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MSW in a Circular Economy: 2020 - 2035 Scenarios for the City of Oslo, Norway

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Abstract. The unfolding of Circular Economy principles will have consequences on the generation rate, amount, and composition of Municipal Solid Waste (MSW) as well as the preferred methods to treat them. In this work, four plausible scenarios on the future of MSW for the period 2020 – 2035 have been developed for the City of Oslo, Norway. The scenario's consequences on (1) MSW amounts and properties and (2) the treatment methods, i.e. Waste-to-Energy (WtE), material recycling and biogas production have been evaluated. The main results can be summarized as such: (1) the evolution of both population and consumption (i.e. waste generated per inhabitant) will have a large impact; (2) meeting EU material recovery target (65% for MSW in 2035) means that several waste fractions have to be recycled at high levels, and this will be challenging without significant logistical and/or treatment capacity changes and/or technological breakthroughs, (3) in 2 out of 4 scenarios, the biogas production capacity must be expanded with a new plant to reach the 65% recovery target, (4) a "business as usual" approach is not sufficient to reach the recovery targets, (5) the combustion properties of MSW to WtE will be affected by increasing recycling, probably towards lower energy contents and higher ash contents and (6) "what-if scenario" studies should be carried out at the city/regional level as specific constraints must be included to bring valuable information.

1. Introduction

The core of the EU approach concerning waste management has been based on the Waste Framework Directive (WFD 2008/98/EC) and the Waste Hierarchy. However, since 2015, focus has shifted from a Linear Economy to a Circular Economy that should be more resource-efficient, promoting, among other things, re-use, material recycling and secondary raw materials. The EU Circular Economy Action Plan [1] is part of the larger EU Green Deal [2] to reach a sustainable society. It is clear that transitioning towards a more Circular Economy will affect most sectors of the economy and society at large, including current Municipal Solid Waste (MSW, a mixture of household waste and similar Commercial & Industrial waste) management systems that are currently based on composting, Anaerobic Digestion (AD) (to produce a biogas and possibly a fertiliser), material recycling (for paper products, metal, glass and plastic) and Waste-to-Energy (heat and/or power production). The essence of the Circular Economy action plan related to MSW management can be described with a few key actions and targets:

- Attain 65% material recycling/recovery rate for MSW by 2035 with specific targets in the Packaging Directive [3]
- Separate collection and treatment of specific waste fractions such as food and textiles
- Reduce food wastage



The way towards integrating and enhancing Circular Economy will be affected by the regulatory framework but also societal evolution (population and consumer/citizen behaviour for example) and technological development, both improvements of existing technologies and the appearance of new technologies.

A few studies have been carried out at the national and European level to understand what this transition will require in terms of waste treatment system, especially concerning overall waste treatment capacities for material recycling and WtE [4-7]. These studies provide interesting results on the overall development of MSW, WtE and material recovery. However, they often focus on parametric, i.e. low – medium – high scenarios with little details on specific waste fractions. Also, they do not often discuss factors such as socio-economic behaviour and technological aspects. Furthermore, studies at national or international (European) level, hide many different local situations. We believe that there are two elements that can be improved for such studies: (1) the right geographical resolution in order to extract results detailed and accurate enough to support industrial actors and decision-makers in their actual planning of future waste systems is at the city/regional level, not the international or national level as many local specificities must be taken into account for the results to make sense and give meaningful insights, (2) furthermore, these studies should consider the fate of all and each main waste fractions constituting MSW, e.g. paper, plastic, food, etc.

In this work, several scenarios have been defined with different boundaries concerning multi key factors. The study concerns the MSW collected and treated under the responsibility of the municipal entity responsible for household waste and some C&I waste (acronym REG) for the City of Oslo, Norway. The focus and novelty of this work have been to predict changes of amounts and properties (composition, energy content, ash content) of waste going to WtE as Circular Economy is unfolding under different boundary conditions. The key factors considered for conducting the scenario analysis include the increase of material recycling rate to reach Circular Economy recycling targets, population evolution (total number of inhabitants) and consumer behaviour (the amount of waste generated per inhabitant per year) but also technical/logistical/system considerations such as the implementation of new technologies or plants relevant to Oslo.

Practically, the amount and composition of waste was evaluated up to year 2035 on a yearly basis for the waste processed by REG. This was done according to specific conditions set in each individual scenario, usually assuming linear or fixed increase/decrease yearly steps to reach set goals/values between in 2035. Many valuable information can be derived concerning waste management systems from such scenario work, e.g. necessary treatment capacities, limitations/bottlenecks in the existing system, technical and non-technical challenges, etc. The availability of comprehensive and detailed statistical data concerning the current and historical situation is important to ensure suitable accuracy. Therefore, the lack of good data in many countries will make such studies difficult.

