Municipal Solid Waste Management in a Circular Economy

Key results, insights and recommendations from the CircWtE project

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Table of contents

The Context

As Circular Economy principles are unfolding...

...in terms of regulatory framework, technologies and societal evolution...

...waste generation will change, in both composition and amount.

The entire waste treatment system will have to adapt to respond to these changes.

How can we best predict and adapt to the manyfold implications of such a transition for waste?

The Approach

The CircWtE project employed several methodologies to support waste actors in this transition to a more circular economy, the main ones being:

- Past and present waste data analysis
- What-if scenarios towards 2035/2050 and waste data projections
- Technology reviews and evaluations
- Modelling:
  MFA – Mass Flow Analysis
  LCA – Life Cycle Analysis
  Dynamic input/output

Main Conclusions

Waste Data
We are still lacking important data (on commercial and industrial waste for instance) and the data is often too aggregated. This makes it challenging to design the best system.

Past/present Waste System
According to official statistics, there has been no major push towards circularity this last decade.

Future Waste System
Our scenarios work shows that business-as-usual is not sufficient. Major systemic changes are necessary to reach targets.

Technologies
Novel solutions could in some cases improve circularity, but they have a cost, and no one-size-fits-all solution is expected.

Residues and Emissions
Incineration ash, CO_2, food waste digestate, and sorting and recycling rejects must be integrated into circularity.

System Evaluation
Current weight-based indicators are too simplistic to ensure high-impact, high-quality circularity.

Recommendations

Waste Data
Develop tools (sensors, AI) for a more systematic, standardised and in-depth waste data collection.

Past/present Waste System
Evaluate your system before making changes. Learn from others for best practices.

Future Waste System
Adopt policies that really promote circularity (such as targeted recycling), better system indicators, and improved or novel technologies.

Technologies
Invest in R&D to improve sorting and recycling technologies – especially for food, plastic and textile waste. A combination of integrated and novel technologies may play a larger role in the future.

Residues and Emissions
Promote ash valorisation, consider CCS, ensure food waste digestate quality, and provide solutions for sorting and recycling rejects.

System Evaluation
Define better indicators to ensure high-impact, high-quality circularity.

Background

As the tsunami of (overwhelmingly EU-based) laws and regulations intended to realise a circular economy (CE) hits, the waste treatment system will have to act, react and adapt in order to not only deliver as expected, but also, hopefully, be an integral part of this (r)evolution.

This broad, far-reaching movement will impact all aspects of our individual, collective, private and professional lives, including a plethora of waste-related questions:

- What is the current state of affairs? Can we dig deeper into existing data?
- What can we learn from the past and present situation?
- What will we consume? What will we throw?
- How will we dispose of our waste (in relation to the collection system, our behaviour, and the changing waste streams)?
- How much will we throw?
- How will the current treatment system (i.e. the technologies available and in use) react, respond and adapt, and what may the consequences of this be (in terms of challenges, opportunities, economics, etc.)?
- Are new, better technologies emerging?
- How might a CE impact the energy system?
- As the system evolves and complexifies, how to handle and valorise the various side-streams, residues and by-products?
- To be sure that we are on the right track, and if necessary, adjust and/or trade-off, we must carefully evaluate the ever-evolving waste treatment system at a systemic, multi-parametric (environment, economy, climate, energy, society) level. How can we do this? And what does it look like when these indicators are applied to the current system?

Even though many questions are about the future, we must start by examining the past and the present. R&D institutes and academia can support the waste treatment sector to reflect over these far-reaching, short-, medium- and long-term questions to be able to grasp opportunities and mitigate challenges.

This is what CircWtE has been doing in close collaboration with actors all along the waste treatment value chain. This brochure presents key results, insights and recommendations from CircWtE's work. This work was primarily carried out for Norway, but many take-aways are applicable to other European countries.

A circular economy is defined by the Corporate Sustainability Reporting Directive (CSRD) and European Sustainability Reporting Standards (ESRS) as:

"An economic system in which the value of products, materials and other resources in the economy is maintained for as long as possible, enhancing their efficient use in production and consumption, thereby reducing the environmental impact of their use, minimising waste and the release of hazardous substances at all stages of their life cycle."

Visit CircWtE's project website for more information

CircWtE in a nutshell

The original set of objectives from the CircWtE project proposal is clear and reflects the straightforward structure of the project. The project is divided into 4 technical sub-projects to address central aspects of waste treatment.

The main objective is to determine how future municipal solid waste (MSW) management systems will look in a CE, and what role they will have in the future energy system.

Sub-objectives:

- Determine the role(s) waste-to-energy (WtE) will have in a CE
- Determine the impact of CE on MSW compositions and amounts
- Determine the impact of CE on MSW treatment solutions to ensure that the different MSW streams go to the right treatment(s)
- Determine how improved valorisation and disposal of the waste treatment residues, sidestreams and emissions can contribute to circularity
- Determine the environmental and socioeconomic impact of CE political, regulatory and social factors on value chains in MSW management systems

Overarching approach

The overarching approach of CircWtE is also straightforward yet powerful:

- Looking at the past whenever relevant: what changes happened and why? Can we learn from our (or others') success and mistakes?
- Mapping the present situation as detailed as possible (bringing forward gaps and challenges), and understanding how and why we reached this point.
- Looking at various future scenarios (rather than one future) and understanding the implications. As the saying goes: "prediction is difficult when dealing with the future".

In this work, we quickly decided two axioms:
(1) we did not want to predict the future, but discuss plausible and/or interesting "what-if" scenarios using historical trends and/or assumptions based on regulatory framework, including existing target goals, and (2) we did not want to carry out parametric studies (i.e. "high" and "low" trends), but anchored the scenario-based work on simple yet powerful narratives that make sense in a real world, e.g. "the public adopts the principles of a CE and reduces its consumption, and, hence, waste production by X% per year over the coming decade". The scenario premises were discussed and elaborated with all CircWtE partners.

In most instances, our work is done in the context of specific cases (e.g. for a city, for selected waste types, for a combination of technologies) to bring meaningful results and insights that, hopefully, can be used and generalised in many other cases.

A wide variety of tools has been used (e.g. data analysis, life-cycle assessments) and are presented in the relevant chapters and respective publications.

Thematic Area 0: The scenarios

To support CircWtE's investigation, the project developed three main scenarios.

For a case study of a typical Norwegian town with 15,500 inhabitants, the associated assumptions and outcomes for each scenario are as follows:

Current Road (Business as usual)

- Waste generation per capita follows past trends
- Sorting behaviours unchanged, plastic/food waste often missorted
- Recycling efficiency unchanged, resulting in significant material losses

Projected outcome

- Total waste increases by 3 % by 2035 due to population and economic growth.
- Plastic sorting only improves slightly, missing EU targets.
- Residual waste remains a dominant fraction, reinforcing the need for waste-to-energy capacity.

Circular Road (Improved sorting)

- Waste generation per capita follows past trends
- 10 % annual improvement in sorting behaviour across all recyclable fractions
- Sorting technology remains the same as today in terms of losses

Projected outcome

- Plastic sorting targets (EU) are met, but recycling targets are still missed due to processing inefficiencies.
- Residual waste decreases by 44 % by 2035.
- Increased food waste collection requires expanded biogas plant capacity.

