Nordic Council of Ministers

Waste incineration in the Nordic countries

A status assessment with regard to emissions and recycling



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This publication is also available online in a web-accessible version at:
https://pub.norden.org/temanord2024-524

Summary

Waste incineration plays a major role in the Nordic countries, both as a means of decreasing waste volumes while avoiding landfills (which are not used for untreated waste on a large scale anymore in the Nordics) and in terms of energy delivery to industry and households, especially in district heating.

This report aims to summarize the status and possible future development of the Nordic waste incineration sector, to analyze trends such as CCUS and circular economy goals and to define questions that need to be answered when trying to find an optimal sector size.

The main findings are:

- As a whole, the Nordic countries have a higher incineration capacity than is needed for their domestic waste. The gap is filled with imported waste from other countries.
- With the district heating sector decarbonizing its operation as a whole, fossil emissions stemming mainly from the incineration of plastic waste make up a large part of the total fossil CO_2 emissions in district heating.
- Some scenarios aim at decreasing the incineration capacity to match each country's projected domestic needs (which in these scenarios are lower than to date), while others point out high public acceptance, available process competence and especially the economic feasibility of an increased Nordic waste incineration sector, supported by the integration with district heating networks in a cold climate. Following that path might turn the Nordic countries into a hub for cost-effective waste handling in Europe.
- CCUS is widely regarded as a means to minimize fossil emissions or even turn waste incineration carbon negative. A long coastline, the presence of a well-established chemical industry (as future CO_2 users) and the proximity to potential storage sites in Norwegian and Danish waters are arguments for deploying CCS on waste incineration sites in the Nordic countries.
- Legislation and rules differ between the Nordic countries – examples are national implementation of the ETS trading scheme and taxation, but also whether changes in capacity are legally specified.
- Ambitious political circular economy goals are in place. Whether they can be reached depends primarily on the future use of plastics, both concerning their amount, composition and sorting rates.
- Illegal handling of waste is a problem, especially where high gate fees and a lack of legal consequences suggest a high financial return at low risk.

Sammanfattning

Avfallsförbränning spelar en viktig roll i de nordiska länderna, både som ett sätt att minska avfallsvolymerna och samtidigt undvika deponier (som inte längre används för obehandlat avfall i stor skala i Norden) och som leverantör av energi till industri och hushåll, särskilt som fjärrvärme.

Denna rapport syftar till att sammanfatta läget och den möjliga framtida utvecklingen av den nordiska avfallsförbränningssektorn, att analysera trender som CCUS och cirkularitetsmål samt att definiera frågor som måste besvaras när en optimal storlek på sektorn ska hittas.

De viktigaste resultaten är följande:

- Som helhet har de nordiska länderna en högre förbränningskapacitet än vad som behövs för deras avfall. Gapet fylls med importerat avfall från andra länder.
- I takt med att fjärrvärmesektorn minskar koldioxidutsläppen från sin verksamhet som helhet, utgör fossila utsläpp som främst härrör från förbränning av plastavfall en växande del av de totala fossila koldioxidutsläppen från fjärrvärme.
- Vissa scenarier siktar på att minska förbränningskapaciteten för att matcha varje lands beräknade inhemska behov (som i dessa scenarier är lägre än hittills), medan andra pekar på hög allmän acceptans, tillgänglig processkompetens och särskilt den ekonomiska genomförbarheten av en växande nordisk avfallsförbränningssektor, som stöds av integrationen med fjärrvärmenät i ett kallt klimat. Att följa sistnämnda väg skulle kunna göra de nordiska länderna till ett nav för kostnadseffektiv avfallshantering i Europa.
- CCUS anses allmänt vara ett sätt att minimera fossila utsläpp eller till och med göra avfallsförbränning koldioxidnegativ. En lång kustlinje, förekomsten av en väletablerad kemisk industri (som framtida CO_2-användare) och närheten till potentiella lagringsplatser i norska och danska vatten är argument för att använda CCS på avfallsförbränningsanläggningar i de nordiska länderna.
- Lagstiftning och regler skiljer sig åt mellan de nordiska länderna - exempel är nationell implementering av ETS-handelssystemet och beskattning, men också huruvida förändringar i kapacitet är politiskt styrda.

- Ambitiösa politiska mål för cirkulär ekonomi finns på plats. Huruvida de kan uppnås beror främst på den framtida användningen av plast, både när det gäller mängd, sammansättning och sorteringsgrad.
- Illegal hantering av avfall är ett problem, särskilt där höga avgifter och avsaknad av rättsliga konsekvenser lovar hög ekonomisk avkastning till låg risk.

Introduction

This report has been prepared by CIT Renergy, Carbon Limits and Motiva Services within the scope of the project "Waste incineration in the Nordic countries - A status assessment with regard to emissions and recycling" and summarizes the data found on this sector for the different countries.

In chapter 1, the status and relevant history of the waste incineration sector is described for every country, covering types and volumes of waste incinerated as well as the generation of heat and power and the resulting CO_2 emissions. Current and projected technological developments are included as well.

The Nordic countries differ greatly in their industrial setup: While forestry and mining play an important role in Finland and Sweden, the oil- and gas industry is vital for Norway's economy. Also, the power- and heating sectors, especially concerning the use of district heating, are diverse. As a result, the overall composition of waste in the Nordic countries is different as well. Thus, this report focuses on municipal waste, which is deemed to be more comparable between countries, even though data on total incineration capacity is also included.

Chapter 2 covers the legislative framework, both from a national, Nordic, and European perspective. The countries' view on including waste incineration in the ETS scheme is discussed as well as their different taxation strategies and the implementation of other EU regulations.

The input from chapters 1 and 2 is used as input for a synthesis in chapter 3, where questions concerning CCUS, circular economy and factors impacting the future sizing of the Nordic waste incineration sector are discussed as well as input from a series of interviews with actors in the waste incineration sector.

Chapter 4 concludes the report with an outlook on near-term trends and different possible long-term outcomes.

1. Current status of the waste incineration sector in the Nordics

1.1 Sweden

Country-specific definitions[1][2]:

The following terms are defined in Swedish legislation, but largely originate in the Waste Framework Directive and can thus be used as a guideline for other countries as well.[3] However, minor differences in the definitions may occur between the different countries.

Waste: Any object, matter or substance belonging to a specific waste category which the holder disposes of or intends or is required to dispose of.

Municipal waste: Waste from households and other sources similar in nature and composition to household waste, excluding manufacturing waste, waste from agriculture and forestry, waste from fishing, wastes from septic tanks, sewage networks and sewage treatment, construction and demolition waste and end-of-life vehicles.

Household waste: Previous definition of waste from households and comparable waste from other activities. The legal term has been dropped and partly replaced by municipal waste; the municipality's exclusive right of collection has also been changed. Nowadays, the term household waste can only be used for waste actually originating from households.

1.1.1 Capacity, energy generation and emissions

Numbers on waste input and energy output

The installed capacity for incineration of mixed waste in Sweden was about 7.1 Mtons in 2021 with a planned use of 6.3 Mtons (including stops for revision and other planned stops). The latest numbers from 2022 show that 6.8 Mtons of waste

1. *Miljöbalken,* https://www.riksdagen.se/sv/dokument-och-lagar/dokument/svensk-forfattningssamling/miljobalk-1998808_sfs-1998-808/
2. *Vägledning till definitionen av kommunalt avfall,* https://www.naturvardsverket.se/4967fb/contentassets/6aa56ee36643417ca7057ccbaa40bb66/vagledning-definitionen-kommunalt-avfall-version-2.pdf
3. *Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance),* https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02008L0098-20180705

was sent to incineration facilities.[4] Of these, roughly 30% stem from pre-sorted municipal waste and 70% from commercial and industrial waste. Not included in these numbers is waste incineration without energy recovery (usually for destruction of hazardous waste), which accounted for 71.000 tons in 2020.[5]

The historical development of municipal waste incineration in Sweden has seen a distinct rise in treated volumes starting from the 1970s, see Figure 1.

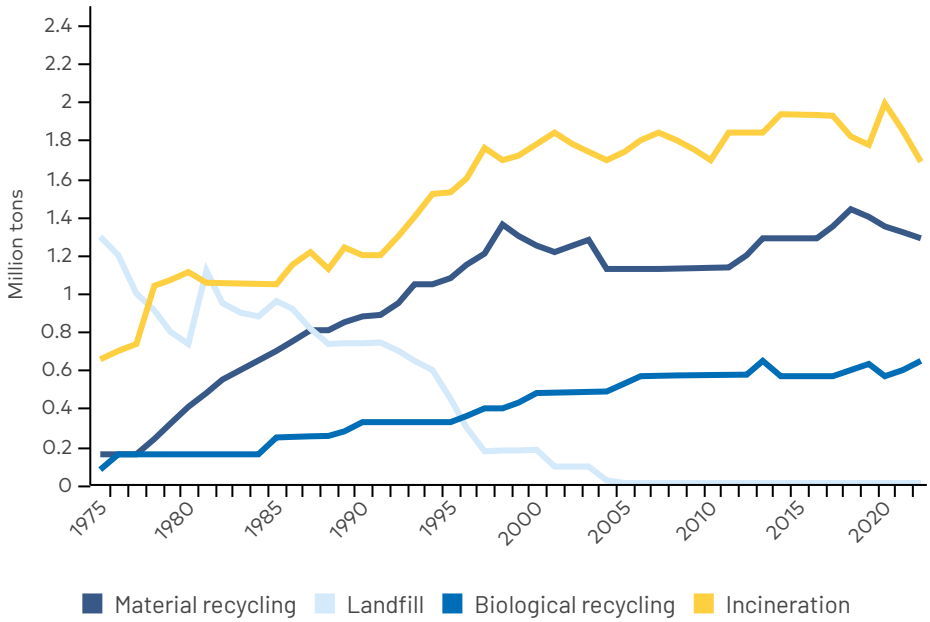

Figure 1 Development of different waste handling methods over time. All numbers concern municipal waste.[6]

While landfill still dominated in 1975, both recycling and waste incineration with energy recovery have grown more important since, with biological treatment of household waste (i.e., composting) steadily increasing as well. Landfill of untreated household waste does not occur on a relevant scale anymore. Almost all waste incineration with energy recovery in Sweden is done in combined heat and power (CHP) plants.

In the coming years, a capacity decrease of around 100 ktons per year is projected, while two new, smaller plants with a combined capacity of around 40 kton per year are planned, leaving the total capacity at a similar level as today.

4. *Kapacitetsutredning 2022-Energiåtervinning och mängder restavfall till år 2027,* Avfall Sverige
5. *Avfall i Sverige 2020*, Naturvårdsverket
6. *Svensk Avfallshantering 2022,* Avfall Sverige

The district heating sector is well-established in Sweden, and waste incineration contributes substantially to the energy balance: 17.9 TWh of heat were generated in 2022, with an additional production of 3 TWh electricity. Some units also produce district cooling, but the volume is marginal in comparison (0.09 TWh in 2022).

In total, waste incineration supplies around 25% of all district heating and around 1.8% of the Swedish electric power.

Among other reasons, the integration with the district heating sector has led to a high per-capita incineration capacity, which in part must be filled by waste from other countries. The import of waste-derived fuels to dedicated waste incineration plants (i.e., excluding sorted waste to recycling facilities and waste-derived fuel used in cement factories or other industries) in Sweden has stagnated at 1.4 to 1.6 Mtons per year since 2017. In the decade before that, a steep increase could be observed. The main countries of origin are Norway and Great Britain. For 2027, Avfall Sverige projects a necessary import volume of 1 to 1.9 Mtons, depending on the degree of sorting in Swedish and imported municipal waste and the development of incineration capacity until then.

Emissions

While emissions of dioxins, NO_x, SO_2 or HCl from waste incineration have been widely discussed and are frequently used as an argument against this technology, the focus of this report is on fossil CO_2 emissions. When assessing these, it must be considered that waste-derived fuels are made up of a mixture of biogenic and fossil sources. The share of fossil and biogenic CO_2 emissions can be determined indirectly by measuring the C14 content in the exhaust gases.

During the last decades, recycling behavior, the composition of waste-derived fuels and the overall fuel mix in CHP plants have changed considerably. The change from fossil- to biofuels in the Swedish CHP sector is distinct: from 2010 to 2021, total CO_2 eq emissions decreased by more than 50%, see Figure 2.

