if so, types of equipment		Frequency of small-scale businesses in homes
Encouragement of private composting (*e.g*. providing composting equipment and/or instructions)		Weight and frequency of newspapers in the region
Types of waste material collected close to property (kerbside) • Convenience and simplicity of collection schedules • Types of bins and/or sacks • Provision of waste bins/sacks		Frequency of pet ownership Frequency of car ownership Frequency of freezer ownership Other cultural and socio-economic differences
• Ownership of and cleaning responsibility for bins Types of waste material collected with bring system (drop-off collection)		People’s varying behaviour when all other factors are identical
• Convenience of location of drop-off points (natural thoroughfares, distance from homes) • Function and attractiveness of drop-off points		Seasonal variations (*e.g*. tourism) Climate
Availability of alternative places for discharge (*e.g*. recycling centres)		
Administrative management of the collection systems (*e.g*. co-ordination in the region, operator ownership)		

Appendix D: Questionnaire about the Optibag waste collection practice in Scandinavia.

QUESTIONNAIRE - OPTIBAG WASTE COLLECTION SYSTEM IN SCANDINAVIAN CITIES

INTRODUCTION STAGE:

- **initial situation:** inhabitants, waste composition, prior collection system

- **scope:** households covered, main type of buildings (apartment blocks or family houses), vehicle fleet, capacities of sorting line/incinerator/biogas plant

- **infrastructure:** which preparatory changes in collection technique had to be made? (container size/location, hauler frequency, employees)

- **how was the introduction promoted in public?**
  - marketing campaigns/ information meetings
  - involvement: did residents have a say in decisions, e.g. which different streams?
  - (financial) incentives for participation?

- **costs:** initial investment costs (CAPEX/depreciation optical sorting line)
  - distribution of coloured bags (for free/charged from residents?)
  - marketing costs for communication
  - unexpected cost factors?

MONITORING:

- **development over time:** increase/decrease in…

…separation rate:
  - quantity of total waste generated
  - quantity per stream (less residual waste? Higher recycling rate?

…participation rate
…purity/quality of waste streams

…operational costs
  - did the collection become more efficient?
  - are truck loads filled to maximum capacity/could hauling frequency be decreased?

- **output:**
  - materials recycled (how is each stream used/final disposal?)
  - biogas/electricity/heat generation outputs from plants

- biggest drawbacks? Handling problems, e.g. concerning waste bag quality/size?

PARTICIPANT'S FEEDBACK (DATA FROM INTERVIEWS, SURVEYS):

- demographic features of participants (in pilot area, e.g. age, family size, income, profession)
- pace of rise in awareness/ knowledge about correct waste separation
- Do they understand the rationale behind waste separation? Do they have trust in the system?
- reasons for (non-) participation, satisfaction, convenience

ENVIRONMENTAL IMPACT:

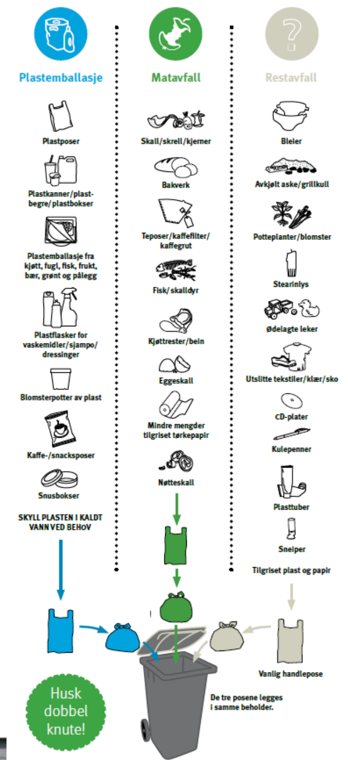
Were there environmental benefits noticeable? E.g. change in CO_2 emissions, more hygienic, feedback about cleaner neighbourhood/less inappropriate disposal (in open spaces, next to containers, toilet)?

Considering the whole project: what did you consider the most critical success factors?

Appendix E: Communication material from Eskilstuna, Linköping and Oslo accompanying the introduction of the Optibag waste collection.

Eskilstuna

Linköping

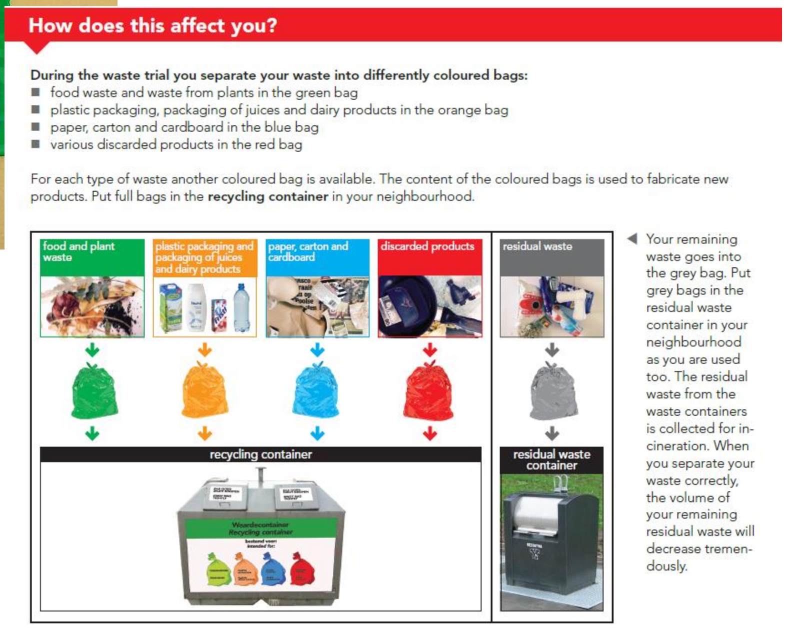


Oslo

Appendix F: Communication material accompanying the Optibag collection pilot project in Amsterdam Zuidoost.