Frugal Road (Waste reduction)

- Households generate less waste
- Edible food waste and paper reading waste are nearly eliminated by 2035
- 10 % annual improvement in sorting behaviour across all recyclable fractions

Projected outcome

- Total waste decreases by 38 % by 2035, reducing overall material use.
- Residual waste drops by 62 %, meaning WtE is still needed (but to a lesser extent).
- Plastic sorting improves the most, but fails to meet the EU plastic recycling targets.

ZOOM ONE

Scenario Analysis Tool for Estimating Future Waste Composition and Amounts Toward a Circular Economy

Cansu Birgen, Tuva Grytli, Michaël Becidan

Journal of Material Cycles and Waste Management, Vol 26, pgs 2742-2740, 2024.
https://doi.org/10.1007/s10163-024-01992-w

An Excel-based scenario analysis tool was created to estimate future municipal solid waste (MSW) amounts and compositions towards 2035 for a typical Norwegian town of 15,500 inhabitants. As such, it is possible to assess whether the current circular economy targets are attainable with the existing infrastructure and treatment technologies. Future sorting and recycling rates across 28 waste containers and 14 waste fractions were calculated.

Three scenarios were modelled: *Current Road* (business as usual), *Circular Road* (improved sorting and recycling) and *Frugal Road* (waste reduction).

Significant findings:

- Total and per capita waste generation does not decline in the Current Road scenario.
- Food waste sorting targets are achieved in all scenarios, but plastic sorting only improved in the more ambitious pathways.
- Sorting rates are set to improve in the Circular Road and Frugal Road scenarios, but EU plastic recycling targets are still not met, highlighting the limits of current recycling technologies. Sorting alone is not enough, low recycling efficincy (i.e. process losses) is a bottleneck for circular economy goals.
- Estimating the correct recyclability of residual waste is key to planning treatment capacities, including WtE.
- The Circular Road and Frugal Road scenarios are ambitious and show how difficult a circular transition is.

This work mapping future possible scenarios can
(1) feed into impact assessment studies;
(2) simulate the effects of different measures and changes regarding waste or technology developments; and
(3) identify bottlenecks and opportunities for decision-makers to optimise the waste management system.

Waste composition analysis. Photo: MEPEX for CIVAC © MEPEX

Thematic Area 1: Municipal Solid Waste (MSW)

Overall goal

- Map the current MSW amounts and compositions in as much detail as possible for different areas/regions to enable strategic, knowledge-based decisions
- Understand waste sorting behaviour in these areas/regions
- Assess the evolution of MSW amounts, compositions and the resulting implications for different systems (e.g. energy production), using the CircWtE scenarios

Tasks performed

- In-depth investigation into fresh, detailed composition analysis data provided by our user partners: amounts & properties at the sub-fraction level for different region/areas, including wrongly sorted materials
- Data analysis regarding which factors affect sorting behaviour
- Data analysis examining different calculation methods for material recovery
- In-depth investigation of specific fractions (plastics, food waste)
- Development and use of a tool for scenario implementation

10 key takeaways for MSW

01 We need to develop sensors and digitalised solutions for composition analysis and data collection to improve data quantity and quality.

02 Looking at historical data, it is not guaranteed that waste amounts will only decrease in the future.

03 If population and waste per capita increase, the total waste amount sent to WtE may not change - regardless of increased sorting.

04 More knowledge on commercial and industrial waste is needed.

05 Handling its own waste rather than exporting it could have economic, environantal and strategic benefits for Norway.

06 Optimising waste treatment systems requires knowledge of local conditions (waste properties, infrastructure, economy, etc.).

07 Data indicates that reaching over 50% sorting for main fractions (food, plastic) is challenging, and requires drastic measures.

08 Digging deep into waste data to a sub-fraction level provides valuable information for optimising waste management.

09 Sorting behaviour is complex, and sorting is not recycling: a lot can happen in between (process losses, rejects, exports, etc.).

10 Reaching sorting and recycling targets will require significant changes in consumer and producer attitudes and technologies.

ZOOM ONE

A Critical Look at Waste Composition Analyses: Challenges and Opportunities

Tuva Grytli, Cansu Birgen

Proceedings of the 33rd European Symposium on Computer Aided Process Engineering (ESCAPE33), 18-21 June 2023, Athens, Greece
 http://dx.doi.org/10.1016/B978-0-443-15274-0.50342-5

This article proposes a multiple linear regression analysis to investigate the impact of five factors on waste sorting behavior, following the ten waste fractions in the mixed waste bin (paper and cardboard; food waste incl. paper towels; garden waste; plastic packaging; glass packaging; metal packaging; other metals; recyclable textiles; hazardous waste; mixed waste).

This study was based on waste composition analysis data from a municipal waste company in Norway that serves more than 100 000 inhabitants. Waste composition analyses of the mixed waste bin were carried out in 2016, 2017, 2019 and 2021.

This study considered five factors to understand their impact on waste sorting behavior. These variables are:

1. Separate food waste collection vs. food waste in the mixed bin,
2. Kerbside glass and metal packaging waste collection vs. central collection points,
3. Underground waste collection vs. traditional waste bins,
4. COVID-19 (before and after 2020), and
5. Year of analysis (time).

The aim was to investigate factors that affect municipal solid waste (MSW) source-sorting results, in order to facilitate achieving circular economy targets.

Significant findings:

- Separate food waste collection reduced the share of food waste in the mixed waste bin by 25 percentage points.
- Kerbside collection of glass and metal packaging waste significantly affected sorting behaviour, halving the share of these materials in the mixed waste bin.
- No significant impact was found over the three remaining variables: time, COVID-19 and the type of mixed waste bins.
- Manual data registration errors were discovered, highlighting the need for improved data quality and quality assurance processes.
- User-friendly sorting systems are needed to improve sorting results. A user-friendly sorting system is intuitive, convenient, and accessible, with clear labeling, consistent design, and is supported by (targeted) educational campaigns to encourage proper sorting.

This study shows the tangible benefits of a well-designed waste collection system towards a circular economy.

ZOOM TWO

Enabling Circularity: Analysis of Factors Influencing MSW Sorting Behaviour in Central Norway

Tuva Grytli, Cansu Birgen

Proceedings of the 33rd European Symposium on Computer Aided Process Engineering (ESCAPE33), 18-21 June 2023, Athens, Greece
 http://dx.doi.org/10.1016/B978-0-443-15274-0.50341-3

A vast waste composition analysis covering 750,000 residents across Central Norway with 20 sample areas was carried out under the auspices of one of the CircWtE partners, CIVAC, in 2021. Over ten tonnes of waste were analysed to assess sorting different behaviours in various locations, each with different waste collection systems. The goal of this article was to dig deep into this data to identify key factors influencing waste sorting. Such knowledge can support the sector to better reach the circular economy targets.

This study is a multiple linear regression model focusing on the impact of three parameters on sorting behaviour:

1. Separate food waste collection,
2. Kerbside glass & metal collection, and
3. Settlement type (city vs. smaller settlements).

The performance of the system was evaluated using the shares of food waste and correctly sorted mixed waste in mixed waste bins.

Significant findings:

- Separate food waste collection resulted in the proportion of food waste share in the mixed waste bin dropping significantly - almost by half.
- Kerbside collection for glass and metal increased correct sorting of these fractions. This shows that the more convenient a system is, the better the sorting results.
- Surprisingly, settlement type did not show any significant effect on the sorting behaviour.
- Transparency and trust are important: a central sorting system (where different colour-coded bags are thrown in the same bin) performed more poorly than source sorting with dedicated bins. This is possibly because users perceived all waste in the same bin as going to the same treatment, reducing the motivation to sort.
- Communication and strict policies work: the one MSW company with active communication strategies, e.g. notifying individual customers of incorrect sorting with pictures and refusing to collect, achieved the best results. This highlights the role of active communication, education and enforcement.