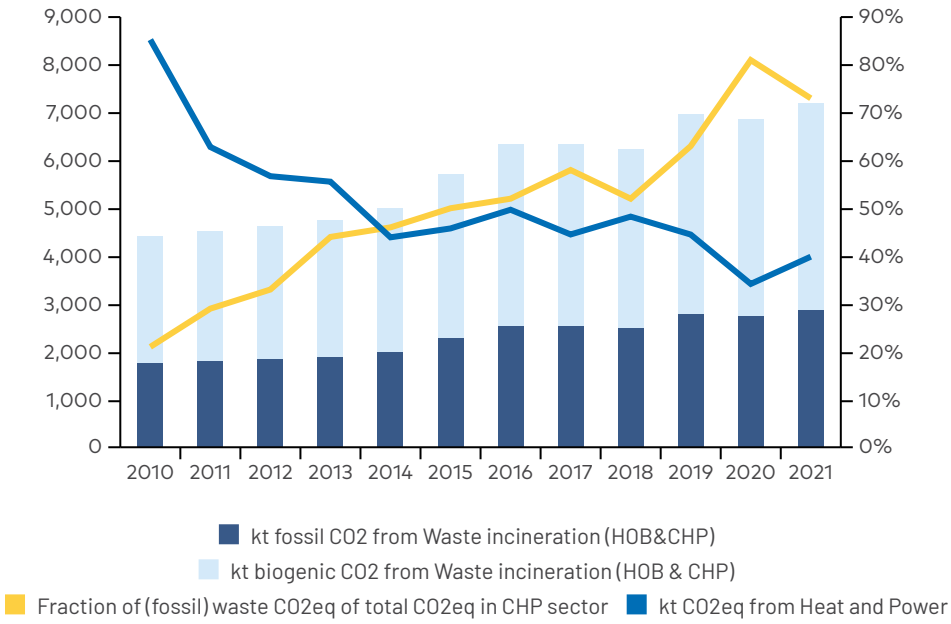

Figure 2 Biogenic and fossil emissions from waste incineration assuming a 60:40 share as gathered from several sources.[7][8][9] Curves show total CO_{2eq} emissions from heat and power generation and the waste incineration sector's rising share (CHP: combined heat and power. HOB: heat only boilers).

In combination with the above-mentioned expansion of waste incineration, the share of fossil CO_2 the sector contributes to total CO_2 emissions from CHP has therefore increased as well: in 2021, 73% of all CO_2 eq emissions in the CHP sector were from waste incineration. This highlights the importance of strategies to decrease these emissions, for example by increasing the recycling ratio of waste currently going to incineration or by deploying CCS in waste incineration.

1.1.2 Technology developments and pilots

As for many other industries, CCUS is considered a promising technology for the waste incineration sector to both handle inevitable fossil CO_2 emissions and provide a feedstock of carbon-containing molecules for the chemical- or fuel industry of the future. No industrial-size pilots have been deployed so far, but projects are being drawn up, e.g., at the Sävenäs plant in Göteborg, where one to two out of four fuel lines might be equipped with CCS until 2030.[10]

7. https://www.energi.se/artiklar/2022/maj-2022/bredda-stodet-till-all-avfallsforbranning/
8. *Restavfallets Klimatpåverkan 2021*, https://www.stockholmexergi.se/content/uploads/2021/07/Rapport-Avfallets-klimatp%C3%A5verkan-2021.pdf
9. Hållbarhetsredovisning 2022, https://www.renova.se/globalassets/02.hallbarhet/renova_hallbarhetsredovisning.pdf
10. *Här blir avfall till el och värme*, Renova, 2023, https://www.renova.se/globalassets/11.-pdf-er/har-blir-avfall-till-el-och-varme/har_blir_avfall_till_el_och_varme_2023_v_2.pdf

Apart from CCS, other technological advances are made in the waste sector:

On the recycling side, an industrial scale pyrolysis plant for material recycling of plastics which cannot be recycled mechanically and with a capacity of initially 25.000 ton/year is planned at Borealis in Stenungsund (the plans for establishment however being put on hold for the time being[11]), and Svensk Plaståtervinning is building a new recycling facility in Motala.[12]

As a means to increase operational flexibility, efficiency and the resilience of the local district heating network, Mälarenergi in Västerås is currently constructing a 300.000m^3 underground hot water reservoir in a rock cavern previously used as heavy oil storage. In case of unplanned outages, the cavern can supply the city of Västerås with district heating for about 2 weeks.

Some research is also conducted towards extracting materials from waste- or ash streams in the future.

1.2 Norway

1.2.1 Capacity, energy generation and emissions

In comparison with other European countries, the Norwegian population generates more waste per person, reaching 726 kg in 2020, than the EU-27 average representing 505 kg.[13] Today, the share of waste being valorized through material recycling or energy recovery is lower than what it was in 2011.[14] It gradually increased from 62% in 1995 to 87% in 2011 and reduced afterwards to 73% in 2021.

This trend was observed while the amount of waste treated has remained fairly stable since 2012, showing a slight increase as shown on Figure 3. It reached a peak in 2018 at 11.8 Mtons and decreased to 11.5 Mtons in 2021. Mechanical recycling remained the main waste treatment with a share of 33% in 2021. Then, incineration has the second biggest flow of waste treated, representing 26.5% in 2021.

11. Personal communication, Marie-Louise Johansson, Borealis, 2023-12-01
12. *Plastic in Sweden – facts and practical advice*, Naturvårdsverket, 2022, https://www.naturvardsverket.se/496fd7/globalassets/media/publikationer-pdf/8800/978-91-620-8888-0.pdf
13. Municipal waste statistics. (n.d.). Retrieved 23 October 2023, from https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Municipal_waste_statistics
14. Avfall i Norge. (2022, December 8). Miljøstatus. https://miljostatus.miljodirektoratet.no/tema/avfall/

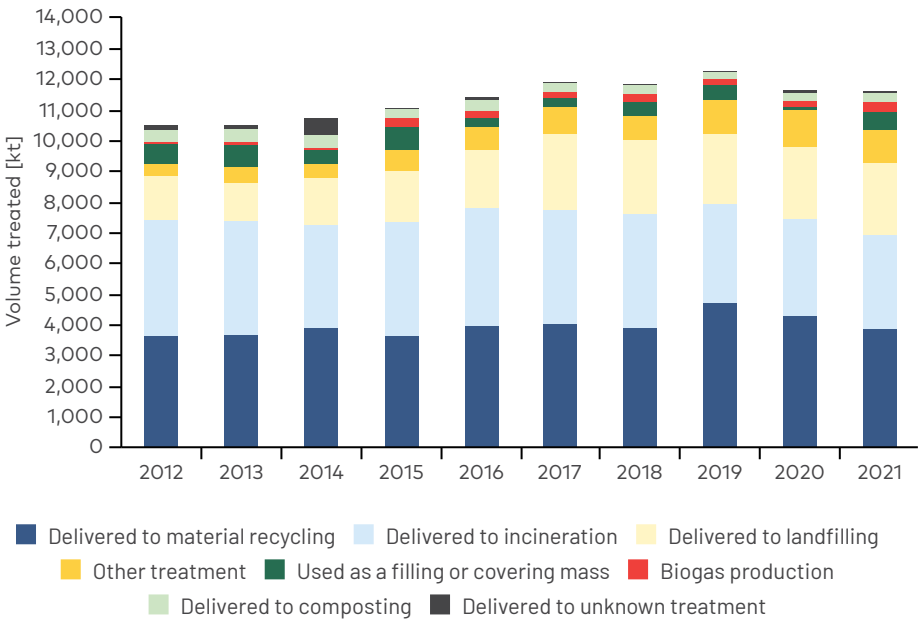

Figure 3 Evolution of waste treatment in Norway. Source: 10513: Avfallsregnskap for Norge (1 000 tonn), etter behandlingsmåte, materialtype, statistikkvariabel og år. Statistikkbanken. (n.d.). SSB. Retrieved 22 October 2023, from https://www.ssb.no/system/

As one of the main treatment options for waste in Norway, the incineration activity is constituted of 18 plants in operation as of 2022. Of which, 7 main incineration plants burning more than 100 000 ton of waste per year.[15] Moreover, two other cement plants happen to incinerate waste. Incineration plants dedicated to wood byproducts and waste are not included in this assessment. In 2021, 3.1 Mtons of waste has been incinerated in total, producing 0.94 Mtons of CO_2 eq.[16] CO_2 from biomass is not included in this accounting methodology but all other greenhouse gases are converted into CO_2 equivalent. Specific emissions of CO_2 will be presented later in this chapter. The CO_2 eq. emissions represent 2.7% of the total Norwegian emissions (35 Mtons CO_2 eq.).[17] Figure 4 represents the evolution of volumes of waste sent to incineration since 1995 and its related emissions.

15. Avfallsforbrenning med energiutnyttelse. (2022, December 9). Miljøstatus. https://miljostatus.miljodirektoratet.no/tema/avfall/avfallshandtering/avfallsforbrenning-med-energiutnyttelse/
16. Avfallsforbrenning med energiutnyttelse. (2022, December 9). Miljøstatus. https://miljostatus.miljodirektoratet.no/tema/avfall/avfallshandtering/avfallsforbrenning-med-energiutnyttelse/
17. 08940: Klimagasser, etter utslippskilde, energiprodukt og komponent, GWP-verder etter Kyotoprotokollen (AR4) (avslutta serie) 1990 - 2022. Statistikkbanken. (n.d.). SSB. Retrieved 17 October 2023, from https://www.ssb.no/statbank/table/08940

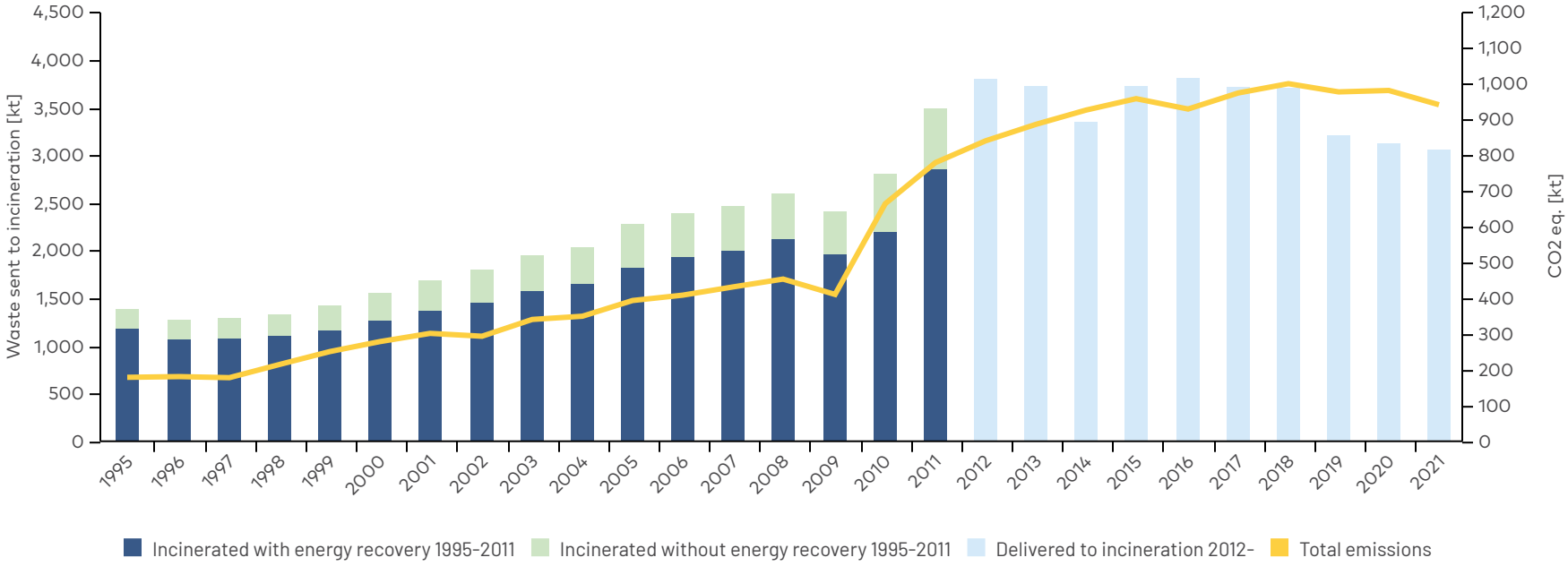

Figure 4 Volume of waste incinerated over time and related emissions. Source: Avfallsforbrenning med energiutnyttelse. (2022, December 9). Miljøstatus. https://miljostatus.miljodirektoratet.no/tema/avfall/avfallshandtering/avfallsforbrenning-med-energiutnyttelse/

The volumes sent to incineration tripled during that period, peaking in 2016 at 3.8 Mtons and decreased steadily from 2018. The economic crisis in 2008 led to a reduced waste generation, coming probably mainly from the construction and service sector.[18] The corona pandemic in 2020 did not significantly influence the total amount of waste generated compared to the observed trend for those years but changed the distribution of waste generation, with a 4% increase in household waste and a decrease of 30% from the service industry.[19] The next year, waste from households decreased by 2% and the service industry waste reached its pre-corona level.