The last element of this work is to determine key combustion properties of the future MSW going to WtE to evaluate effects on operation and energy production. The goal of this work is not to predict and investigate all "plausible" futures but develop a simple methodology to quickly evaluate any "what-if" scenarios that actors in the sector might want to evaluate for a given city/region. It is important for actors in the waste sector to understand how the implementation of Circular Economy may affect the whole value chain as this will impact their development strategy especially concerning future investments and might offer both challenges and opportunities. This work is a first step in this direction.

2. Methodology (the scenarios)

The overall methodology can be described as such:

- (1) Detailed description of the current situation (2019) using data from REG and Statistics Norway
- (2) The scenarios' main frameworks are defined: the goal(s) to be reached by 2035, the yearly evolution of the population, the yearly evolution of the MSW generation rate per inhabitant (translating customer/citizen behaviour and wealth)
- (3) The scenarios' specific events (significant changes in the system) are defined and implemented at given dates

Given the specific conditions, the following results can be deduced for each year between 2020 and 2035: total MSW amounts and compositions (main fractions and residual waste) and MSW amounts to the different treatment methods for each year; these are obtained assuming linear evolution between 2020 and 2035 to attain the defined goal(s) and adjusted for specific scenario events whenever necessary. The main combustion properties of MSW going to WtE (i.e. energy content and ash content) can also be estimated. An Excel-based calculation tool has been developed to carry out the calculations. The tool does not claim to be a comprehensive model but aims mainly at approximate yet plausible quantifications on amount and properties of MSW for discussions on the future of MSW treatment.

Table 1 summarises the Circular Economy goal, main framework (using Statistics Norway data), and specific events/comments for each scenario. The rationale behind each scenario is as such:

- Scenario 1 – Consumption (and hence waste production) has been stabilised. 10-year average for population evolution.
- Scenario 2 – Customers have integrated Circular Economy principles and are reducing their consumption (and hence waste production). 10-year average for population evolution.
- Scenario 3 – As scenario #1 for main framework. Plastics material recycling will take place in Norway from 2025, not abroad as today. Rejects from material recycling (estimated to 50% of the amount of plastic sent to material recovery) will be incinerated in the local WtE plant.
- Scenario 4 – "Business as usual", i.e. the framework is based on 5-year average values without targeting any Circular Economy goal.

Table 1. Key features of the scenarios

Scenario	Circular Economy goal	Main framework	Specific events/comments
#1	65% material recycling target in 2035*	Population: +1.85%/y MSW generation rate: +0%**	None
#2	65% material recycling target in 2035*	Population: +1.85%/y MSW generation rate: -2%**	None
#3	65% material recycling target in 2035*	Population: +1.85%/y MSW generation rate: +0%**	Plastic recycling plant in Norway from 2025***. Rejects (50%) to local WtE.
#4	None	Population: +1.50%/y MSW generation rate: -3%** Material recycling rate: +1.4%/y	"Business as usual" - historical average data over 5 years for framework

* Material recycling includes here material recycling, composting and anaerobic digestion (AD, biogas + fertiliser).

** kg/per inhabitant/year.

*** Plastic material recycling is currently taking place abroad.

3. The results

A variety of data can be derived from the four scenarios investigated. Selected data illustrating key trends and important results are presented here.

3.1 The current situation (2019)

In 2019, approximately 242 ktons MSW were produced in Oslo, out of which 209 ktons household waste. In addition, REG collected 32 ktons commercial and industrial (C&I) waste. In Oslo city, there is one of the world's most advanced optical sorting plant for treating household waste. The food waste and plastic waste are sealed in green and blue bags respectively at each household and thrown into the garbage bin. After being collected and delivered to Haraldrud sorting plant, green bags containing food waste and blue bags containing plastic waste, are separated by optical recognition. The separated food waste is sent to produce biogas and fertiliser in the Romerike biogas digester. The plastic waste is delivered to plants abroad for further sorting, separating and material recycling. After optical sorting, the remaining household waste is delivered to incineration for energy recovery at Haraldrud WtE plant.