Post-sorting means that mixed waste from households or businesses is collected and sorted at a central facility, instead of being fully separated by people (aka source-sorting/separation). The facility uses mechanical, optical or manual techniques to pull out recyclables (plastics, paper, metals, etc.) from the residual waste stream.

This study intends to better utilise the potential offered by the wealth of information "hidden" in waste composition analyses. The findings contribute to a deeper understanding of sorting behaviour and its drivers. The study can help MSW companies design better collection systems, and policymakers implement efficient measures to increase circularity.

Towards a Circular Economy for Plastic Packaging: Current Practice and Perspectives in the City of Oslo

Cansu Birgen, Michaël Becidan

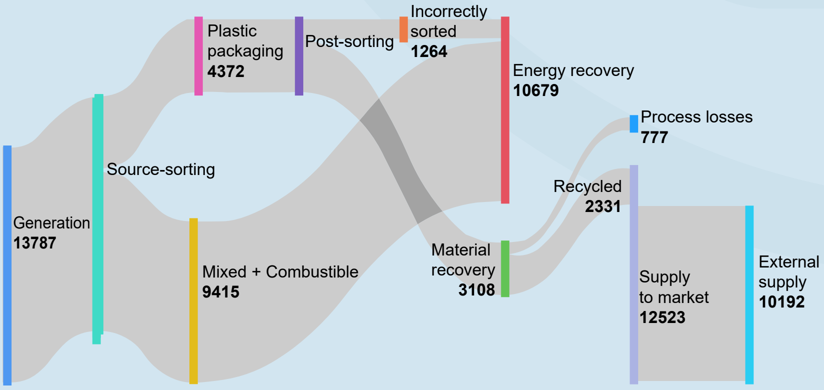
Chemical Engineering Transactions Vol. 92, 2022
 ISBN 978-88-95608-90-7; ISSN 2283-9216.
https://doi.org/10.3303/CET2292021

This study quantified the plastic packaging MSW streams in the largest city of Norway in 2019. The resulting recycling/recovery rate for this material was calculated using different methods. The main goal was to highlight potential bottlenecks and improvements in specific sections of the waste management system to improve recovery.

Firstly, the sources, amounts and treatment methods of the main MSW fractions were quantified by combining local and national data. Secondly, the specific mass flows of plastic packaging were estimated for the city. Thirdly, using this data, three methods were used to calculate plastic packaging recovery rates.

Significant findings:

- There are data-related challenges, as little is known of Commercial and Industrial (C&I) waste and the amount of plastic packaging supplied to the market is only known at the national level.
- 25 % of plastic packaging is source-sorted correctly, while 67 % is found in the mixed waste bin. This shows a large potential for improvement, more specifically in pinpointing source-sorting by households.
- Depending on the method, the recovery rate was estimated to be 19-32 %. In comparison, the EU set a 50 % recovery target for 2025.
- Increasing sorting and recovery rates could be achieved by different strategies: targeted communication to better reach all urban households, and investment in innovative technologies, e.g. post-sorting, chemical recycling.
- Recovery rate calculation methods should (1) not overestimate recycling by including losses, water, rejects or materials that are not actually recycled or recyclable; (2) be reliable, i.e. based on sound, accurate statistics; (3) be calculated at the city/region level to enable efficient decision-making; and (4) have unambiguous measurement points.
- Most sorted plastic packaging is exported for recycling. Expanding national recycling industries could be an additional driver for promoting a circular economy.



Material Flow of Plastic Packaging for Oslo (2019, in tonnes)

Recycling (also called **material recovery**) involves collecting, transporting, sorting/separating, cleaning and processing waste to recover resources such as metals, plastics, paper, glass or biomass (organic waste).

Recovery processes require energy and resources (e.g. water for cleaning) that depend on the material. Common examples are mechanical recycling of plastic, melting of new glass, producing biogas and digestate from food waste and composting organic waste.

One often forgotten aspect is that the actual economic, environmental and/or functional value of different processes will also vary (this is sometimes referred to as **upcycling** or **downcycling** when it comes to value and/or functionality).

While Norway has set sorting targets for household waste fractions in its legislation (*Avfallsforskriften*), the EU has set recycling targets. The Commission Implementing Decision that establishes the rules for calculating, verifying and reporting data on waste in the EU is *EU 2019/1004*.

Photo: © Oslo Kommune Renovasjons- og gjenvinningsetaten

Photo: Waste sorting at home © Oslo Kommune Renovasjons- og gjenvinningsetaten

Thematic Area 2: Waste treatment technologies

Overall goal

- Perform a technical evaluation of the current technologies in a circular economy context (i.e. identify opportunities and risks as waste flows change)
- Assess how the introduction of novel technologies will impact the system's performance in a circular economy perspective

Tasks performed

- Analysis of the current waste treatment systems for three regions
- Assess the performance of alternative treatment systems for higher circularity (e.g. central sorting, chemical recycling)
- Review innovative technologies

10 key takeaways for waste treatment technologies

01 If source sorting is high, central sorting will only have a marginal impact.

02 Central sorting could improve sorting rates but it has a cost, and may also have a negative affect on source sorting.

03 Official data shows that the percentages of waste sent to recycling, WtE and landfills have been stable for over a decade.

04 While there is no "one-size-fits all" solution, there are some promising alternative technologies for separated fractions.

05 In the EU, higher percentages of recycling are correlated with higher levels of WtE. The technologies can be said to be complementary.

06 Chemical recycling could treat non-mechanically recyclable plastic fractions, but more data is needed on its efficacy.

07 WtE has many roles (e.g. local energy, removing contaminants), and it is unlikely to disappear in the near future.

08 Several WtE CCS initiatives are underway in Norway, which will help us better understand the future role of CCS in waste management.

09 When selecting waste treatment technologies, local conditions play an important role (e.g. infrastructure, waste amounts).

10 Reaching sorting and recycling targets will require significant changes in consumer and producer attitudes and technologies.

ZOOM ONE

Current Municipal Solid Waste Management in a Large City and Evaluation of Alternative Management Scenarios