The emission curve related to the incineration activity follows the evolution of the total waste delivered. Different data series have been gathered by the Environment Agency to produce Figure 4 and the split between incineration with or without energy recovery is not registered in this reporting since 2012, even though a limited incineration activity that does not recover energy still remains today.[20] Moreover, the energy recovery must be of a minimum of 60–65% for the activity to be categorized as energy recovery. In 2018, four plants were below that requirement so the volume of waste that was treated by these plants was reported similarly to a "disposing/landfilling" activity.[21] Those four plants treated about 9% of the total waste delivered to incineration this year. This indicates that about 5% of the total waste delivered was mixed waste being "disposed". Industrial waste similar to household and delivered to that "disposing" activity most likely represented the same amount as the usual household mixed waste. Today, that waste is accounted in the "other treatment" category.[22]

The type of waste that is sent to incineration is represented in Figure 5. The split has not significantly changed since 2012. Most of the waste is mixed waste, representing 60% of the total share in 2021. Then, wood waste (18%), hazardous waste (12%), plastic (3%) and sludge (3%) make up the rest of the volume in 2021. All other categories are under 1% each.

18. Avfall i Norge. (2022, December 8). Miljøstatus. https://miljostatus.miljodirektoratet.no/tema/avfall/
19. Avfall i Norge. (2022, December 8). Miljøstatus. https://miljostatus.miljodirektoratet.no/tema/avfall/
20. Miljødirektoratet. (2019). Avfallsplan 2020-2025—Status og planer for avfallshåndtering, inkludert avfallsforebyggingsprogram (1582; p. 72). Miljødirektoratet. https://www.regjeringen.no/contentassets/c6a9a384d90c4af18bfd8458f3167708/avfallsplan-2020-2025.pdf
21. Miljødirektoratet. (2019). Avfallsplan 2020-2025—Status og planer for avfallshåndtering, inkludert avfallsforebyggingsprogram (1582; p. 72). Miljødirektoratet. https://www.regjeringen.no/contentassets/c6a9a384d90c4af18bfd8458f3167708/avfallsplan-2020-2025.pdf
22. Veileder for KOSTRA rapporteringsåret 2020 -Skjema 21: Husholdningsavfall 2020. (n.d.). https://www.ssb.no/forside/_attachment/440910

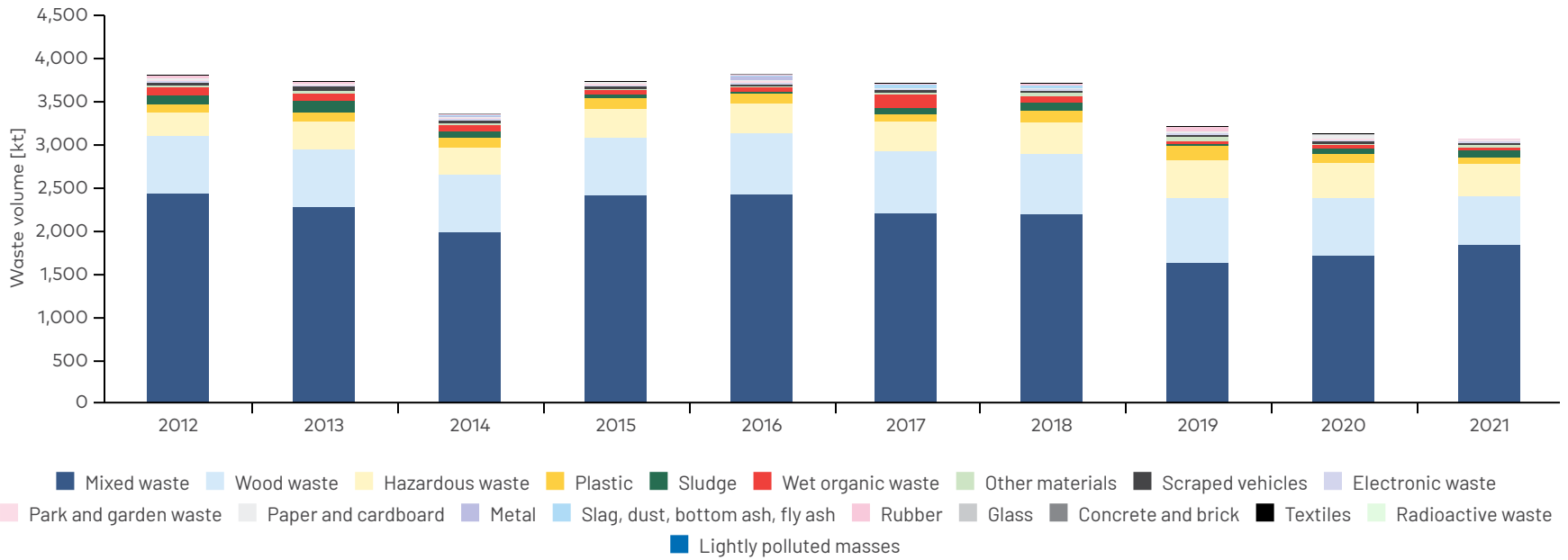

Figure 5 Type of waste incinerated over time. Source: Avfallsforbrenning med energiutnyttelse. (2022, December 9). Miljøstatus. https://miljostatus.miljodirektoratet.no/tema/avfall/avfallshandtering/avfallsforbrenning-med-energiutnyttelse/

Some trends in terms of volume and type of waste can be identified. Historically, a decrease in paper waste has been observed. This decrease is due to changes in newspaper reading habits.[23]

There are no official national statistics regarding the composition of mixed waste that goes to waste incinerators, however, analyses have been conducted at the municipal level for the commune of Oslo and the intercommunal area of Romsdal in 2017. The results are shown in Figures 5.1 and 5.2 below. They reveal that both regions share similarities in the overall composition of mixed waste, i.e. the dominance of food waste as a significant component of mixed waste (32.3% in Oslo and 20.9% in Romsdal) or the relatively low percentage in hazardous and/or EE-waste. Nevertheless, the variations in percentages suggest that waste composition is not uniform and can vary between regions, i.e. due to local consumption patterns or waste management strategies.[24]

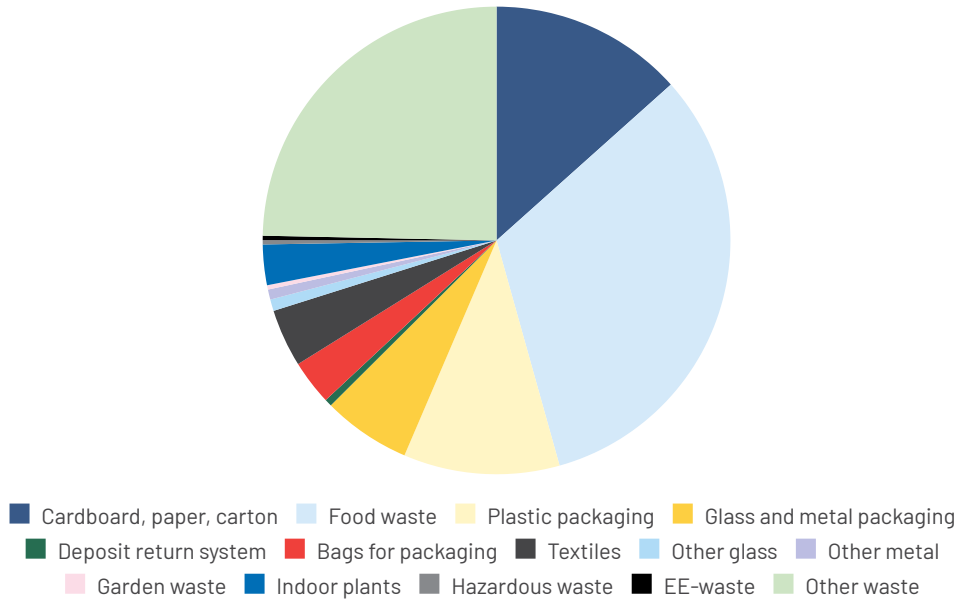

Figure 5.1 The composition of residual waste in the commune of Oslo Source: Hjellnes Consult AS for Renovasjonsetaten. (2017) Avfallsanalysen Oslo 2017https://avfallnorge.no/fagomraader-og-faggrupper/plukkanalyser/analyse-i-oslo-kommune

23. Sveinung, B., Frode, S., & Andreas, D. (2019). Avfallsmengder fram mot 2035—Energigjenvinningens rolle i sirkulærøkonomi (07/2019; p. 32). Mepex Consult AS. https://avfallnorge.no/fagomraader-og-faggrupper/rapporter/avfallsmengder-fram-mot-2035
24. Hjellnes Consult AS for Renovasjonsetaten. (2017) Avfallsanalysen Oslo 2017 (p.23) https://avfallnorge.no/fagomraader-og-faggrupper/plukkanalyser/analyse-i-oslo-kommune ; Sveinung, B., Frode, S. (2018) Plukkanalyse RIR 2017 (p.5). https://avfallnorge.no/fagomraader-og-faggrupper/plukkanalyser/plukkanalyse-romsdalen-interkommunale-renovasjons-selskap-iks

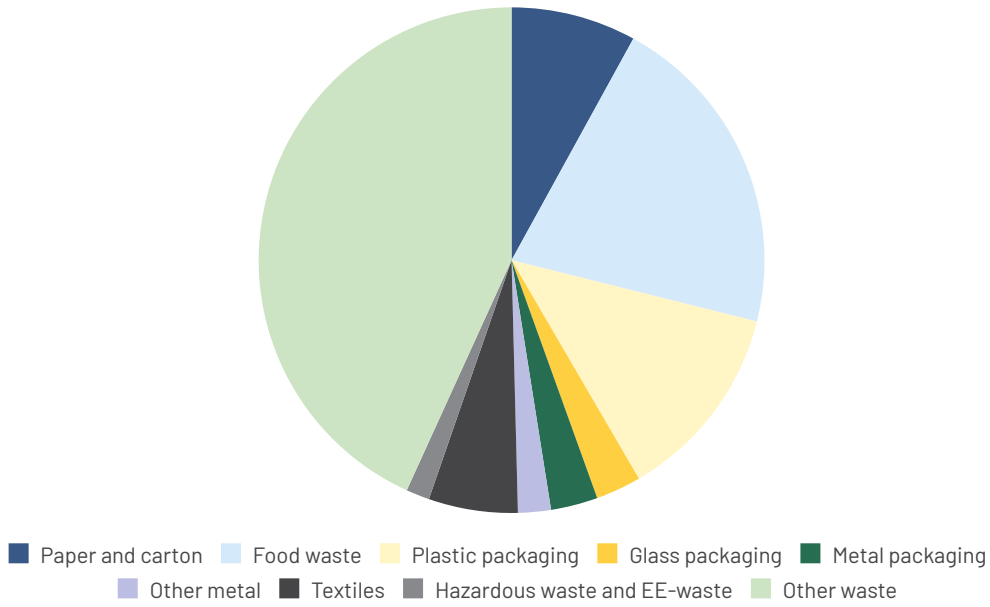

Figure 5.2 The composition of residual waste in the intercommunal area of Romsdal Source: Sveinung, B., Frode, S. (2018) Plukkanalyse RIR 2017. https://avfallnorge.no/fagomraader-og-faggrupper/plukkanalyser/plukkanalyse-romsdalen-interkommunale-renovasjons-selskap-iks

Furthermore, the continuous developments in sensor and sorting technology occurring upstream allow to deliver more waste to material recycling and have an influence on the type of waste that the incineration plants receive.[25] A general reduction in household waste delivered to incineration has been observed, while industrial waste has been increasing.[26] At the same time, efforts are being made in the industry and at the product design stage, especially for packaging, aiming at increasing the material recyclability of products. On the other hand, new types of waste will have to be treated (depending on the volume generated), such as decommissioned windmills or artificial football pitches for example.[27] The incineration sector might play a role for some of them when relevant.

25. Miljødirektoratet. (2019). Avfallsplan 2020-2025—Status og planer for avfallshåndtering, inkludert avfallsforebyggingsprogram (1582; p. 72). Miljødirektoratet. https://www.regjeringen.no/contentassets/c6a9a384d90c4af18bfd8458f3167708/avfallsplan-2020-2025.pdf
26. Sveinung, B., Frode, S., & Andreas, D. (2019). Avfallsmengder fram mot 2035—Energigjenvinningens rolle i sirkulørækonomi (07/2019; p. 32). Mepex Consult AS. https://avfallnorge.no/fagomraader-og-faggrupper/rapporter/avfallsmengder-fram-mot-2035
27. Miljødirektoratet. (2019). Avfallsplan 2020-2025—Status og planer for avfallshåndtering, inkludert avfallsforebyggingsprogram (1582; p. 72). Miljødirektoratet. https://www.regjeringen.no/contentassets/c6a9a384d90c4af18bfd8458f3167708/avfallsplan-2020-2025.pdf

A potential for incinerating more hazardous waste has been observed.[28] Hazardous waste tagged in green on the official list of hazardous waste such as impregnated wood with chromated copper arsenate (CCA) or waste containing brominated compounds could be incinerated in usual incineration plants. The decision to allow the incineration of such waste lies at each regional authority level. This could allow the waste incineration sector to substitute a relevant amount of waste[29] that is expected to decrease with the Circular Economy strategy presented in the next paragraph.