As shown in ta 1(A), 39% and 58% of the household waste were sent to material recycling and energy recovery (WtE), respectively. Figure 1 (B) shows the composition of MSW received for energy recovery. Household waste to WtE contains significant proportions of food waste (28%), wood waste (13%), plastic (9%) and paper (7%), which have distinct combustion properties. Additionally, there is about 27% of household waste that does not belong to any category shown in the Figure 1(B), which is categorised as rest. This part of the waste is a complex, heterogeneous mixture that is difficult to characterise. In addition, there is no detailed analysis on properties of the C&I waste fractions.

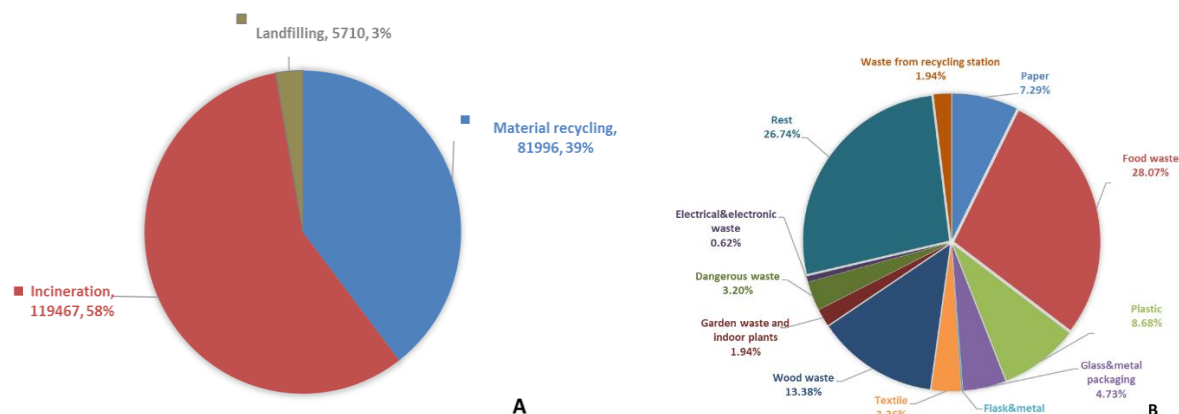


Figure 1. (A) Household waste in 2019 in Oslo; (B) Composition of Household waste to WtE.[8-9]

3.2 MSW total amounts

Figure 2 presents the evolution of the total amounts of MSW for scenario #1 to #4. All cases can be observed: decrease – increase – stability. Scenario #1 and #3 show an increase from ca. 240 to ca. 325 ktons/year in 2035; in scenario #2 the total MSW amount remains stable, while in scenario #4 the amount of MSW is decreasing to reach ca. 205 ktons/year in 2035.

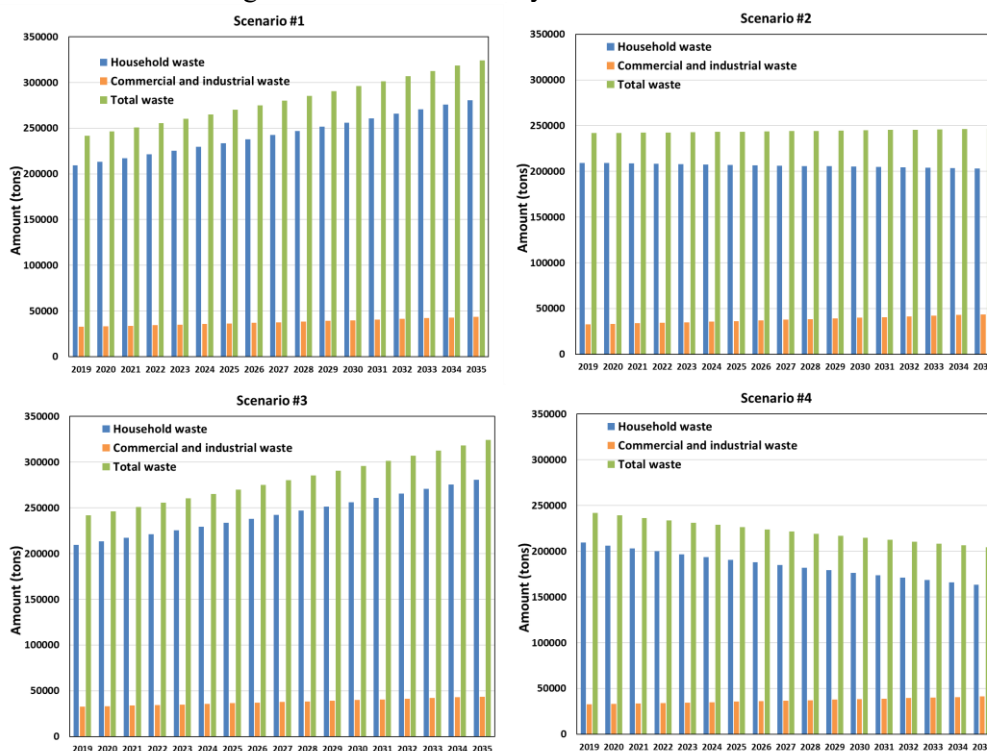


Figure 2. Total MSW amounts for all 4 scenarios in 2020-2035.