Elisa Magnanelli, Cansu Birgen, Michaël Becidan

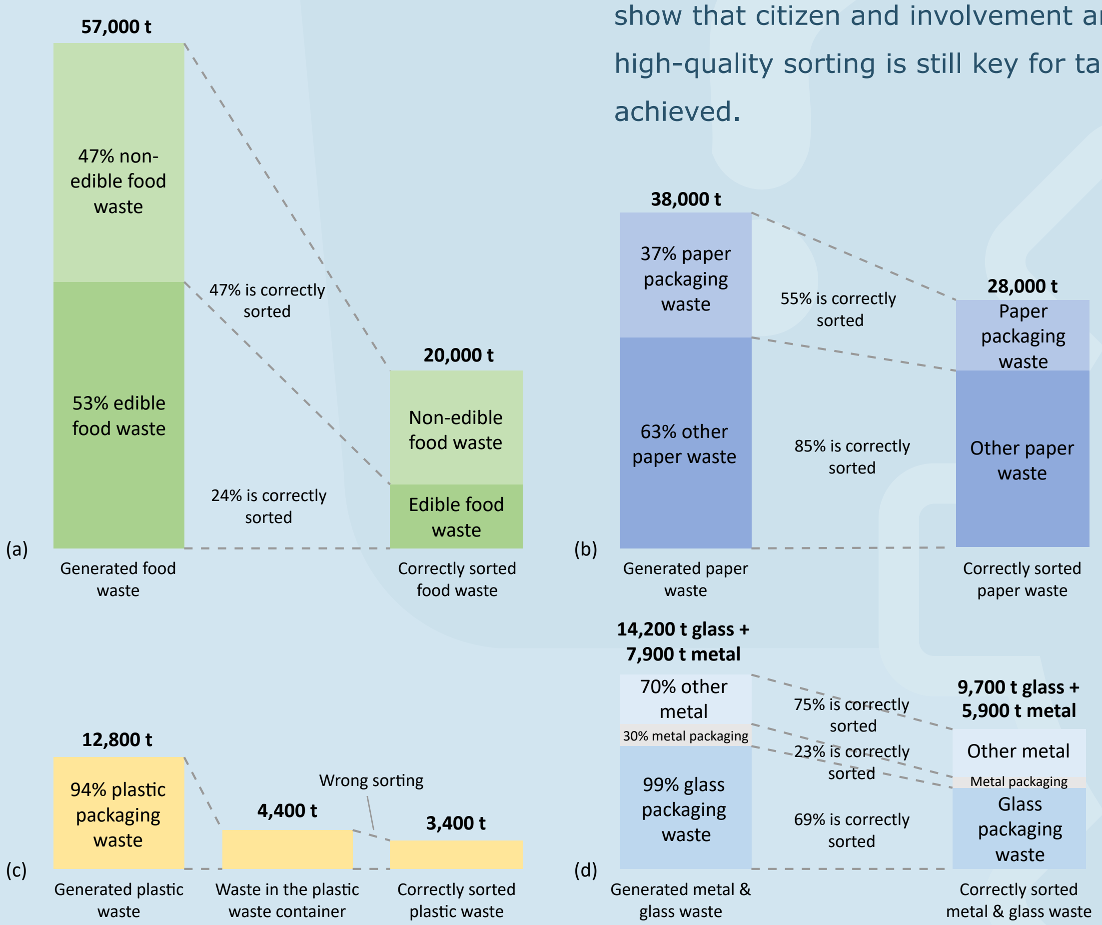
Chemical Engineering Transactions, Vol. 98, 2003
 ISBN 978-88-95608-97-6; ISSN 2283-9216. https://doi.org/10.3303/CET2398038

This study looked at the effect of novel technologies in a waste treatment system, i.e. central sorting and plastic chemical recycling, on sorting and recycling rates.

The aim of this work was to evaluate the performance of the current MSW management system in a large city, and understand how to close the gaps between performance in 2019 and future sorting and recycling targets. The work focuses on fractions for which targets have been set by the EU, i.e. food, plastic, paper and cardboard, glass and metal.

Significant findings:

- Results of the in-depth analysis showed a large potential for improvement in waste sorting: almost two thirds of the current residual waste could have been sent to recycling.
- There is limited available real-life data on central sorting and chemical recycling, but it seems to indicate that sorting rates and plastic recycling can be improved. This would require large investments. However, even with the introduction of these technologies, results show that citizen and involvement and high-quality sorting is still key for targets to be achieved.



ZOOM TWO

Innovative Technologies for Treatment of Mixed and Sorted Waste Fractions

Kim Kluin, Adrian Werner

SINTEF Report No:2023:00836. https://sintef.brage.unit.no/sintef-xmlui/handle/11250/3104044

This report provides an overview of selected innovative waste treatment technologies, focusing on approaches to handle plastic, food, wood and textile waste. Aspects such as technology readiness level, R&D, limitations, energy requirements, environmental performance, complexity and costs, integrability with the existing system and versatility were discussed.

Technology name	Process type	Food waste	Plastic waste	Textile	Impregnated wood	Industrial wood
Thermal hydrolysis	Thermal	✓				
Hydrothermal carbonisation	Hydrothermal	✓				✓
Chemical looping combustion	Chemical	✓	✓			
Conventional pyrolysis	Thermal	✓	✓			
Hydrothermal liquefaction	Hydrothermal	✓	✓			✓
Advanced gasification	Thermal		✓			
Biochar production	Thermal	✓				
Chemical leaching	Chemical				✓	
Wood to fibreboard	Mechanical					✓
Fiber2Fiber recycling	Chemical			✓		
Monomer recycling	Chemical			✓		
Polymer recycling	Chemical			✓		
Separation of fibre blends	Chemical			✓		
Microbial polyester hydrolases	Biological		✓	✓		

Out of a list of over 30 novel technologies, 14 are investigated in detail.

Most of these technologies can only handle mono-streams, and these quality requirements can limit their robustness and applicability for challenging mixed/low-quality waste streams. The need for pre-treatment may also impact their potential success and applicability.

While this report provides an overview of several waste recycling technologies with long-term potential, further research, collaboration, and investments are required to fully harness their benefits. A significant share of the reviewed technologies has not been implemented on a commercial scale yet, underscoring the need for R&D. Continued exploration holds great promise for improved resource recovery, environmental preservation, and a more sustainable future.

Chemical recycling of plastic waste is a set of processes (e.g. pyrolysis, gasification) that break plastics down into their chemical blocks (monomers, oils or gases), which can then be used to make new plastics or other products.

There is no silver bullet that will solve all waste challenges, but several promising technologies for specific fractions could be on their way.

Thematic Area 3: Sidestreams

Overall goal

It is not good enough to focus solely on the main, valuable product(s) of a waste treatment process. All waste treatment solutions also lead to residues that may require further treatment or disposal. Given insights from CircWtE scenario work, we can identify and study the main flows to consider and their possible role in a circular economy.

Tasks performed

- Investigation of five sidestreams:
  - Total (bottom and fly) ash from WtE (composition and amounts)
  - Digestate from biogas production (from source-separated food waste)
  - CO_2 from WtE (biogenic and fossil)
  - Fly ash valorisation (from WtE, with or without air pollution control residues)
  - Collection of data on rejects and losses from sorting and recycling

10 key takeaways for sidestreams

01 There are uncertainties on the amount and composition of WtE ash, but they contain valuable resources (e.g. P, metals).

02 Anaerobic digestion produces slurry/digestate, which may need thermal processing before being used as fertiliser/soil enhancement.

03 Regarding CCS, WtE flue gas composition poses specific challenges, while unused heat presents opportunities.

04 The evolution of biogenic carbon in the waste has implications in terms of negative emissions (CCS) and waste incineration tax.

05 Increased recycling will produce large quantities of rejects that are low-quality fractions to be handled.

06 Rejects from recycling will almost certainly have to be handled via WtE or another robust thermochemical process.

07 There has been no market revolution towards a circular economy, but there have still been positive developments.

08 Several technologies for valorising fly ash have reached TRL 8-9 since 2018, but with limited commercial success.

09 Legislation is only becoming stricter for residues (e.g. digestate quality for agricultural purposes, waste combustion tax).

10 Final disposal of residues is often challenging regarding public perception, e.g. new landfills for hazardous waste.

ZOOM ONE

MSW for Energy Recovery - 2020-2035 Scenarios for a Large City

Liang Wang, Cansu Birgen, Michaël Becidan

CHEMICAL ENGINEERING TRANSACTIONS Vol. 105, 2023
 ISBN 979-12-81206-04-5; ISSN 2283-9216.
https://doi.org/10.3303/cet23105092

This study models three scenarios for municipal solid waste incineration in Oslo from 2020 to 2035. The amount and detailed composition of MSW generated in 2019 are used as the reference and initial input data. The study provides detailed information on key properties of the MSW sent to incineration under the different scenarios.