Role of waste incineration in waste treatment

The national strategy for Circular Economy sets time-incremented goals as shown in Table 1.

Table 1 Preparation for reuse and material recycling goals in Norway in 2035[30]

Requirements	2020	2025	2030	2035
Preparation for reuse and material recycling of household waste and similar waste from the industry			65%	70%
Material recycling of all packaging		65%	70%	70%
Preparation for reuse and material recycling of building and construction waste	70%			
Reduction in food waste	15%	30%	50%	

No goal is set for waste incineration in this strategy, but it is mentioned that a significant amount of the remaining waste not being reused or recycled will have to be incinerated. It is however required that the plant should produce heat and electricity from it.[31] The waste incineration sector plays therefore a role in this strategy. Moreover, the installation of carbon capture solutions on waste

28. Sveinung, B., Frode, S., & Andreas, D. (2019). Avfallsmengder fram mot 2035—Energigjenvinningens rolle i sirkulærøkonomi (07/2019; p. 32). Mepex Consult AS. https://avfallnorge.no/fagomraader-og-faggrupper/rapporter/avfallsmengder-fram-mot-2035
29. Sveinung, B., Frode, S., & Andreas, D. (2019). Avfallsmengder fram mot 2035—Energigjenvinningens rolle i sirkulærøkonomi (07/2019; p. 32). Mepex Consult AS. https://avfallnorge.no/fagomraader-og-faggrupper/rapporter/avfallsmengder-fram-mot-2035
30. Klima- og miljødepartementet. (2021). Nasjonal strategi for ein grøn, sirkulær økonomi (978-82-457-0524–9; T-1573 N, p. 164). https://www.regjeringen.no/no/dokumenter/nasjonal-strategi-for-ein-gron-sirkular-okonomi/id2861253/
31. Klima- og miljødepartementet. (2021). Nasjonal strategi for ein grøn, sirkulær økonomi (978-82-457-0524–9; T-1573 N, p. 164). https://www.regjeringen.no/no/dokumenter/nasjonal-strategi-for-ein-gron-sirkular-okonomi/id2861253/

incineration plants is also seen as a way to increase the circularity of carbon dioxide in case it is then reused in the economy.

Moreover, a further requirement has been implemented since January 2023: all food and plastic waste must be sorted out.[32] This regulation concerns households but also private entities and institutions that produce similar waste as households and plastic from agriculture. This waste should be recycled or prepared for reuse.

Role of waste incineration in the energy sector

The incineration sector plays a significant role as a district heating provider. As shown in Figure 6, waste incineration has been the main provider of heat used in district heating since 2013, representing 43% of the total production in 2022, reaching 3036GWh. Wood chips incineration has gained a bigger role over time, reaching 28% in 2022.

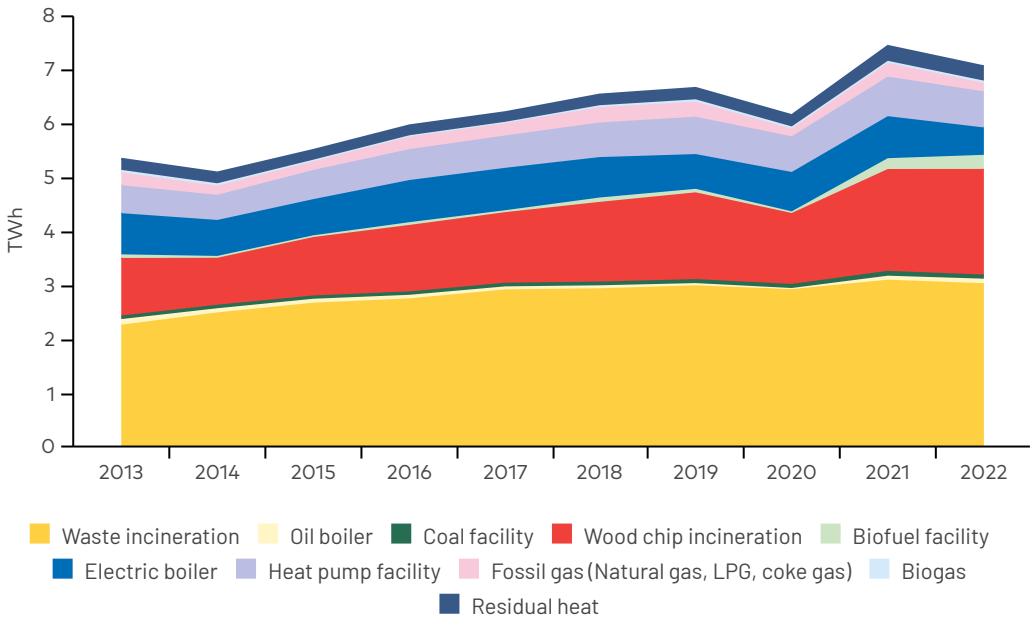

Figure 6 District heating supply in Norway over time. Source: Fjernvarme og fjernkjøling. (n.d.). SSB. Retrieved 3 October 2023, from https://www.ssb.no/energi-og-industri/energi/statistikk/fjernvarme-og-fjernkjoling

On the other hand, waste incineration plays a less significant role in electricity generation. With 83MW of installed capacity in 2022, waste incineration represents 13% of the total installed capacity provided by thermal plants in Norway and only 0.2% of the total installed capacity overall as shown in Table 2. The Norwegian

32. miljødepartementet, K. (2022, June 7). Strengere krav til kildesortering av avfall [Nyhet]. Regjeringen.no; regjeringen.no. https://www.regjeringen.no/no/aktuelt/strengere-krav-til-kildesortering-av-avfall/id2917708/

Energy Regulatory Authority does not provide normal year production for the waste incineration activity. By taking the 13% ratio of installed capacity and assuming a normal year production for all the thermal plants, it is estimated that the waste incineration would produce 0.4TWh.

Table 2 Electricity production in Norway. Modified from: Kraftproduksjon—NVE. (n.d.). Retrieved 23 October 2023, from https://www.nve.no/energi/energisystem/kraftproduksjon/

Technology	Installed capacity (MW)	Normal year production (TWh)
Hydroelectric	33730	136.9
Wind	5083	16.9
Thermal	559	2.7
Waste incineration	83	0.4
Total	**39455**	**156.9**

International trade linked to waste incineration

The Norwegian waste policy is framed by the European Economic Agreement (EEA). It ensures a common waste market in the European economic area and each year Norway exports 2 Mtons and imports a bit below 1 Mtons of waste (all waste treatment types included).[33] Waste that has low environmental risk and that is sent to recycling does not need to be reported to the Norwegian Environment Agency and is not included in export statistics. All other types of waste export have to be reported. The waste categorization is based on the Basel convention[34] and the European List of Waste (LoW).[35]

33. Klima- og miljødepartementet. (2021). Nasjonal strategi for ein grøn, sirkulær økonomi (978-82-457-0524–9; T-1573 N, p. 164). https://www.regjeringen.no/no/dokumenter/nasjonal-strategi-for-ein-gron-sirkular-okonomi/id2861253/
34. Secretariat of the Basel Convention. (2020). BASEL CONVENTION ON THE CONTROL OF TRANSBOUNDARY MOVEMENTS OF HAZARDOUS WASTES AND THEIR DISPOSAL (p. 98). https://www.basel.int/TheConvention/Overview/TextoftheConvention/tabid/1275/Default.aspx
35. Commission Decision of 3 May 2000 replacing Decision 94/3/EC establishing a list of wastes pursuant to Article 1(a) of Council Directive 75/442/EEC on waste and Council Decision 94/904/EC establishing a list of hazardous waste pursuant to Article 1(4) of Council Directive 91/689/EEC on hazardous waste (notified under document number C(2000) 1147) (Text with EEA relevance) (2000/532/EC), (2015). http://data.europa.eu/eli/dec/2000/532/2015-06-01/eng

The export of waste has increased since 2010, partly due to an increase of mixed waste export to incineration plants in Sweden. With a total incineration capacity of around 1.7–2 Mtons of mixed waste in 2019,[36][37] Norway has to export its excess waste. Moreover, Swedish plants have had available capacity for a number of years and offered competitive prices for the reception and incineration of mixed waste.[38]

While 750 000 tons of mixed waste was exported to Sweden for incineration in 2018, 160 000 tons of mixed waste coming from the UK has been imported the same year to be incinerated in Norway.[39]

CO_2 emissions from the waste incineration sector

Dedicated statistics on fossil and biogenic CO_2 are available from the national industrial registry. Trends can be observed even though emission reporting data for some plants is missing in the registry. Figure 7 indicates a progression in total CO_2 emissions from 160ktons in 2000, to 1.5 Mtons in 2022. There has been a general decrease to 194ktons emitted in 2007 but it increased steadily after that. The share of biogenic CO_2 fluctuated between 12% in 2003 and 62% in 2009. There have been 0.74 Mtons of biogenic CO_2 emissions in 2022, representing 51% of total CO_2 emitted. The fluctuation of the biogenic share might be due to the change in waste type and reporting practices from companies. Some companies are monitoring their biogenic CO_2 and others base their reporting on a standard ratio. This aspect will be further discussed in the legislative framework chapter on Norway.

36. Sveinung, B., Frode, S., & Andreas, D. (2019). Avfallsmengder fram mot 2035—Energigjenvinningens rolle i sirkulærøkonomi (07/2019; p. 32). Mepex Consult AS. https://avfallnorge.no/fagomraader-og-faggrupper/rapporter/avfallsmengder-fram-mot-2035
37. Import og eksport av avfall. (2022, June 20). Miljøstatus. https://miljostatus.miljodirektoratet.no/tema/avfall/import-og-eksport-av-avfall/
38. Miljødirektoratet. (2019). Avfallsplan 2020-2025—Status og planer for avfallshåndtering, inkludert avfallsforebyggingsprogram (1582; p. 72). Miljødirektoratet. https://www.regjeringen.no/contentassets/c6a9a384d90c4af18bfd8458f3167708/avfallsplan-2020-2025.pdf
39. Miljødirektoratet. (2019). Avfallsplan 2020-2025—Status og planer for avfallshåndtering, inkludert avfallsforebyggingsprogram (1582; p. 72). Miljødirektoratet. https://www.regjeringen.no/contentassets/c6a9a384d90c4af18bfd8458f3167708/avfallsplan-2020-2025.pdf

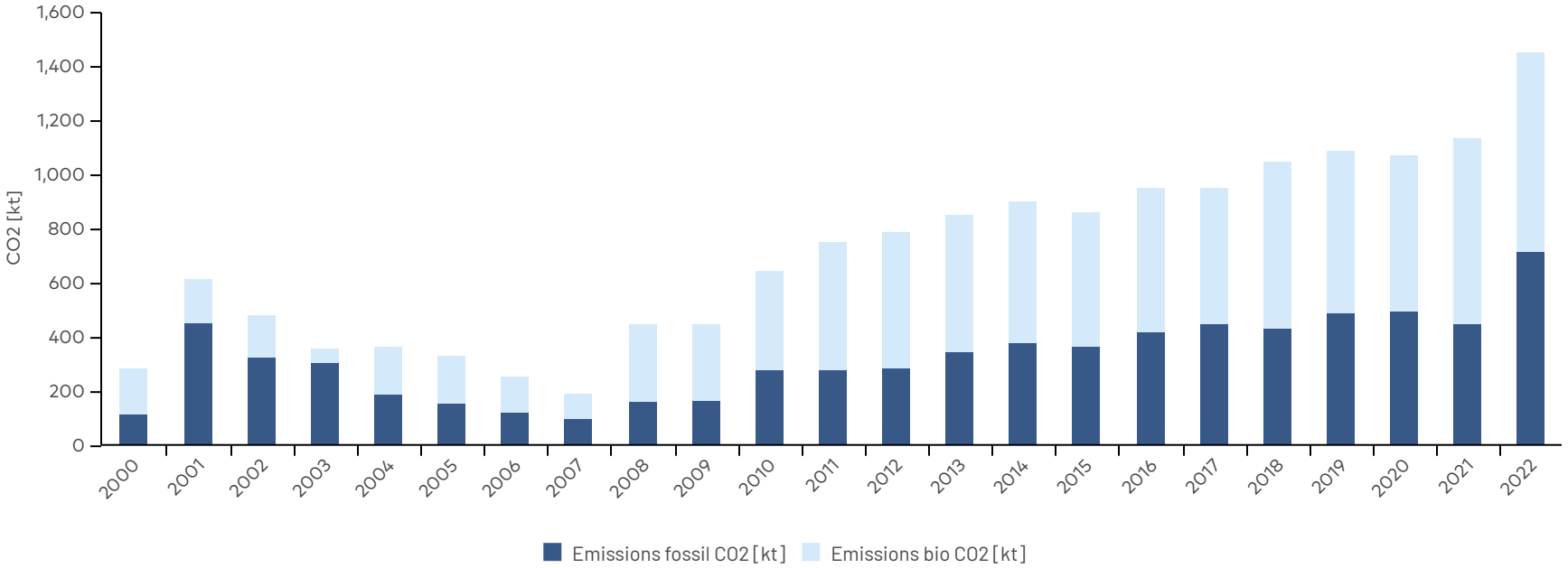

Figure 7 Fossil and biogenic CO_2 emissions over time. Source: Norske utslipp, Landbasert industri. (n.d.). Retrieved 23 October 2023, from https://www.norskeutslipp.no/no/Landbasert-industri/?SectorID=600