3.3 MSW treatment methods

Given the scenario-specific goals, events and framework conditions, it is possible to calculate the evolution in terms of amounts of MSW processed by the various treatment methods. Figure 3 presents the results for scenario #1, #2, #3 and #4. The 100 000 tons line represents the nominal capacity of the WtE Haraldrud plant operated by REG Oslo.

In all scenarios, the WtE capacity necessary will decrease over time but not to the same extent. It is worth to notice that the 2035 required WtE capacity will stay rather close to the 100 000 ton/year line, either 114, 103 or 86 ktons/year. This shows that, under the plausible futures mapped out in this study, a WtE capacity like the one currently installed should probably be maintained in the coming 15 years. In scenario #2, a governing trend is the decreasing production of MSW per inhabitant over the 2020 – 2035 period. This trend could be observed in the long term, also as wealth is increasing, even though the decoupling between GDP growth and waste production is far from being self-evident, if citizens were to change their consumption patterns because of a strong environmental conscience and the integration of Circular Economy principles in their habits. This will require active (and probably costly) campaigns as the one carried out in Oslo city when separate collection of food waste from households (to produce biogas and fertiliser) was initiated in the 2010s. This could manifest as more repair, re-use (second-hand clothes for example) or simply reduced consumption. Interestingly, the 2025 events in scenario #3, i.e. a new plastic recycling plant in Norway (with the rejects being incinerated locally), are barely noticeable when considering the overall system even though it can be said to lead to significant logistical changes, requiring careful planning and investments. Scenario #4 is a different proposition altogether as this scenario does not attempt to reach any specific goal but proposes a "business as usual" alternative and hence uses average values (over the last 5 years for Oslo) from Statistics Norway concerning the increase/decrease of the population, the waste generation rate and the recycling rate (see Table 1).