The narrative behind the three scenarios was:

- **Business as usual** - this scenario uses historical, region-specific data (e.g. 2015-2019 averages) for yearly changes (waste generation, waste composition, population, etc.):
- **Frugal Road** - this scenario focuses on the impact of waste reduction: decreasing yearly historical trends regarding waste fractions' generations are used, while increasing ones are set to 0.
- **Circular Road** - this scenario uses similar 2015-2019 averages as the business-as-usual scenario for waste generation but significant improvements are made in terms of correct sorting, i.e. each year X% (set by us) of a given waste fraction found in residual waste is moved to the correct bin.

Significant findings:

- The total amount of residual waste to WtE decreases in all scenarios, but at varying degrees – from less than 20% to about 50%.
- The impact of population (de)growth on the total amounts of waste to be handled should not be underestimated.

Chimney at Haraldrud waste sorting facility © Silje Løken, Oslo Kommune Renovasjons- og gjenvinningsetaten

Waste fraction	Residual	Food	Plastic	Paper	Glass	Metal	E waste	Garden	Dangerous	Waste wood	Construction	Other
Yearly change	-2%	+4%	+5%	-4%	+2%	+4%	-3%	-4%	+1%	-1%	0%	0%

Business-as-usual scenario data averages from 2015-2019.

These scenario-based calculations help to discuss the consequences of plausible, future trends in MSW properties, providing valuable insights for WtE plant operators and policymakers planning waste management strategies.

Forecasting End Products in Food Waste Management System for a Circular Future

Cansu Birgen, Liang Wang, Michaël Becidan

EUBCE 2025 Online Conference Proceedings. http://www.etaflorence.it/proceedings/

Using data from a large Scandinavian city, this study predicts the evolution of food waste (total amount and sorting rate) between 2022 and 2035 to assess the impact on the waste treatment system and the necessary actions to ensure circularity. The preferred food waste treatment is anaerobic digestion (AD), which produces biogas and a digestate that can hopefully be used as a fertiliser.

Significant findings:

- In 2022, just under half of the food waste was sorted correctly. This may increase to 62 % in 2035 if this trend continues.
- About 16 % of the waste found in the food waste bin in 2022 was not food waste and must be removed before the AD process can begin.
- Total food waste is predicted to increase to 20 %, while source-sorted food waste is predicted to increase by over 50 % between 2022 and 2035.
- A large increase in sorted food waste will require a significant increase in specific treatment capacity.
- If AD treatment capacity is not swiftly scaled to the increasing source-sorted food waste amounts, an alternative temporary solution may have to be utilised, e.g. WtE or central composting and/or cooperation with other municipalities.
- Using WtE as a temporary solution for "surplus" food waste may impact the combustion process (operation, energy production, emissions, ash composition).
- Increasing AD capacity will increase the amount of digestate produced, offering opportunities and challenges depending on the local situation: market/local actors, land use, quality compliance (microplastics, metals), costs, etc.

Variable	2022	2035
Source-sorted food waste per person (kg)	22.5	30.5
Food waste sorting rate (%)	48	62
Population	709588	814342
Total source-sorted food waste (ton)	15995	24837
Incorrectly sorted food waste (ton)	17672	15549
Total food waste (ton)	33667	40386

Forecasting results at a glance

The results of this study can help planning food waste management systems and anticipating challenges to avoid sub-optimal treatment, especially to reach the ambitious sorting and recovery targets. The work emphasises the need to balance local infrastructure with changing waste flows, regulations and circular economy goals.

ZOOM THREE

Circular Economy and CO_2 Emissions from MSW Incineration: Current Status and Perspectives in the City of Oslo

Elisa Magnanelli, Liang Wang, Michaël Becidan

To be submitted to a scientific journal

This work assessed how the 2020-2035 evolution of municipal solid waste (MSW) generation (amount and composition) might influence emissions of fossil and biogenic CO_2 from WtE plants in a large city. Other MSW parametres were also estimated, i.e. moisture content, energy content and total energy production.

MSW properties were estimated using a tool compiling a detailed composition analysis of the waste fractions sent to incineration. Predictions were made according to the three CircWtE scenarios (adapted to this study, see Thematic 0): Current Road (business as usual), Circular Road (more sorting and recycling) and Frugal Road (reduced waste generation).

Significant findings:

- The amount of MSW sent to WtE was found to decrease in all scenarios by 18 %, 45 % and 62 % respectively, between 2019 and 2035.
- This decrease was associated with an overall decrease in CO_2 emissions, but since the MSW composition followed different trends in the scenarios, overall CO_2 emissions decreased at different rates: 16 %, 36 % and 55 % respectively in 2035.
- Due to the different trajectories followed by the MSW composition in the scenarios, while fossil CO_2 comprises 39 % of CO_2 emissions today as well as in the 2035 Current and Circular Road scenarios and 33 % in the Frugal Road scenario.
- Since most CO_2 emissions are biogenic in the scenarios, the integration of CCS in WtE plants would probably allow for negative emissions.
- Since CCS is energy intensive, the ratio between CO_2 emissions and MSW energy content is an important parameter when considering energy integration. The total CO_2 emissions per energy unit in the waste did not change significantly (326-334 tonne CO_2/GWh) in the scenarios (it is strongly correlated to carbon content).

	2019	2035			Change from 2019 to 2035		
	Today	Current	Circular	Frugal	Current	Circular	Frugal
tonne CO_2 per tonn MSW	1.14	1.18	1.35	1.37	+3 %	+18 %	+19 %
tonne fossil CO_2 per tonn MSW	0.44	0.45	0.52	0.45	+1 %	+17 %	+0 %
tonne CO_2 per GWh in MSW	334	333	327	326	-0 %	-2 %	-22 %
tonne fossil CO_2 per GWh in MSW	129	127	127	107	+2 %	-2 %	-18 %
Moisture content (%)	28	27	19	16	-4 %	-34 %	-43 %
Energy content (LHV), MJ/kg	12.3	12.7	14.8	15.1	+3 %	+20 %	+22 %
Total energy production (GWh)	472	397	308	218	-16 %	-35 %	-54 %

Evolution of key MSW properties in three CircWtE scenarios.

Fly Ash Treatment Technologies* &
Fly Ash Treatment Technologies - an Updated Overview**

*Michaël Becidan, **Liang Wang, Michaël Becidan

*SINTEF report 2018:00466 (Restricted but made available by the client NOAH AS)
** SINTEF report 2025:XXXX (Open report, under completion)

2018 overview

Treatment technology	TRL estimate	Countries of application	TRL 9 expected within*
Carbon8 - solidification (carbonation)	TRL 9	UK. Will probably require new legislation in Norway.	n/a
FLUWA/FLUREC - chemical extraction/stabilisation (and thermal treatment)	TRL 9	Switzerland, Germany. Will probably require new legislation in Norway.	n/a
NOAH - chemical neutralisation/stabilisation	TRL 9	Norway/Scandinavia	n/a
Terrateam - cement solidification	TRL 9	Norway/Scandinavia	n/a
Renova - chemical extraction (and thermal treatment)	TRL 6-7	Will probably require new legislation in Norway.	3-5 years
Halosep - chemical extraction/stabilisation	TRL 6-7	Will probably require new legislation in Norway.	3-5 years
Scanarc - plasma vitrification	TRL 5-7	Will probably require new legislation in Norway.	3-6 years
Ash2Salt - salts extraction	TRL 5-7	Will probably require new legislation in Norway.	3-6 years
NOAH - carbonation	TRL 5-6	Will probably require new legislation in Norway.	4-6 years
Scanwatt - furnace vitrification	TRL 3-6	Will probably require new legislation in Norway.	5-8 years
Norsep - chemical extraction/stabilisation	TRL 3-4	Will probably require new legislation in Norway.	6-12 years