1.2.2 Technology developments and pilots

Carbon capture and storage

The Norwegian government has made major funding commitments to the Longship Project which aims to realize the first industrial Carbon Capture and Storage (CCS) chain. As part of the project, for the implementation of a carbon capture installation that will capture up to 400 000 tons of CO_2 per year, the WtE plant Hafslund Oslo Celsio has secured a state aid agreement with the Norwegian government that gives, up to a certain level (NOK3.08 billion[40]), certainty for cost coverage for both capital expenditure and operation, including subsidies for CO_2 captured outside the ETS sector.[41] Hafslund Oslo Celsio has also secured investments up to NOK6 billion from the City of Oslo (NOK 2.1 billion) and its partners but since April 2023 the project is set on hold and entered a 12-month cost reduction period after its biannual cost and uncertainty analysis revealed a risk to exceed the maximum budget in its funding agreement.[42]

Further opportunities to secure investments and revenues for CCS technology are being explored within the context of voluntary carbon markets (VCMs), where bio-CCS (or often called BECCS) certificates from waste incineration could be sold to potential buyers. Hafslund Oslo Celsio is working with CCS+, an initiative that aims to unlock the potential of certified CO_2 capture, utilization, removal, and storage solutions, to develop the appropriate carbon accounting methodologies for that purpose.[43] However, the feasibility of such practice faces certain challenges. On the one hand, questions regarding claims that can be made by VCM buyers purchasing BECCS credits from Norwegian waste incineration plants need to be settled, as emissions reductions under the current policy framework are to contribute to national targets.[44] On the other hand, Celsio's Longship state aid agreement sets out a limitation requiring the deduction of incomes from the sale of BECCS certificates from state support. Securing real financial benefits through the sale of certificates in the VCM is therefore contingent upon high enough price levels but these are oftentimes fluctuating.

40. Karbonfangst i Oslo realiseres. (n.d.). Hafslund. Retrieved 20 October 2023, from https://hafslund.no/nyheter/karbonfangst-i-oslo-realiseres
41. Regulatory Lessons Learned from Longship – The public sector's involvement in Europe's first industrial CCS chain. (n.d.). Fullskala. Retrieved October 19, 2023, from https://ccsnorway.com/publication/regulatory-lessons-learned/
42. The City of Oslo ensures realisation of carbon capture and storage (CCS). (2022, March 23). Oslo Kommune. https://www.oslo.kommune.no/politics-and-administration/politics/press-releases/the-city-of-oslo-ensures-realisation-of-carbon-capture-and-storage-ccs ; Status june 2023, Longship. (2023, August 8). Fullskala. https://ccsnorway.com/status-june-2023-longship/
43. CCS+ initiative—Partners. (n.d.). CCS+ Initiative. Retrieved October 12, 2023, from https://ccsplus.org/governance/
44. For further discussion see, i.e. Möllersten, K., & Zetterberg, L. (2023). Bringing BECCS credits to voluntary carbon markets—A policy brief by Sustainable Finance Lab

The Returkraft waste incineration plant in Kristiansand is testing out CCS technology with support from CLIMIT since May 2023 after having received funding for research, development and demonstration of CCS technologies under the CLIMIT programme run by Gassnova SF.[45]

Other waste incineration actors are also looking to implement carbon capture. As most of them face the same challenges, 8 of the main actors active in waste incineration decided to create a common collaboration entity (KAN) to share information and work together to solve different challenges linked to the implementation of CCUS.[46]

1.3 Finland

Definitions (Waste Act 646/2011)

Municipal waste means waste generated from permanent dwellings, free-time dwellings and residential homes as well as other residential waste, including paper, cardboard, glass, metal, plastic, textile and biowaste as well as discarded electrical and electronic equipment, discarded batteries and accumulators, and discarded large items, as well as waste that is similar in nature generated from administrative, service and business activities excluding, however, septic tank and cesspool sludge.

Mixed municipal waste means the municipal waste remaining after fractions specified by waste type have been separately collected at source.

1.3.1 Capacity, energy generation and emissions

In the report "The circular economy of waste incineration and influencing the climate effects with different control methods" from the year 2021, it is pointed out that currently in Finland approximately 56% of the total amount of municipal waste is incinerated. Based on environmental permits, the combustion capacity of waste incineration plants is a total of approximately 1.8 Mtons/year. Based on the environmental reports of waste incineration plants, the incineration capacity utilization rate is approximately 90%. The situation has changed a little since this, because during this survey, nine waste incineration plants were in use, and currently 11 waste incineration plants are in operation, whereby the waste incineration capacity has increased to 2.1 Mtons/a.

45. Returkraft is testing out membrane technology with support from CLIMIT. (2023, June 29). Climit. https://climit.no/en/news/returkraft-is-testing-out-membrane-technology-with-support-from-climit/
46. KAN - Klimakur for Avfallsforbrenning. (n.d.). KAN - Klimakur for Avfallsforbrenning. Retrieved 23 October 2023, from https://www.kanco2.no

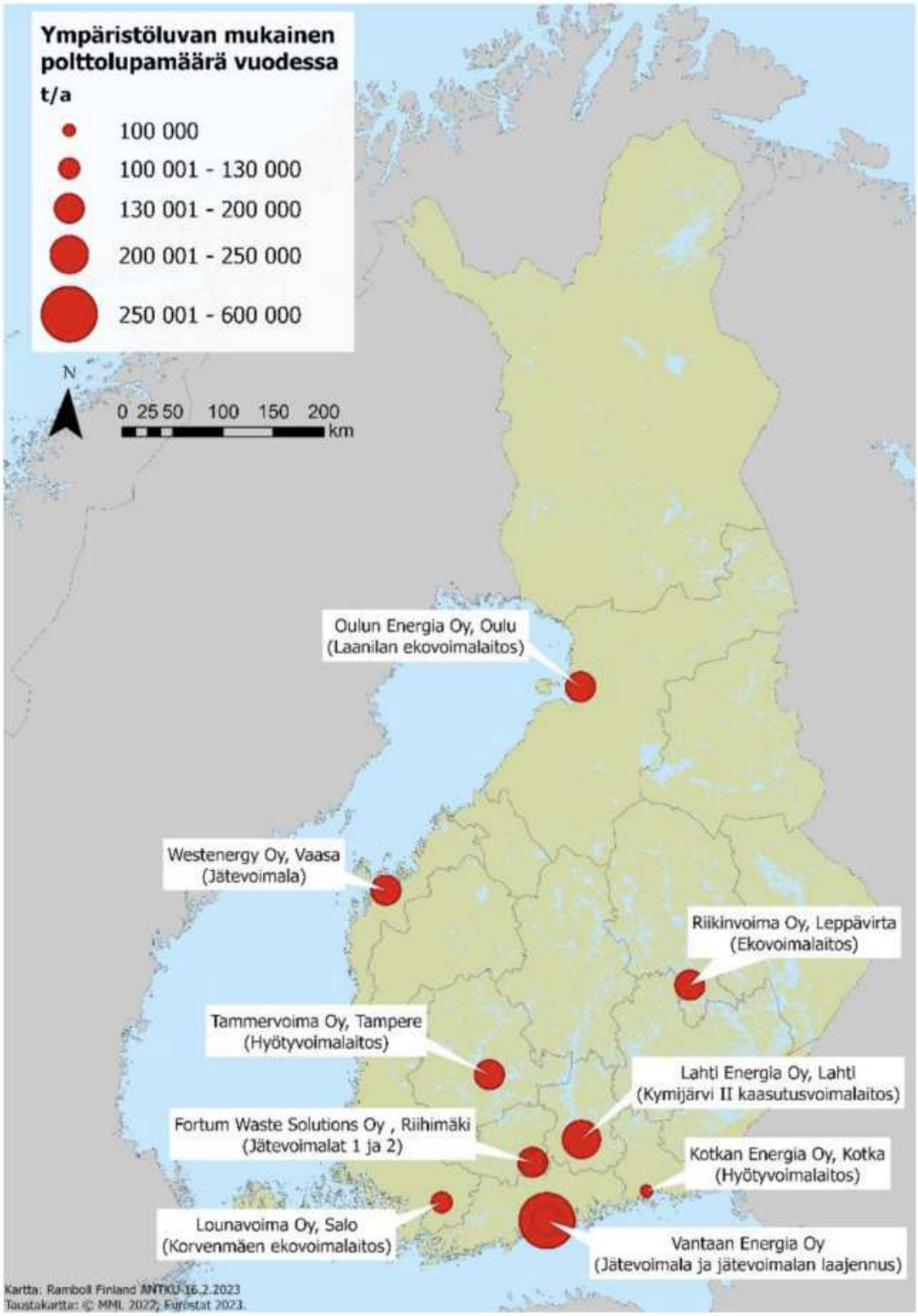

Figure 8 Location of Finnish waste incineration plants (Ministry of Economic Affairs and Employment: Waste incineration inclusion to the emission trade, 2023)

Table 3 Capacity of Finnish incineration plants

Plant	Location	Capacity, t/a	Started at
Fortum Waste Solution 1	Riihimäki	175 000	2007
Fortum Waste Solution 2	Riihimäki	130 000	2012
Kotkan Energia Oy	Kotka	120 000	2009
Oulun Energia Oy	Oulu	175 000	2012
Lahti Energia Oy, Kymijärvi II	Lahti	250 000	2012
Westenergy Oy	Lahti	200 000	2013
Vantaan Energia Oy	Vantaa	420 000	2014
Vantaan Energia Oy, Expansion	Vantaa	180 000	2022
Tammervoima Oy	Tampere	180 000	2016
Riikinvoima Oy	Leppävirta	170 000	2016
Lounavoima Oy	Salo	120 000	2021
Total		**2 120 000**	

In 2021, energy utilization of waste accounted for 62% of municipal waste processing, in 2020 the corresponding figure was 57%. Waste incineration has increased since 2020 at the expense of material recycling. In 2021, the share of material recycling in municipal waste processing was 37%, while in 2020 the share was 42%. (Ministry of Economic Affairs and Employment in Finland) (tem.fi), p. 9)

Table 4 Finnish municipal waste by treatment method in 2021.