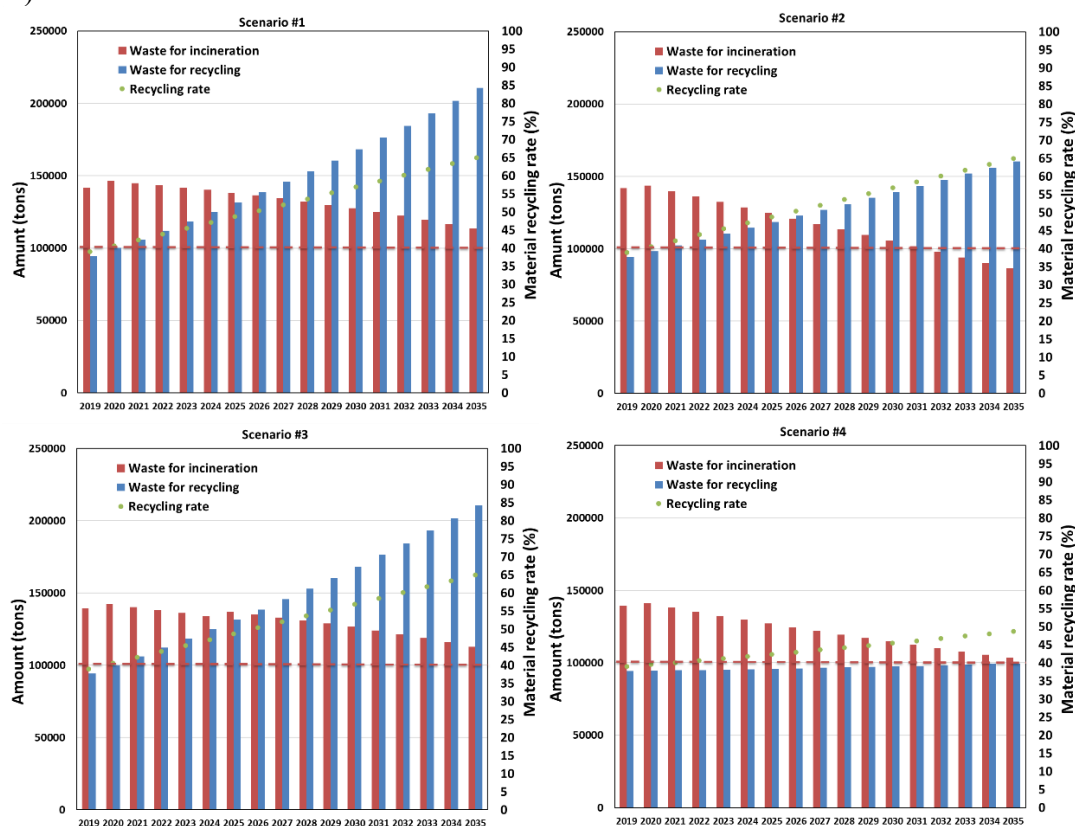


Figure 3. MSW to recycling and incineration from 2020 to 2035 for the four scenarios.

Figure 3 shows two important features of this "business as usual" scenario #4: (1) the last few years, the total amount of waste collected per inhabitant by REG Oslo could decrease faster than the population growth, a trend (if persisting in the future) leading to a significant decrease in the total amount of waste by 2035 as already mentioned. This is a rather positive evolution concerning resources and climate change even though it may be said that the Circular Economy principles have barely started to infiltrate the general public and the decision-makers so the actual cause(s) of the decrease is (are) complex; and (2) the pace at which MSW recycling rate is currently increasing is too slow as the final number calculated for 2035 would reach 49% in scenario #4, a long way from the 65% target. It is a clear signal that a *laissez faire* approach is not appropriate. Efforts should be intensified to accelerate the evolution of material recycling if targets are to be attained. Concerning WtE in scenario #4, the required capacity in the mid-2030s will be about 100 ktons/year, the nominal capacity of the Haraldrud WtE plant operated by REG (excess amounts can be handled in cooperation with other actors).

Further comments can set the results into perspective. Firstly, the average values used are based on datasets with large mean absolute deviations, e.g. for the recycling rate in scenario #4 (+1.4 %/year), its value is 2.7. This shows that the progress of material recycling is not linear and monotonous and that its value for a given year is difficult to estimate, large fluctuations including positive and negative values can happen. This may be due to a variety of factors (political, societal, logistical, etc.) often difficult to estimate quantitatively and that may be intertwined and short-lived. However, some events can be seen, e.g. the 2008 financial crisis was synonymous with a period of decreasing MSW amounts. Secondly, local conditions may vary significantly, e.g. the average yearly change in household waste amount for the last 5 years in Norway is -0.1% (with positive and negative values) while it is -3.0% for Oslo.

3.4 MSW fractions to recycling (i.e. material recovery, composting and biogas)

This section focuses on recycling of MSW fractions, namely paper, plastic and food waste. As previously mentioned, REG operates an optical sorting facility in the vicinity of Haraldrud WtE plant.