2025 updated overview

Treatment technology	TRL estimate	Comments
O.C.O. (prev. Carbon8) - solidification (carbonation)	TRL 9	Used in the UK.
FLUWA/FLUREC - chemical extraction/stabilisation (and thermal treatment)	TRL 9	Used in Switzerland, EU countries.
NOAH - chemical neutralisation/stabilisation	TRL 9	R&D projects underway.
Terrateam - cement solidification	TRL 9	Expansion and other projects underway.
Ash2Salt - salts extraction	TRL 8	Licence agreement with Hitachi Zosen Inova in 2021.
Halosep - chemical extraction/stabilisation	TRL 8	Full-scale demonstration plant in operation in Denmark. Commercial operations ceased 1 Jan 2025.
Renova - chemical extraction (and thermal treatment)	TRL 8	Full-scale demonstration plant in operation in Sweden.
Scanarc - plasma vitrification	TRL 5-7	No activities found since 2018.
NOAH - carbonation	TRL 5-6	
Scanwatt - furnace vitrification	TRL 3-6	Active?
Norsep - chemical extraction/stabilisation	TRL 3-4	Bankrupt in 2023.

Thematic Area 4: Waste management in a system perspective

Overall goal

- Define scenarios as a flexible forecasting framework for the whole project (see Thematic 0)
- Study environmental sustainability of waste management, today and in the future
- Perform a socio-economic analysis of waste management in different what-if scenarios for Norway

Tasks performed

- Investigation into the impact of specific legislation on waste treatment
- Study on the evolution of waste treatment performance from 2009-2019, using LCA system indicators in combination with Mass Flow Analysis (MFA)
- System analysis of electronic waste treatment in Norway, including opportunities and challenges towards a circular economy
- Macroeconomic analysis of what-if scenarios that examine the role and impact of MSW management systems in a circular economy
- In-depth review and analysis of 90 waste composition analyses, and the implications for sorting, emissions and food waste avoidance
- Investigation into factors increasing or decreasing the MSW generation per capita

10 key takeaways for waste in a system perspective

01 Current circularity indicators are few and simplistic. We need a new set for multi-dimension assessment and decision making.

02 We need higher quality data for material recycling processes and their different outputs.

03 Strategies are needed to encourage waste prevention and reduction, i.e. reduced (over)consumption.

04 Circular economies do not currently reduce primary production, as secondary materials are more expensive than primary materials.

05 Less consumption of goods does not necessarily lower the environmental impact (known as "the rebound effect").

06 The decision of whether to export waste or develop national capacities (WtE, recycling) is an important topic with many implications.

07 Data indicates that circular economic principles have not yet been fully adopted by society (e.g. stable household waste per capita).

08 Targeted recycling, rather than the current aggregated targets, may be an efficient method of achieving high-impact circularity.

09 50-70 % of residual waste could be sorted out for potential recycling.

10 MSW generation per capita is affected by several socioeconomic factors, such as wealth, leisure preferences and interest rates.

ZOOM ONE

Incineration Economy: Waste Management Policy Failing the Circular Economy Transition in Norway

Kim Rainer Mattson, Johan Berg Pettersen, Helge Brattebø

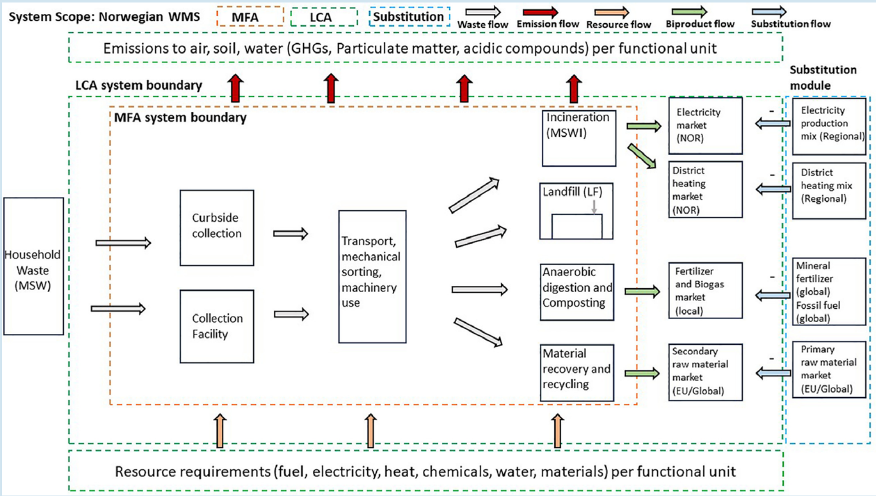
Resources, Conservation and Recycling, Vol. 210, November 2024, 107838

This work developed a hybrid Material Flow Analysis (MFA) and Life Cycle Assessment (LCA) model for Norway's household waste (HHW) management system to assess changes between 2009 and 2019 regarding waste flows, incineration, recycling rates and environmental impact.

The LCA used 18 indicators with the functional unit being the collection and treatment of all household MSW generated within a given year. Recycling rates were estimated, accounting for sorting and processing losses in the spirit of the EU recycling calculation rules (Commission Implementing Decision (EU) 2019/1004). This study analysed policy effectiveness in reducing waste and promoting recycling, specificially the 2009 landfill ban on biodegradable waste.

Significant findings (2009-2019):

- The 2009 landfill ban diverted HHW towards WtE, but failed to support waste prevention, reuse or recyling.
- Recycling rates remain stagnant (28% and 29% for 2009 and 2019, respectively). When accounting for various losses, they are lower than official statistics that report 41-44%.
- Incineration represents 48 % of total CO_2-equivalent emissions from the waste management system in 2019. CCS could potentially play a role in reducing these emissions.
- HHW increased by 0.6 % per capita.
- Waste statistics lack detailed tracking of what happens to materials after collection. Waste accounting must be transparent and less aggregated; recycling is manyfold and dominated by downcycling. Quality recycling could be supported by value-based metrics instead of the current, mass-based recycling rates.
- The residual waste fraction contains 60-70 % of recyclable materials.
- The environmental impact of HHW treatment has improved between 2009 and 2019.



Norway's waste management system.

Current circular economy incentives are not working. Advancements are necessary: efficient policies (e.g. targeted recycling), better system indicators, improved data collection and novel technologies could unlock the circual economy potential of waste treatment.