2021	Amount of waste, tons
In total	3 490 676
Energy utilization	2 109 565
Disposal incineration	6 088
Material utilization	1 360 524
Landfill placement and other disposal	14 499

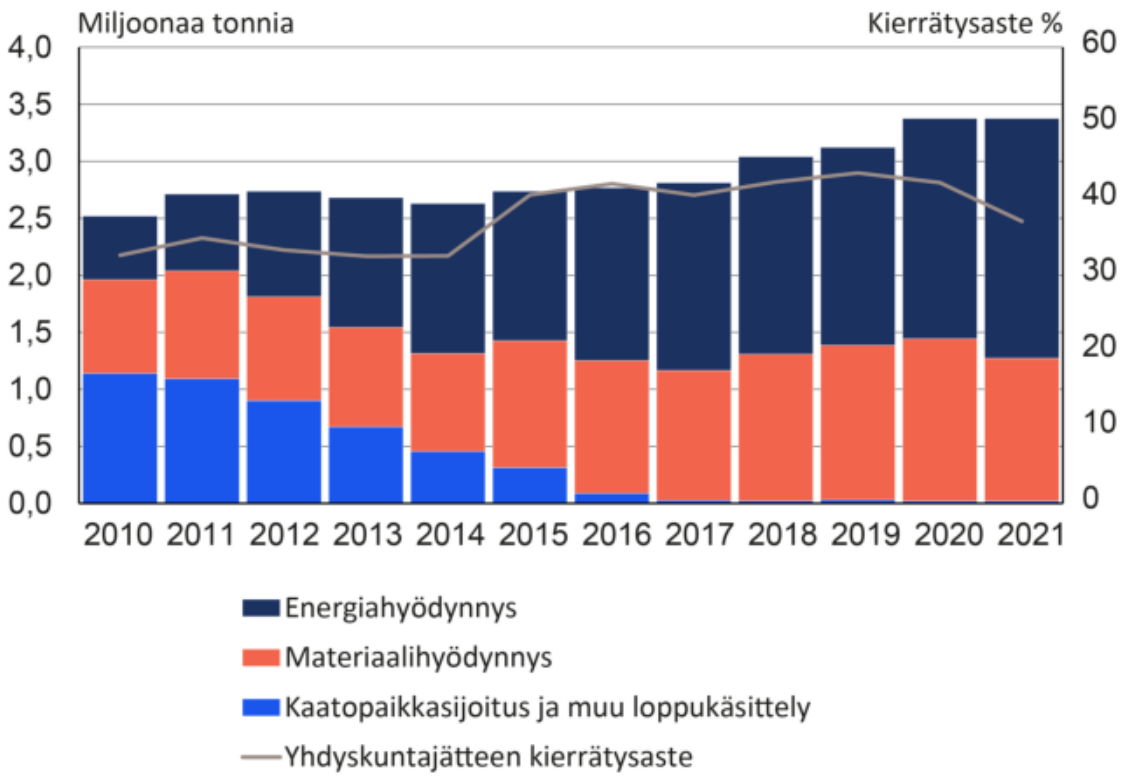

Figure 9 Treatment of municipal waste in Finland: energy utilization (dark blue), material recycling (red), landfill (light blue)

Table 5 Amounts of different wastes by treatment 2021[47]

2021	Amount of waste (1000 tons)				
	Total	Energy recovery	Incineration without energy recovery	Material recovery	Lanfilling and other disposal
Chemical waste	403	29	99	105	171
Metallic waste	1 411	0	0	1 411	1
Glass waste	107	0	0	106	0
Paper and cardboard waste	272	11	0	261	0
Plastic and rubber waste	112	94	1	17	1
Wood waste	2 774	2 675	3	95	0
Animal and vegetal waste	900	171	0	726	3
Household and mixed waste	2 914	2 411	9	442	52
Sludges	1 061	361	21	217	462
Mineral waste	116 179	460	3	7 307	108 409
Other waste	878	276	29	491	83
Of which hazardous waste	*25 056*	*97*	*121*	*254*	*24 584*
Total	**127 012**	**6 490**	**165**	**11 176**	**109 182**

47. ISSN=2323-5314. Helsinki: Statistics Finland [Referenced: 20.10.2023]. Access method: https://stat.fi/en/statistics/jate)

According to Statistics Finland's data, electricity production in 2021 was 69.3 TWh, and waste incineration plants produced approximately 1% of this amount (approx. 0.7 TWh). District heat production in 2021 was a total of 40.8 TWh, and waste incineration plants accounted for about 7% of this (approx. 3 TWh). Co-incineration plants are excluded from this review, but they increase the share of electricity and heat produced by waste incineration. For example, in 2019, 2.3 TWh/a of energy obtained from waste was produced in co-incineration plants (AFRY Management Consulting Oy, 2021).

Municipal waste as a fuel differs to some extent from other typically used fossil - and biofuels. Municipal waste is highly inhomogeneous, which makes determining the quality of the waste often unreliable and creates challenges for truthful reporting of emissions and dividing emissions into biogenic and fossil. This is, however, inherent to municipal waste being a mix of different materials and not exclusive for Finland.

The calculations are based on the CO_2 factors given by Statistics Finland, which estimates annually the composition of wastes and amounts of biogenic and fossil carbon and the emission rate. In 2023 the share of biogenic carbon has been estimated 60% for SRF (solid recovered fuel) and 50% for municipal or mixed wastes.

Carbon dioxide emissions from incineration plants was 0,7 Mton in 2021 (Statistics Finland). This figure does not include emission data from co-incineration plants, so the total carbon dioxide emissions from waste combustion are higher.

Finland's co-incineration plants are allowed to burn a total of just over 1 Mtons of waste per year based on environmental permits. With the completion of the co-incineration plants under construction, the capacity according to environmental permits will increase by about 85,000 tons. Combustion permits have been issued in co-incineration plants for several waste fractions, such as SRF, recycled/dismantled wood, municipal waste, sludge, forest industry production rejects, industrial side streams and collected oils. Based on the environmental reports of the co-incineration plants, waste incineration permits are not used to their full extent. According to the data of the latest reports, only about 40% of the capacity according to the environmental permits is in use. More than 50% of the amount of recycled fuel permitted by the environmental permit is used in only 7 co-incineration plants. (Influencing the circular economy and climate effects of waste incineration with different control methods, 2021)

Municipal waste was not imported remarkably during 2017–2021, however, after that the import has increased partly due to incineration capacity available and ending the import of wood from Russia. The numbers on import are not available for 2022, but there is evidence that the import has been increasing.[48] Before 2022, municipal waste was exported due to lack of capacity in incineration.

48. https://www.tekniikkatalous.fi/uutiset/onko-tassa-mitaan-jarkea-jopa-200-000-tonnia-sekajatetta-rahdataan-valimerelta-suomeen-poltettavaksi-markkinatalous-toimii-niin/6a0f5fe6-304d-4957-b669-54070a8ef680

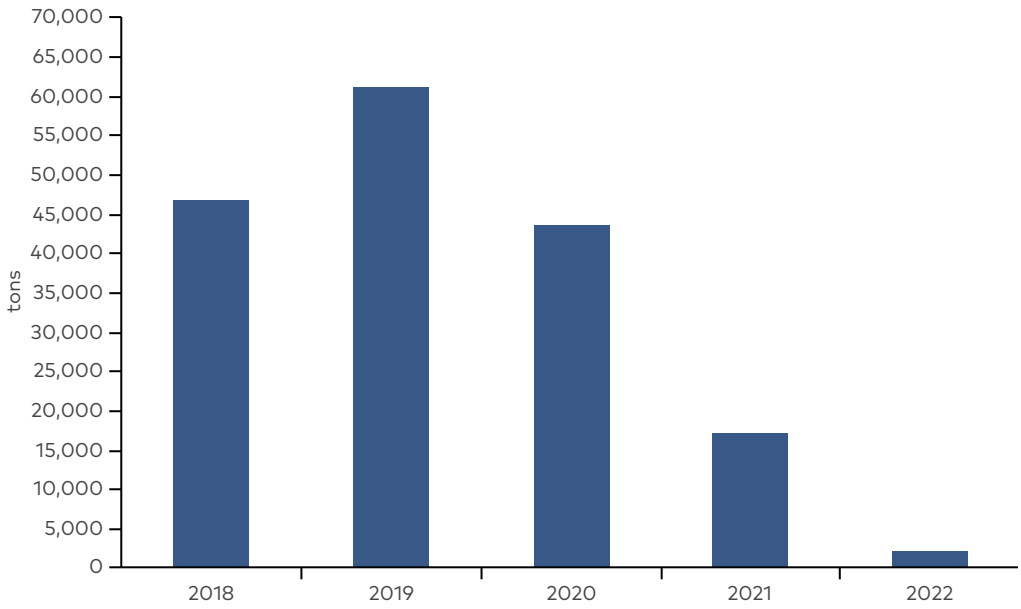

Figure 10 Export of municipal waste from Finland

Åland

In 2020, the Region of Åland produced 47 400 tons of non-hazardous waste of which 21 100 tons was transported and handled outside the region. Of the transported waste 48% equaling 10 200 tons was transported to the mainland of Finland and 52% equaling 10 900 tons to Sweden. A vast majority of the combustible household waste is transported to Sweden for combustion due to the shorter distance. There are no plans on establishing an own combustion plant on Åland at the moment due to the small amount of combustible waste generated. The government of Åland is preparing a new law regarding waste which will aim at a greater recycling rate.

1.3.2 Near-term trends

Finland is far behind the targets in recycling wastes. Municipal waste is not placed on landfills, but material recycling should reduce waste incineration. The recycling rate of municipal waste was 39% in 2021, when the targets are 55% for 2025 and 60% for 2030.

Waste incineration plants are sized according to estimated waste quantities and energy demand, and they are designed for base load production. The plants are also relatively new and are designed for long-term use. The current capacity covers the whole of Finland, and no larger new facilities are planned. The import of waste-based fuels has been increasing (year 2022: 47 thousand tons), but the future trends are not available.

According to interviews, most of the facilities have a plan or road map for implementing CCU, where CO_2 is used to produce methane and other chemicals. For example, Nordic Ren-Gas Oy has development agreements with several incineration plants.[49] There are no plans to introduce CCS. There is a plan to build a carbon capture unit in Mustasaari Incineration plant which will use all the plant's CO_2 for methane production. When completed, the project will be the first facility of this scale in the world.[50]

1.4 Denmark

1.4.1 Capacity, energy generation and emissions

Denmark's Energy Agency (Energistyrelsen) publishes annual benchmarking reports covering the Danish waste sector. The most recent report is based on data for the year 2020.[51] In 2020, Denmark had 26 plants with a combined waste incineration capacity of ca 4.5 Mtons per year (based on the plants' environmental permits). Of the 26 plants, 19 were dedicated waste incineration plants, 4 were multifuel plants and 3 handled special waste fractions. The total *waste* capacity of the 23 dedicated and multifuel plants was ca 4.0 Mtons per year. The 26 plants and their respective capacities are listed in Figure 11.

49. https://ren-gas.com/en/
50. https://www.uusiouutiset.fi/westenergy-oy-investoi-uuden-sukupolven-hiilidioksidien-talteenottolaitokseen-jatehuollosta-entista-ymparistoystavallisempaa-kun-paastoista-tehdaan-polttoainetta/
51. https://ens.dk/ansvarsomraader/affald/effektivisering-af-forbraendingssektoren

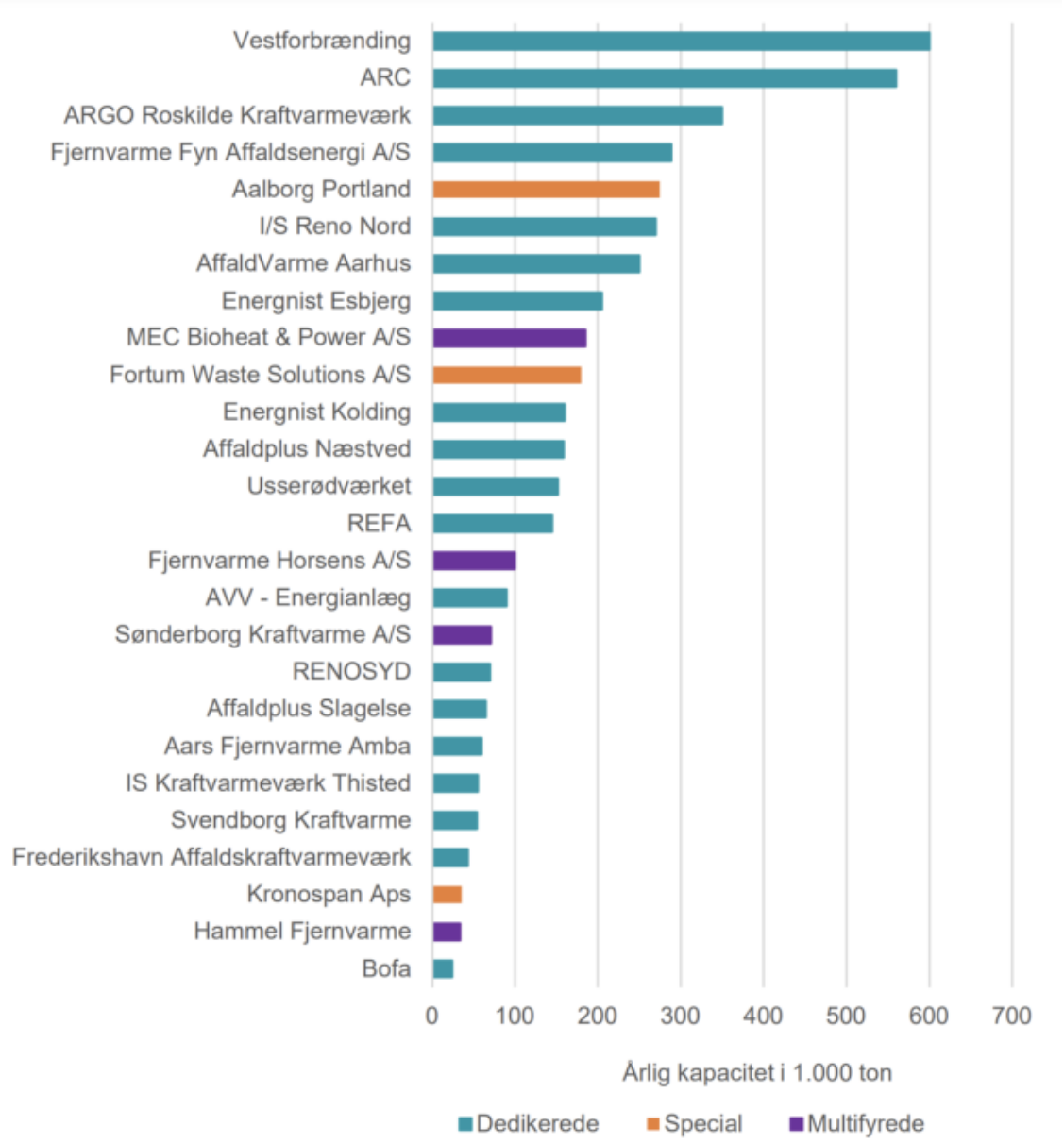

Figure 11 Capacity of Denmark's waste incineration plants in 2020 according to their environmental permits. Green: dedicated waste incineration plants, orange: special waste fractions, purple: multifuel[52]

The sector is a major contributor to the Danish energy system: in 2020, it covered 24% of the total heat input to the country's district heating network and 4.3% of its electricity supply, see Figure 12 and Figure 13.