Content of the starter package for each household

Sorting guide in English



How does this affect you?

During the waste trial you separate your waste into differently coloured bags:

- food waste and waste from plants in the green bag
- plastic packaging, packaging of juices and dairy products in the orange bag
- paper, carton and cardboard in the blue bag
- various discarded products in the red bag

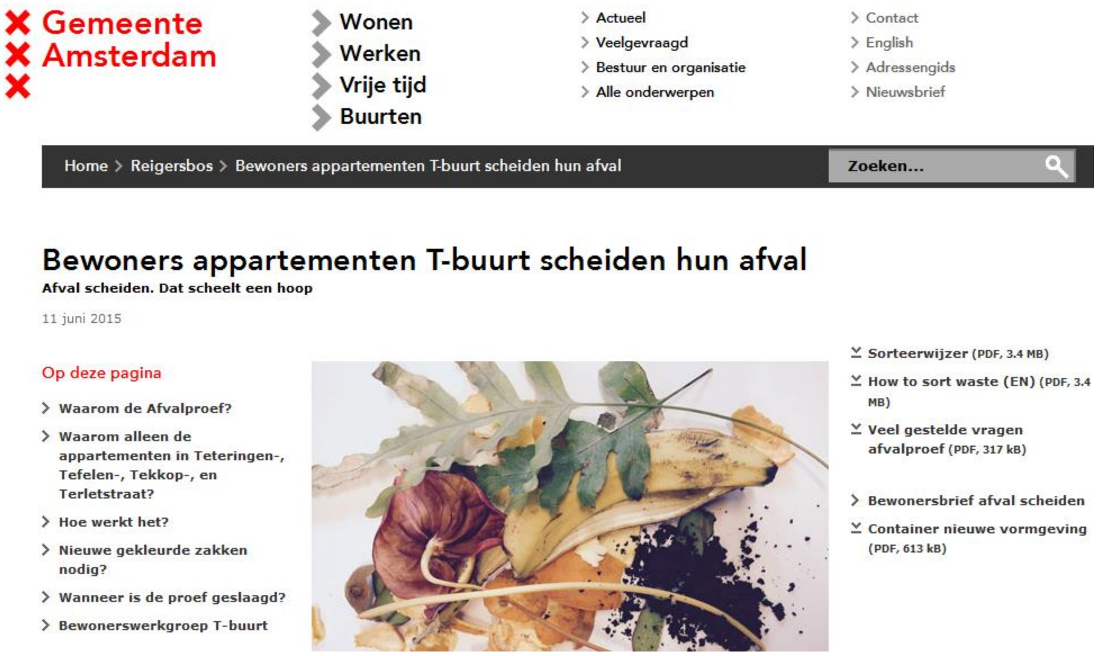
For each type of waste another coloured bag is available. The content of the coloured bags is used to fabricate new products. Put full bags in the **recycling container** in your neighbourhood.

food and plant waste | plastic packaging and packaging of juices and dairy products | paper, carton and cardboard | discarded products | residual waste

recycling container | residual waste container

Your remaining waste goes into the grey bag. Put grey bags in the residual waste container in your neighbourhood as you are used too. The residual waste from the waste containers is collected for incineration. When you separate your waste correctly, the volume of your remaining residual waste will decrease tremendously.

Webpage



Gemeente Amsterdam

Wonen | Werken | Vrije tijd | Buurten

Actueel | Veelgevraagd | Bestuur en organisatie | Alle onderwerpen

Contact | English | Adressengids | Nieuwsbrief

Home > Reigersbos > Bewoners appartementen T-buurt scheiden hun afval

Zoeken...

Bewoners appartementen T-buurt scheiden hun afval

Afval scheiden. Dat scheelt een hoop

11 juni 2015

Op deze pagina

- Waarom de Afvalproef?
- Waarom alleen de appartementen in Teteringen-, Tefelen-, Tekkop-, en Terletstraat?
- Hoe werkt het?
- Nieuwe gekleurde zakken nodig?
- Wanneer is de proef geslaagd?
- Bewonerswerkgroep T-buurt

- Sorteerwijzer (PDF, 3.4 MB)
- How to sort waste (EN) (PDF, 3.4 MB)
- Veel gestelde vragen afvalproef (PDF, 317 kB)
- Bewonersbrief afval scheiden
- Container nieuwe vormgeving (PDF, 613 kB)

Erklärung

Hiermit erkläre ich, dass ich die vorliegende Bachelor-Thesis mit dem Titel

„**Innovative waste management for a Circular Economy in the Netherlands – Assessing the potential of a multi-stream waste collection system for the city of Amsterdam**“

selbstständig verfasst und hierzu keine anderen als die angegebenen Hilfsmittel verwendet habe. Alle Stellen der Arbeit, die wörtlich oder sinngemäß aus fremden Quellen entnommen wurden, sind als solche kenntlich gemacht. Die Arbeit wurde bisher in gleicher oder ähnlicher Form in keinem anderen Studiengang als Prüfungsleistung vorgelegt oder an anderer Stelle veröffentlicht.

Trier, den