ZOOM TWO

Electronic Waste Treatment Flows in Norway: Investigating Recycling Rates and Embodied Emissions

Kim Rainer Mattson, Lærke Lindgreen Lauritsen, Johan Berg Pettersen

Detritus, Vol. 25, 2023, pgs 54-64.

https://doi.org/10.31025/2611-4135/2023.18331

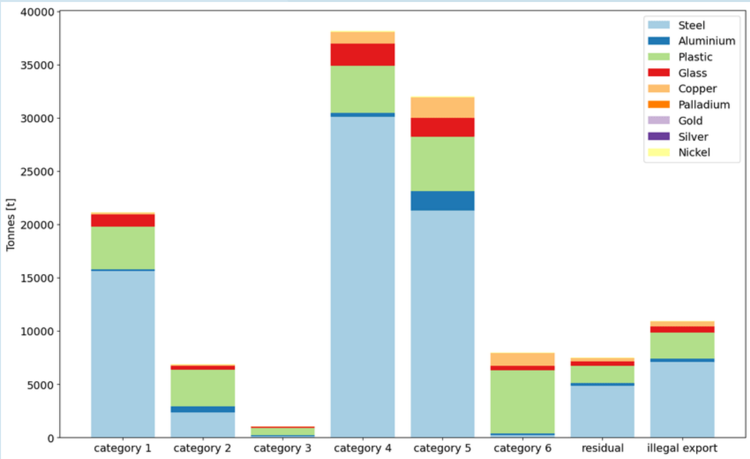
This study gathered information from official databases, literature and communication with industrial actors to map the fate of waste electrical and electronic equipment (WEEE) in Norway.

The material flow of consumer WEEE was followed from collection to end-treatment. The content of WEEE was characterised, covering metals containing iron and steel, non-ferrous metals, plastic, glass, and selected precious metals.

To assess embodied emissions of WEEE materials (GHG emissions generated during production and transportation), a life cycle assessment method to calculate the CO_2-equivalent (CO_2-eq) emissions associated with production, and the emissions generated by recycling, incineration, or landfilling of the respective materials was developed.

Significant findings (2009-2019):

- Material recycling of source-separated WEEE sent to recycling treatments was estimated at 68 %. Official statistics indicate an 80.5% recycling rate. Official figures report sorting for recycling, not actual yields, while losses occur in the process.
- Reporting standards are low and uncertainty is high for downstream processing, making it difficult to track real material recovery and assess environmental impact.
- Although precious metals (e.g. gold, silver, copper, aluminium) are a minute fraction of WEEE mass, they contribute disproportionately to environmental impact. If they are not recovered, emission savings from recycling are significantly reduced, but their recovery is challenging. Design for easy dismantling might be a solution.
- The study estimates 320 kg CO_2-eq embedded emissions per household in WEEE. Incineration of plastic from WEEE is a major source of emissions.



Bar graph showing the total yearly mass per WEEE category and its subsequent share of embodied materials.

The study concludes that current policies focus on aggregated and simple quantitative indicators that are not efficient enough to ensure optimal materials valorisation. Recycling should target material fractions with high environmental impact rather than bulk percentages. Furthermore, stricter, transparent reporting on recycling yields is essential for effective circular economy policies.

ZOOM THREE

Scenario Implementation and Impact Indicator Calculation in Dynamic Input-Output Modelling

Megan Geldermann, Jørgen Kjøsen Lindgren, Gerardo A. Perez-Valdes, Adrian Werner

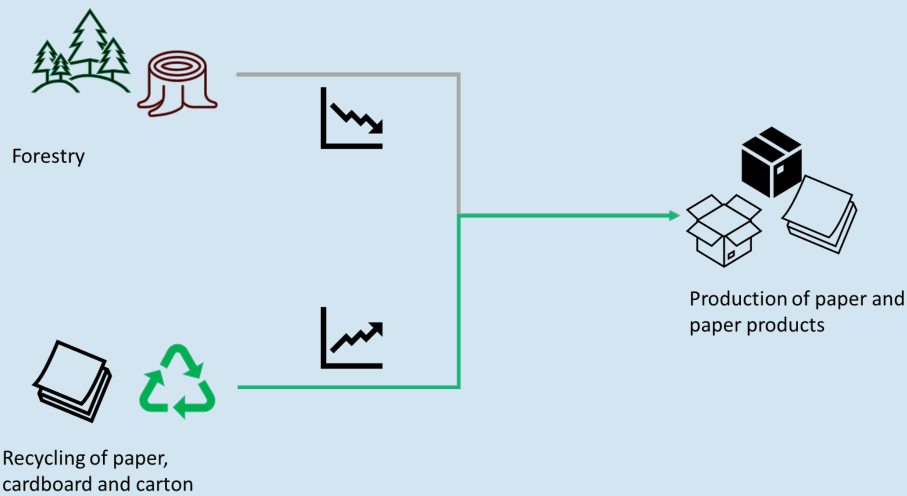
SINTEF Report 2022:00753 - Unrestricted. https://hdl.handle.net/11250/3031661

This report presents the input-output model-building work for the project's scenarios for MSW management: 1.Current Road (business as usual); 2. Frugal Road (eco-conscious citizens); 3. Circular Road (recycling focus); and 4. Carbon Road (climate action priority).

While designing and building up the modelling approach and parametres for applying the dynamic input-output model SUMSNorway to the waste management scenarios, it was possible to outline main macroeconomic mechanisms at play from a qualitative point of view already before running the model itself.

Significant findings (2009-2019):

- Pushing for higher recycling rates does not automatically lead to significant carbon emission reductions. This is due to energy-intensive recycling processes, emissions during transport, and the challenge of replacing virgin materials with recyclates. "More recycling = better sustainability" is too simplistic.
- Recycling must be paired with other measures, such as lower consumption, eco-design, resource efficiency (energy, chemicals, water), and phasing out non-recyclable materials.
- Waste policies have environmental effects but also socioeconomic effects (e.g. employment). Transition requires adaptation, but it does not seem that the circular transition harms economic growth or has negative social costs overall.
- Recycling challenges include diminishing returns and market demand for recyclates (quality, price). Stimulating demand for recyclates (incentivised, mandatory, procurement) is important.
- A combination of measures is the most efficient way to better circularity/sustainability, including strong governance, innovation and public participation.



Model changes in paper, cardboard and carton value chain with increased recycling.

Circularity and Waste Treatment in a Macroeconomic Perspective

Adrian Werner, Meron Assefa Arega

SINTEF Report 2025:00625 - Unrestricted. https://hdl.handle.net/11250/3202670

This study presents a macroeconomic analysis of two scenarios applied to Norway's waste management sector, with projections to 2035 compared to the Current Road scenario. The analysis employed SINTEF's SUMSNorway model, a dynamic input-output (supply-and-use) approach, to project the effects of policies on the Norwegian economy.

The CircWtE scenarios as modelled in SUMSNorway:

1. Current Road: baseline trajectory, projecting present trends forward without major structural or behavioural shifts,
2. Frugal Road: 50 % reduction in MSW by 2035 due to behavioural change, where reduced consumption of goods is compensated by higher spending on durable, repairable products and leisure activities.
3. Circular Road: excellent sorting and recycling enable domestic recycling chains, especially for plastic, increasing the use of recycled materials in Norwegian manufacturing.

The indicators assessed are:

- Environmental impact (GHG emissions) ,
- Economy (value-added or GDP),
- Social (employment).

Significant findings:

Frugal Road Scenario:

- Modest GDP (+1 %) and employment (+ 33,000 jobs) increases overall, but may still be challenging for the WtE sector.
- There is a slight increase in GHG emissions due to the rebound effects from increased use of leisure and repair services.
- There is a lower waste treatment demand, which reflects a dramatic behavioural change.
- Waste actors could adapt by pivoting to reuse and repair services.

Circular Road Scenario:

- There was a minor overall increase in GDP (+0.1 %) and employment (+2,000 jobs).
- GHG emissions increased slightly, mainly due to domestic plastics recycling.
- Waste management and material recovery sectors benefit, with clear emission efficiency gains.
- Waste actors could adapt by transitioning to become suppliers of recycled materials.