52. *Benchmarking af affaldssektoren – Forbrænding,* 2020, Energistyrelsen

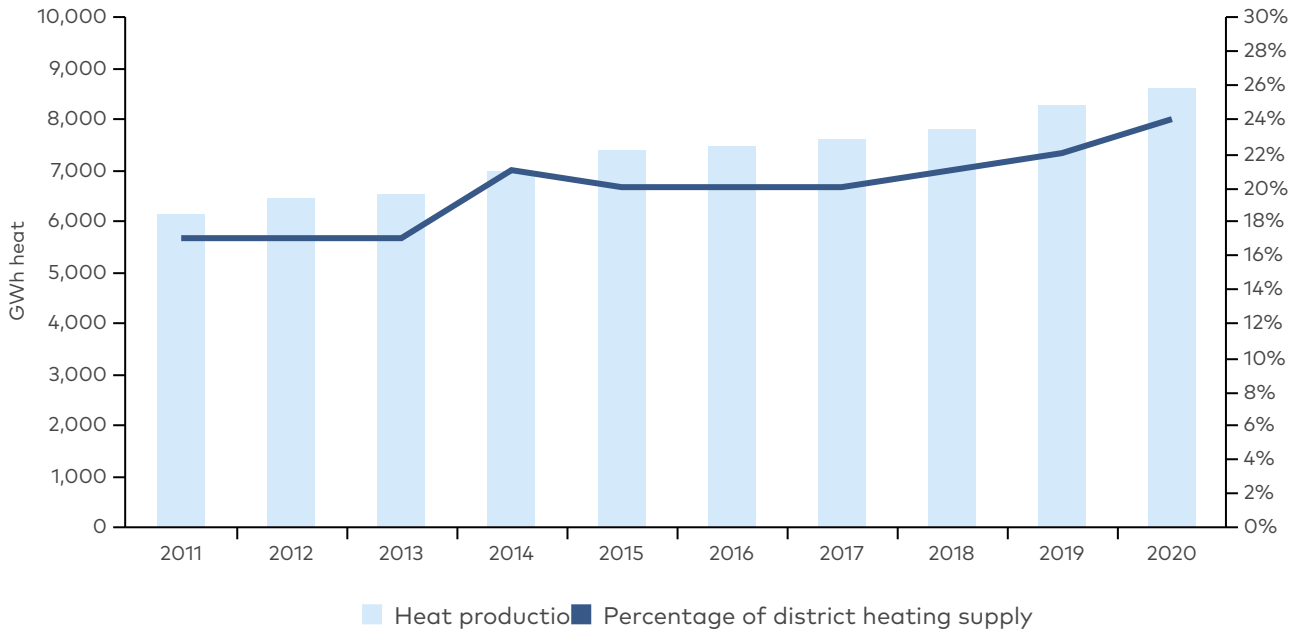

Figure 12 Heat supply from Danish waste incineration plants.

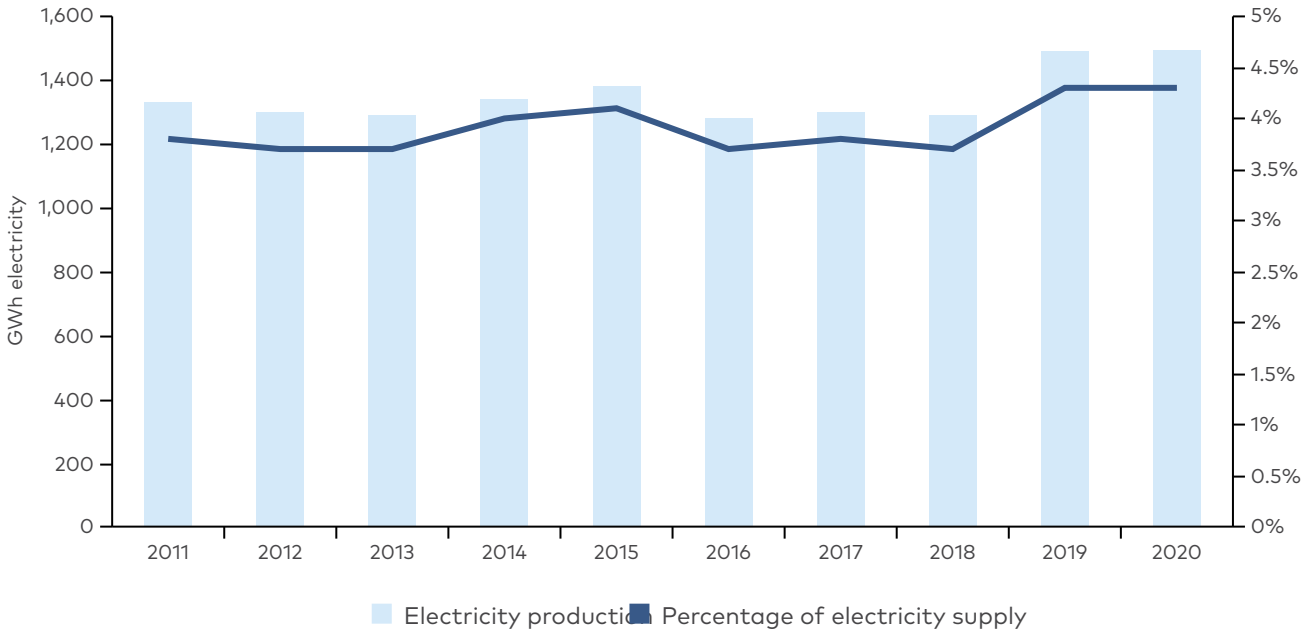

Figure 13 Electricity supply from Danish waste incineration plants.

Fossil CO_2 emissions (CO_{2eq}.) were 1.6 Mtons in 2019. Biogenic emissions were higher (ca 2.2–2.3 Mtons CO_2),[53] which is in line with the 40–60%-ratio also observed in Swedish data, see chapter 1.1.1.

Greenland

In Greenland, there are currently no centralized waste incineration units installed, but waste is taken care of locally either by incineration or landfill. In 2020, about 20 small scale incineration plants for handling non-hazardous waste have been in operation distributed among the five municipalities. In addition, more than 20 waste incineration plants not being in operation exist.[54]

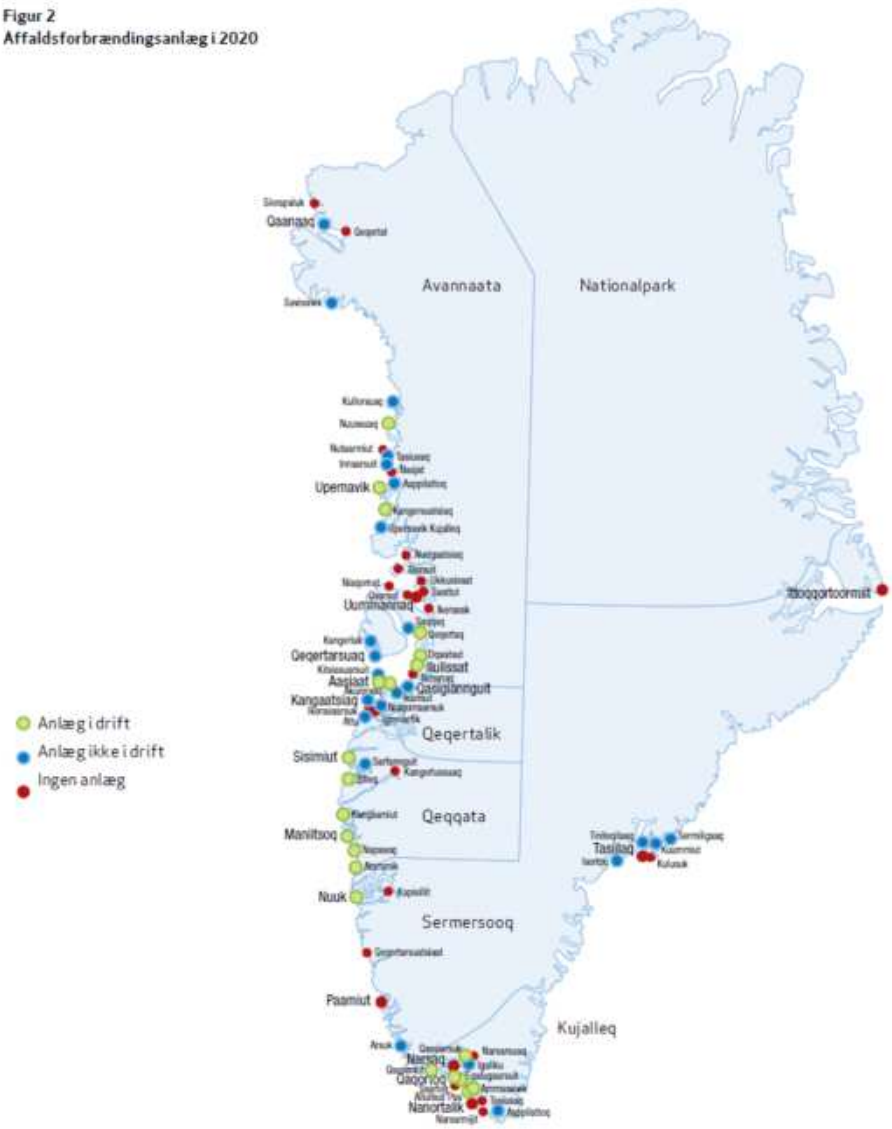

Figure 14 Waste incineration units in Greenland (green – in operation, blue – not in operation, red – no unit at local community).

53. *Benchmarking af affaldssektoren – Forbrænding*, 2020, Energistyrelsen
54. *Affaldshandlingsplan 2020-2031*, 2020, Departementet for Forskning og Miljø

The Government of Greenland has developed a long-term waste management plan to improve the sector. Within that plan, the establishment of two larger centralized waste incineration plants is decided. The plants are to be built in Nuuk and Sisimiut with a total capacity of 140 tons per day and are planned to supply district heat locally. The plants are to be finished by 2023 and 2024, respectively.[55] The logistics of transporting the waste from all municipalities to the two central plants are a challenging part that is addressed in the national waste management plan.

There is little data available on the total amounts of waste generated in Greenland, an article from 2011 estimating it to about 50 000 tons.[56] A large fraction is landfilled and – historically – a part of biological waste from the fishing industry dumped in the sea,[57] making improvements in waste management an important issue. The establishment of the national waste management company ESANI – also being responsible for the future waste incineration plants – in 2019 was a first step towards a more sustainable and circular waste management in Greenland.

Faroe Islands

There are two waste incineration plants in operation on the Faroe Islands, taking care of the waste management for the 54 000 inhabitants. One plant in the capital of Tórshavn and another one in Leirvik, operated by the waste management company IRF and taking care of the waste from the remaining 28 municipalities. The plant in Leirvik incinerates about 25000 tons of waste per year and delivers heat to nearby industries in the range of 20 GWh, using about 20–30% of the heat generated. The waste incineration plant in Tórshavn incinerates about 17 000 tons of waste, supplying about 32 GWh of district heat. In total, about 42 000 tons of waste are incinerated, generating roughly 50 GWh of district heat, see Table 6.