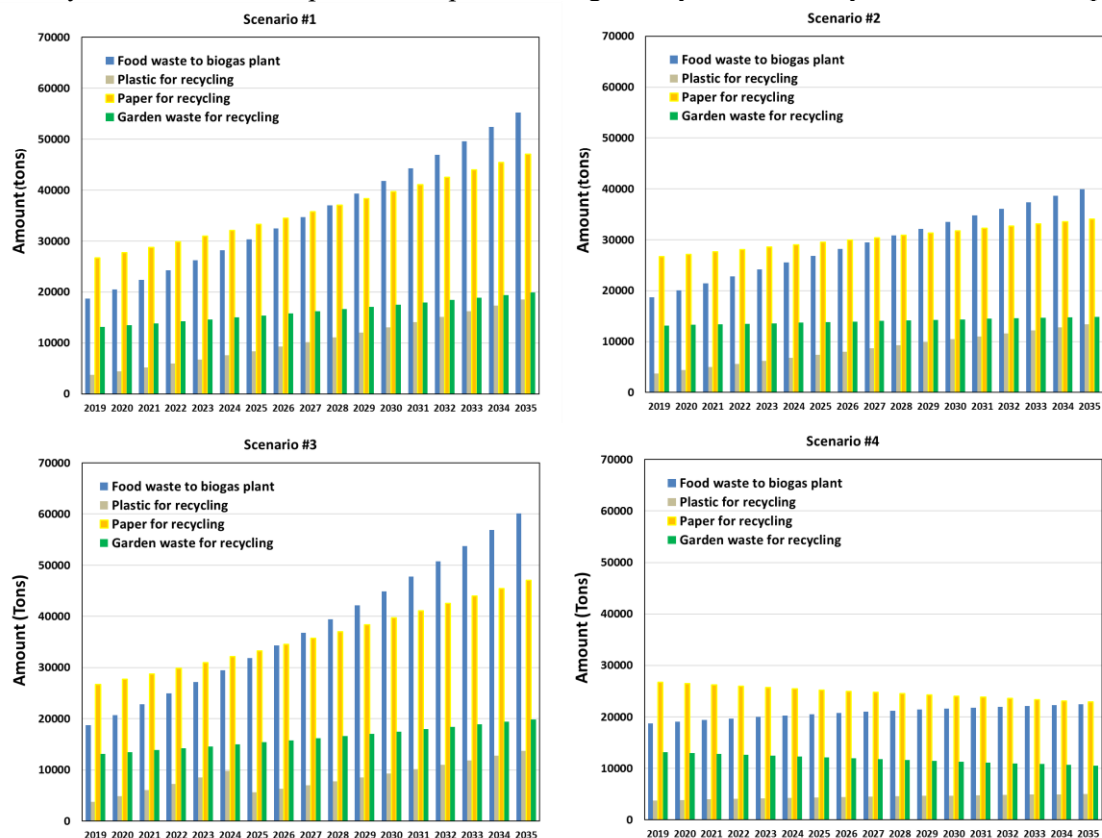


Figure 4. Food waste, plastic & paper to recycling from 2020 to 2035.

Figure 4 presents for scenarios #1, 2, 3 & 4 for the period from year 2020 to 2035: (a) the amounts of source-sorted food waste going to biogas and fertiliser production, (b) the amounts of plastic waste to material recovery and (c) the amounts of paper waste to material recovery.

As scenarios #1-3 are aiming at a specific recycling target, the amounts of materials to recycling are increasing at a fixed yearly rate adapted to the specific conditions set in each scenario, the waste fractions to WtE being calculated by difference. The different increasing rates for the different fractions are interesting to discuss. With our methodology, there exists (in many cases) *several solutions* to reach the 65% goal in a scenario. As an example, the recycling of 1 ton of plastic waste each year could be "replaced" by the recycling of 1 ton of paper waste to attain the 65% recycling target in year 2035. The values set here have been selected to represent acceptable paths both logistically and technologically. In this context, a further result can be extracted from the scenarios: for scenarios #1 and #3, the amounts of food waste to AD will be exceeding the maximum capacity of the existing biogas plant, i.e. 50 000 t/y, in 2034 and 2032 respectively. This means that these two scenarios can take place only if the AD capacity is expanded.

Table 2 presents the individual recycling rates of four waste fractions: food, plastic, paper, and garden waste in the 2020 – 2035 period for the four scenarios. The values for scenarios #1 to #3 show that to reach the ambitious 65% recycling target for MSW it is necessary to attain high or even very high (85+%) recycling levels for several fractions. These values can be compared to the specific targets found in the Packaging Directive [3]. Reaching such levels might be challenging with the current materials (composites, etc.) and technologies and may very well require logistical and technological breakthroughs in the waste management sector, e.g. chemical recycling, and improved sorting. Another approach could also aim at changing the production of paper and plastic products, e.g. avoid complex, composite materials and promote ready-to-recycle items.

Table 2. Recycling rates (%) for key waste fractions.

Year	Fraction	Scenario #1	Scenario #2	Scenario #3	Scenario #4
2019	Paper & cardboard	75	75	75	75
	Food waste	36	36	36	36
	Plastic	27	27	27	27
	Garden waste	85	85	85	85
2025	Paper & cardboard	84	84	84	78
	Food waste	52	52	55	43
	Plastic	53	53	36	34
	Garden waste	89	90	89	86
2030	Paper & cardboard	92	92	92	81
	Food waste	65	65	70	49
	Plastic	75	75	54	40
	Garden waste	92	95	92	87
2035	Paper & cardboard	99	99	99	83
	Food waste	79	79	86	55
	Plastic	98	98	73	45
	Garden waste	96	99	96	87

What are the effects of the 2025 event defined in scenario #3? In scenario #3, plastic wastes produced in Oslo city are now recycled in Norway instead of abroad, an important Circular Economy measure as it gives a much better control on the actual fate of plastic sent to material recycling. Evidently, this change does not have an impact on the recycling numbers in our study. However, there is a secondary

effect: the rejects from material recycling, set here at 50% of the total amount of plastic waste sent to material recycling, will be sent to the local WtE plant, i.e. REG's Haraldrud plant. WtE will be discussed in detail in the next section.