Overall:

- The persistent rise in GHG emissions suggets that incremental changes, though valuable, are insufficient for systematic change.
- Circular transitions do not seem to harm the economy or society overall. However, the redistribution of activities has significant workforce implications, in terms of skills, expertise and education levels.
- Stronger policy coordination (regulations, technological innovation, incentives) that can balance the various interests of economic growth and environnmental and social sustainability is necessary to guide circular transitions.
- The lack of robust, harmonised waste (and economic) data limits the precision of macroeconomic analyses of waste management impacts, and requires supplementary assumptions.

ZOOM FIVE

Regionalised Composition Analysis of Norwegian Residual Waste and Its Implications for Waste Sorting, Emission Accounting and Food Waste Avoidance

Kim Rainer Mattson, Johan Berg Pettersen

Manuscript submitted to a scientific journal and is under review

Abstract:

Residual waste generation within municipal solid waste is characterised as a mix of various waste fractions that are either correctly or incorrectly discarded in residual bins. We denote this as residuals and assess its average and regional composition in Norway, based on 90 waste composition analyses.

We observe substantial variability between generation origins, and a clear pattern of food waste accumulation in urban residuals. We assess the greenhouse gas emissions of treating the various waste compositions with incineration, and estimate that approximately 54 %, 55 % and 64 % of rural, suburban and urban residuals could potentially be recyclable, with a significant potential for reducing avoidable food waste.

Successful implementation of the national "food waste avoidance" strategy could prevent this waste, and consequently production of 110 ktons of food for Norwegian households annually.

Suggested improvements focus on convenient and clear sorting practices, better resolution on non-household residual compositions, and more multidisciplinary and regionalised assessment approaches.

Photo: Haraldrud waste sorting facility in Norway © Oslo Kommune Renovasjons- og gjenvinningsetaten

Municipal Solid Waste Generation in Norway: A Panel Analysis Investigating the Waste Kuznets Curve

Kim Rainer Mattson, Julia Sborz, Elisa Henning, Juudit Ottelin

Under preparation

Abstract:
Municipal Solid Waste (MSW) generation is a considerable issue in terms of environmental pollution and global warming and is closely linked to household consumption. The investigation of factors increasing or decreasing the MSW per capita generation has been performed using the Waste Kuznets Curve (WKC) hypothesis, looking to identify the link between various socioeconomic variables and waste generation, specifically the decoupling of economic activity and waste.

We analyse a panel data set of 244 municipalities in Norway between 2006 and 2023, identifying variables that influence MSW generation at both the general and the individual municipality level. Three regression models are used: the fixed effect model, the ordinary least squares model, and the system Generalised Method of Moments (GMM) model.

We find evidence of relative decoupling between income and MSW/capita, however, for income levels and a timeframe that arguably makes actual decoupling unlikely under current modes of consumption. Reducing MSW/capita towards the lowest levels observed in our data would take an estimated 46 years. We find that vacation home practice, measured as cabins per capita, of municipalities is a significant driver of higher MSW generation, and that periods of high interest rate reduce MSW generation. We also observed no significant effect of policy implementation on generation rates over the investigated period.

The GMM model is the most representative of the models and indicates that MSW/capita rates are consistent and historically determined, meaning that changing their trajectories will require significant changes to the current material consumption regime in Norway.

Photo: MEPEX waste analysis for CIVAC © MEPEX

Conclusions

1. We need better, faster and stronger waste data collection tools that can delve deep into various systems. Many tools could contribute here: sensors, AI, neural networks, machine learning, digitalisation, etc.

2. We need to develop an advanced set of circularity indicators to thoroughly evaluate the system at multiple levels (climate, energy, environment, economy and costs, jobs, etc.), as well as the performance and intention of relevant legislation and policies in order to adjust and adapt.

3. Future WtE must be more flexible (capacity, feedstocks, energy, etc.) in terms of the potential changes in waste amounts and properties.

4. Work on all fronts is needed to increase the quality and quantity of sorting and recycling, from customer behaviour to technologies to product design.

5. A better mapping of recycling processes and their outputs (composting, downcycling, upcycling, etc.) is necessary. The focus should be on high-impact solutions, and targeted efforts are preferable (e.g. towards specific metals), even if they may not contribute to the current targets. Furthermore, the recyclates market needs help to compete with virgin materials, e.g. through incentives, mandatory shares.

6. Waste management poses specific challenges in terms of its physical and chemical properties. Technology development (including CCS) requires work on all fronts (biological, thermal, mechanical, chemical, hydrothermal), for both novel and existing solutions. There is no "one-size-fits-all" solution.

7. Consumption patterns and habits are strongly ingrained, and not easy to influence. We cannot just expect significant, voluntary changes for the better. Instead, we must ensure that we spread knowledge/information to everyone (especially decision-makers). People should be provided with transparent, intuitive solutions.

8. We need more action before waste is created, e.g. through curbing primary production (secondhand, re-use) and adapting production to create a less wasteful, more circular production industry (designing for recycling).

9. All sidestreams from waste treatment must be valorised and integrated into the Circular Economy, from ash to digestate and sorting/recycling rejects.

10. While a national perspective can be advantageous, waste management should be developed locally/regionally. There is no "one-size-fits-all" solution; instead, solutions should be adapted to the particular site and region's advantages and limitations.

11. National treatment capacities (WtE, recycling, landfills) should be prioritised as much as possible, with exporting waste used as a last resource.

Recommendations

Industry

Industrial actors / waste sector

1. Make as much data as possible available to researchers.
2. Have realistic expectations regarding the performance of novel technologies.
3. Have a value chain approach, from resources to market, identify actors.
4. Consider opportunities to expand your activities to benefit from the unfolding of the circular economy.

Technology providers

1. We need better sorting and recycling technologies for plastic waste, food waste, waste wood and textile waste.
2. We need (innovative) solutions for rejects from sorting and recycling.
3. CCS in WtE needs special attention due to unique challenges (gas composition, energy integration, negative emissions).

R&D & Academia

1. Technology development for sorting and recycling technologies is still necessary.
2. Collaboration with technology providers is crucial to ensure the needed innovations, from advanced waste characterisation to WtE operation optimisation.
3. As the waste system is becoming more complex to respond to stringent regulations and targets, combinations of technologies may be a part of the solution. This will require integration and optimisation.

Decision-makers

Policymakers / government

We need:

1. better indicators to evaluate waste management circularity;
2. recycling targets with high impact, rather than bulk ones;
3. to evaluate circular economy policies regularly, and adjust if necessary;
4. incentives and regulations for the recycling markets to function;
5. stronger visions and strategies (regulations, innovation, public information and participation, incentives);
6. to limit the production of non-recyclable materials and goods;
7. a more integrated waste management approach (from transport to energy to climate, to employment, to crisis preparedness).

National authorities / bodies

1. We still need more and better waste data.
2. We need to consider our reliance on foreign waste treatment capacity.
3. We need to evaluate waste incineration tax and circularity.

Local authorities

1. Ensure public involvement and information.
2. Learn from each other's successes and failures, especially regarding novel technologies.
3. Design user-friendly, transparent systems to ensure high participation.

General public

1. You can support change both individually and collectively, by learning more and requesting legislative changes and industrial action.
2. Consider the impact of everyday actions and reflect on your consumption habits. A lot of what we consider to be "waste" can also be a potential resource.
3. Even small actions, such as sorting correctly at home, can contribute to a more sustainable system.