In scenario #4, the "business as usual" future, both food waste and plastic waste will have recovery rates below 60%. To avoid such an unfavourable development, appropriate measures should be taken at all levels: producers (industry), consumers (individual citizens) and politicians (decision-makers). These measures should focus both on information to the public and the promotion of positive actions, but also towards framework/legislative initiatives to prevent the very possibility of inadequate decisions.

3.5 MSW fractions to WtE

Figure 5 shows the amounts of paper, plastic and food waste going to WtE for the four scenarios for 2020 - 2035. The main remaining fraction to WtE is the so-called "rest" fraction (see Figure 1). This is a complex, heterogeneous and ever-changing mixture made of a wide variety of items and materials. A few interesting information can be extracted from the scenarios: food waste is the main well-identified (in opposition to residual waste) fraction handled by WtE; in scenario #1 and #2 almost no plastic and paper are being sent to WtE in 2035 *as is* (but remember that these materials will also be found in the rest fraction), while in scenario #3, the impact of local plastic recycling and the resulting incineration of rejects is visible with ca. 5000 t plastic to WtE in 2035. In the "business as usual" scenario #4, significant amounts of paper and plastic are still sent to WtE in 2035.

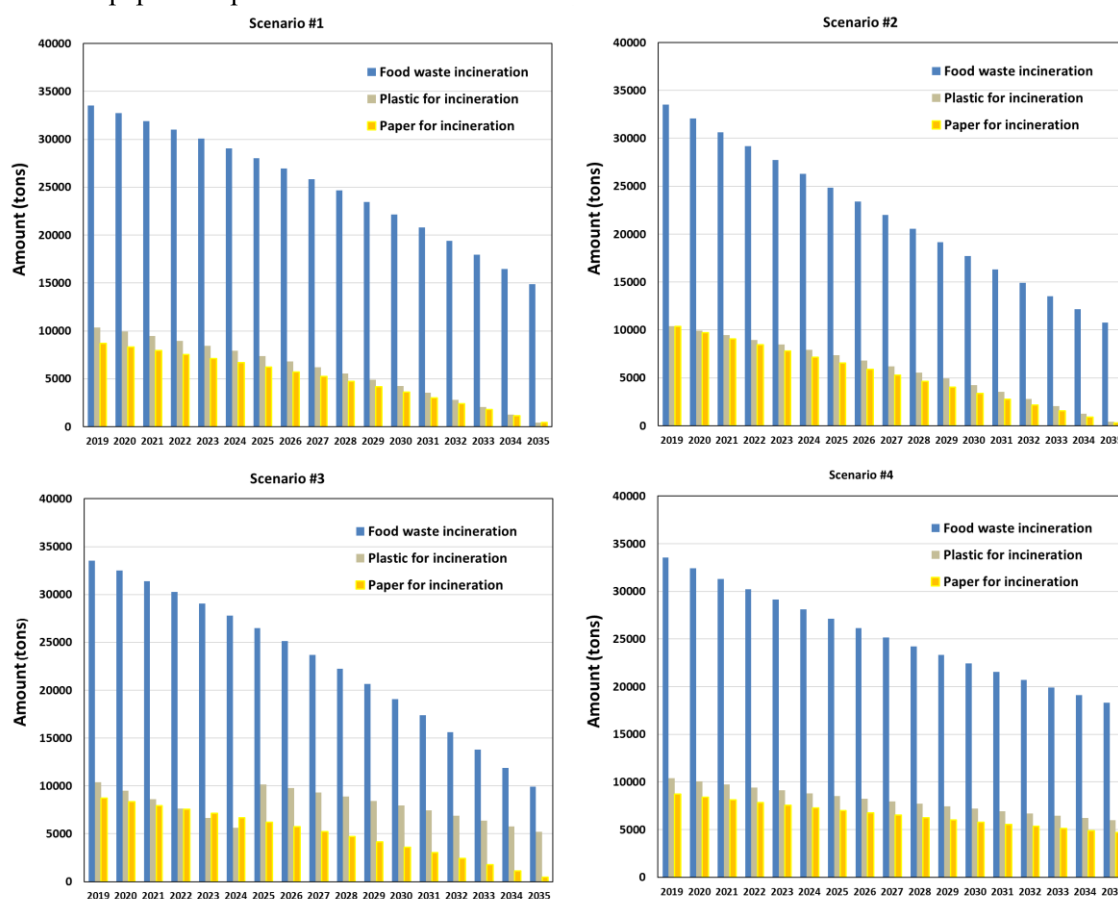


Figure 5. Food, plastic, and paper to WtE for 2020 – 2035.

The MSW fractions discussed here (plastic waste, paper waste, food waste, residual waste) have a common feature: they are all made of a variety of sub-categories, e.g. paper waste is made of glossy paper, journal paper, cardboard, etc. that have significantly different physical and chemical properties.

These four fractions are also quite different from one another when it comes to combustion. To briefly mention a few key combustion properties, it can be said that: plastic has a high energy content and little moisture; paper products are many and may contain an array of different additives, food waste are biologically degradable and can have a high moisture content while residual waste is highly heterogeneous and poorly identified, an additional challenge for WtE optimal operation.

Key MSW properties related to combustion were calculated for the different scenarios combining the main fractional composition of MSW to WtE and an extensive database [10] compiling the properties (elemental composition, ash concentration, energy content, etc.) of more than 50 individual materials (different types of paper, plastic, food items, etc.). The results are summarised in Table 3. MSW to WtE energy content is decreasing in all scenarios, but only significantly for scenarios #1 to #3, the ones aiming at the 65% recovery target where LHV drops below 10 MJ/kg in year 2035 from 11.6 MJ/kg in year 2019. This decrease is related to the low combined amounts of plastic and paper being incinerated. Interestingly, in scenario #3, the presence of high-energy plastic rejects does not contribute significantly to an increase in energy content (it represents about 5% of MSW to WtE in this scenario). The similarity between these three scenarios shows that the 65% recycling target is the driving force dominating the changes in composition and hence combustion properties as it displaces fractions from WtE to recycling. Such 25% decrease in LHV may be challenging for the WtE plant to handle but as it is happening over a 15-year period, it would probably be possible to adapt operation if necessary. In the "business as usual" scenario #4, the predicted decrease in LHV is less than 7% between year 2019 and 2035. The ash contents of MSW to WtE in scenarios #1 to #4 in year 2035 are similar and only slightly higher than in year 2019. We believe that the trend is correct but difficult to estimate accurately because of the poor knowledge concerning the properties of the residual fraction to WtE.

Table 3. Key combustion properties of MSW to WtE (calculated)

Scenario	Year	Energy content (LHV, MJ/kg)	Ash content (wt%, wet basis*)
Reference	2019	11.6	16.8
#1	2035	8.7	17.3
#2	2035	8.7	17.2
#3	2035	9.8	17.0
#4	2035	10.8	17.7

* 20 wt% moisture.

4. Conclusions

It is difficult to predict the future of MSW and MSW treatment methods as many factors can play a role and are difficult to quantify, but it is certain that both will be greatly affected by the implementation of Circular Economy principles. In this study, we defined four scenarios for 2020-2035 with plausible frameworks for key elements (population, waste generation, recycling target) and evaluated the main consequences on MSW management in Oslo, Norway.

The main results can be summarized as such: (1) the evolution of both population (i.e. the number of inhabitants) and consumption (i.e. waste generation rate per inhabitant) will have a large impact; (2) meeting EU material recycling target (65% for MSW by 2035) means that several waste fractions have to be recycled at high levels, and this may be difficult to implement without significant logistical changes and/or technological breakthroughs, (3) in 2 out of 4 scenarios, the AD capacity must be increased to reach the 65% recycling target, (4) a "business as usual" approach is not sufficient to reach the 65% recycling target, (5) combustion properties of MSW to WtE will be affected by increasing material recycling, probably towards lower energy contents and higher ash contents and (6) such "what-if scenario" studies should be carried out at the city/regional level as many specific conditions and constraints must be included to bring valuable information (separate collection and treatment of food waste, local recycling of plastic, new process implementation, etc.).

The developed calculation tool is Excel-based and can be used to evaluate simple "what-if scenarios" providing that data, both historical and on the current situation, are of satisfying quality. This might be a challenge for many developing countries.

Other scenarios of interest could investigate differentiated evolution rates for different waste fractions (also varying over time in the future) to reflect changing consumers' habits. It would also be beneficial to account for the implementation of novel or improved technologies, e.g. technical breakthroughs in thermal treatments such as chemical recycling or advanced sorting techniques.

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