Waste incineration is an important part of the waste management system on the Faroe Islands, avoiding transport by ship, the sludge and fly ash being disposed of locally on deposits as well. There also is a high level of awareness of the sustainability aspects in relation to waste handling, with Burðardygt Vinnulív (the Faroese Sustainable Business Initiative) having started a network of businesses working actively towards achieving the Sustainable Development Goals, thereby also addressing waste management.[58]

55. https://esani.gl/ (accessed 2023-10-05)
56. Eisted, R., & Christensen, T. H. (2011). Waste management in Greenland: current situation and challenges. Waste Management & Research: The Journal for a Sustainable Circular Economy, 29(10), 1064–1070. https://doi.org/10.1177/0734242X10395421
57. Global Recycling (2021) Greenland – Waste Management on thin Ice, https://global-recycling.info/archives/5971
58. Burðardygt Vinnulív, https://www.burdardygtvinnuliv.fo/ (accessed 2023-10-05)

Table 6 Waste incinerated and district heat delivered in the plants on Faroe Island. [59][60][61]

		2020	2021	2022
IRF - Leirvik	Waste incinerated [tons]	24 728	25 080	23 378
	Heat generated [MWh]	73 596	70 352	66 578
	District heat delivered [MWh]	16 389	14 765	20 545
Tórshavn	Waste incinerated [tons]	17 361	16 812	15 871
	District heat delivered [MWh]	32 000	32 000	32 000

1.4.2 Near-term trends

In the period until 2035, Energistyrelsen projects a steep decline of the amount of waste being incinerated – caused by a decrease of available incineration capacity and a changed composition of waste (i.e., lower plastic content and heating value) due to higher sorting efficiency and less import.

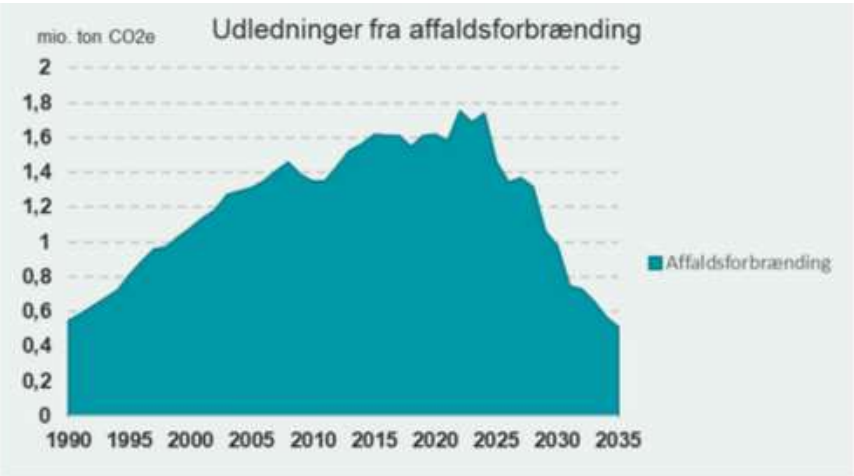

Figure 15 Historic and projected CO2eq emissions from waste incineration in Denmark[62]

59. Irf (2023) Ársfrásøgn 2022 (Annual report 2022), available at https://irf.fo/arsfragreidingar/
60. Kommunala Brennistøðin, https://www.torshavn.fo/um-kommununa/fakta-og-bygnadur/politiskur-og-fyrisitingarligur-bygnadur/kommunala-brennistoedin (accessed 2023-10-05)
61. Umhvørvisstovan – Faroese Environment Agency https://www.us.fo/
62. https://ens.dk/sites/ens.dk/files/Affald/kf23_sektornotat_9a_affaldsforbraending.pdf

In line with the above-mentioned goal, the Danish government has also recently passed a law to adjust the waste incineration capacity by introducing a tender-based model, forcing the waste incineration plants to compete for waste.[63] The initial plan was to start a governmental investigation on what incineration plants to close down but the political agreement ended in liberalizing the market as it was considered to be a more cost-effective measure. This decision has been criticized by the waste management sector as planning uncertainties for all plant operators increase, reducing the capacity to plan for long-term strategic investments in for example carbon capture projects.[64]

Another interesting example on a local island level is Bornholm, having established a vision of being an island without waste by the year 2032.[65] The waste incineration plant is planned to be shut down by 2032 and the community is not planning to establish a replacement incineration unit. The aim is to be a leading actor in circular economy, working in international collaborations to make use of new technologies to even tackle more complex waste streams in the future.

Concerning CCS, the Danish government recently awarded storage licenses for 13 Mton carbon per year to be filled in 2030,[66] highlighting the country's ambition to become a player in the storage market in this decade.

1.5 Iceland

1.5.1 Capacity, energy generation and emissions

Iceland has one waste incineration plant – the Kalka plant – which, according to its environmental permit, is allowed to incinerate 25 ktons of waste per year. According to Iceland's 5th biennial report to the UNFCCC emissions from waste incineration were 6 ktons CO_2eq. in 2020. At full capacity, the Kalka plant emits about 14 ktons per year CO_2eq.

1.5.2 Near-term trends

According to Iceland's 5th biennial report to the UNFCCC, no expansion of the country's waste incineration sector is expected.

63. https://www.ft.dk/samling/20222/lovforslag/l115/index.htm
64. https://avfall2resurs.se/2023/06/19/den-danska-forbranningspolitiken-ar-idioti/ (accessed 2023-12-07)
65. Bornholm showing the way – without waste 2032, https://bofa.dk/wp-content/uploads/2019/01/BOFA_mini-publikation_UK_A4_160119.pdf
66. https://en.kefm.dk/news/news-archive/2023/feb/denmark-is-open-for-a-new-green-business-

1.5.3 Technology developments and pilots

Carbon Centric will install a carbon capture plant at the Kalka waste incinerator.[67] The project aims to be fully operational in 2025 and will capture 10 ktons per year CO_2.

1.6 The overall picture for the Nordics

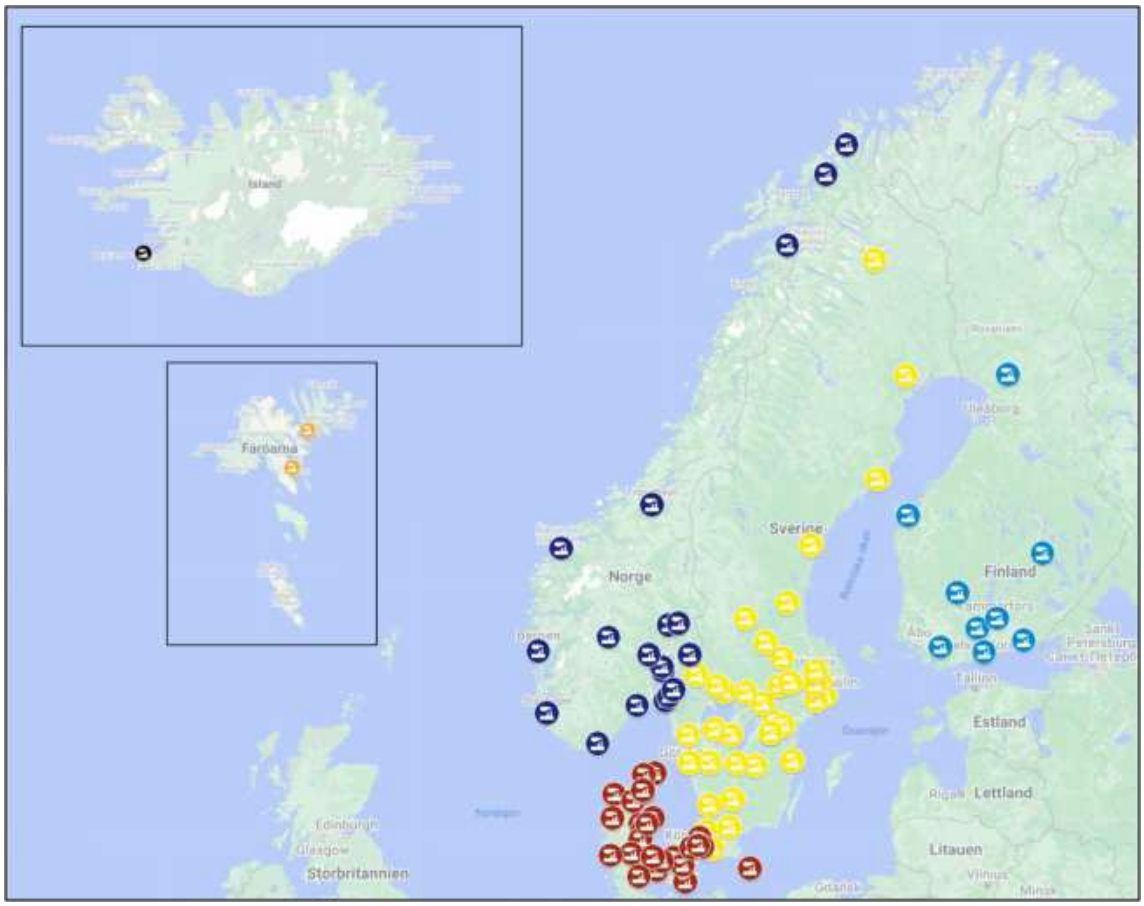

Figure 16 Overview of locations of waste incineration plants in the Nordics (own data collection visualized in Google maps).

67. https://carbonherald.com/carbon-centric-launches-first-carbon-capture-project-in-iceland/

As was mentioned in the introduction, the waste incineration sector plays an important role for the Nordic countries' energy systems. Comparing the different countries is not a trivial task – different definitions of what waste is, how and by whom it is collected, and which waste should be incinerated make comparisons over longer time periods and countries difficult. In this section, data from Eurostat, the European Statistical Office, is used. Due to the reporting procedure and requirements,[68] renewable industrial waste is excluded from these numbers, which consequently differ from the ones described in the countries' sections.

A decrease in landfill can be observed historically in all analyzed countries, meaning that almost no organic waste is disposed of in that way anymore. Instead, both recycling – at first, biodegradable waste to composting, followed by plastics, paper, metal and other recyclable materials – and waste incineration have grown more and more important. Figure 17 to Figure 19 show the incinerated volumes of waste and the generation of heat and power from the sector.

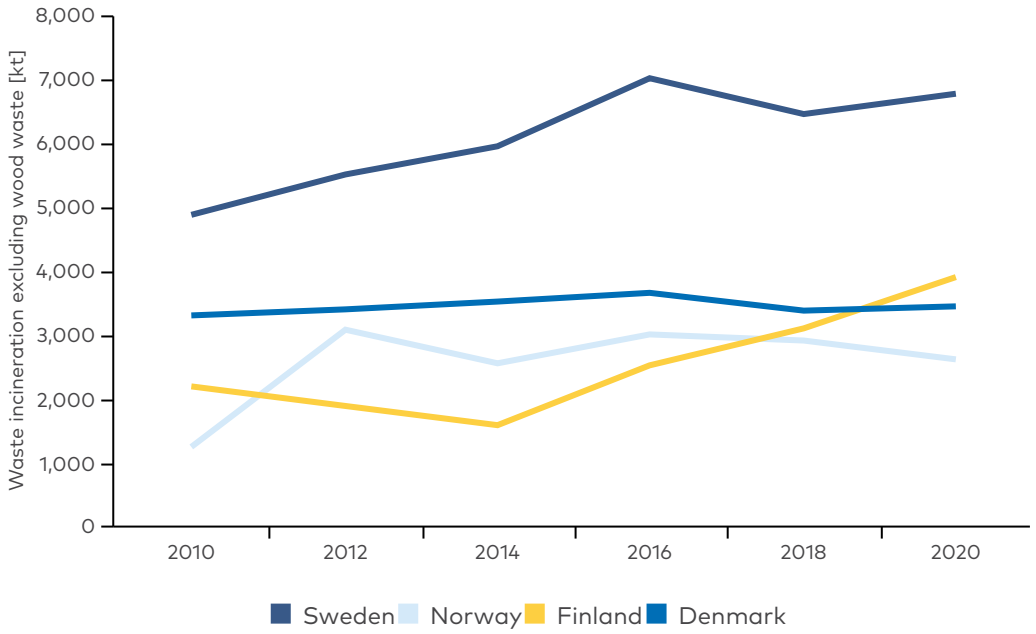

Figure 17 Total waste incineration volumes in the Nordic countries. Numbers exclude industrial renewable waste.

Especially for district heating, waste incineration delivers important baseload capacity and covers 7% (Finland) to 43% (Norway) of the total heating energy demand.

68. https://ec.europa.eu/eurostat/documents/38154/9287955/Renewables_Reporting_instructions_2017_2021.pdf/99adf26c-1c1f-4e45-a7bc-561513e96e20

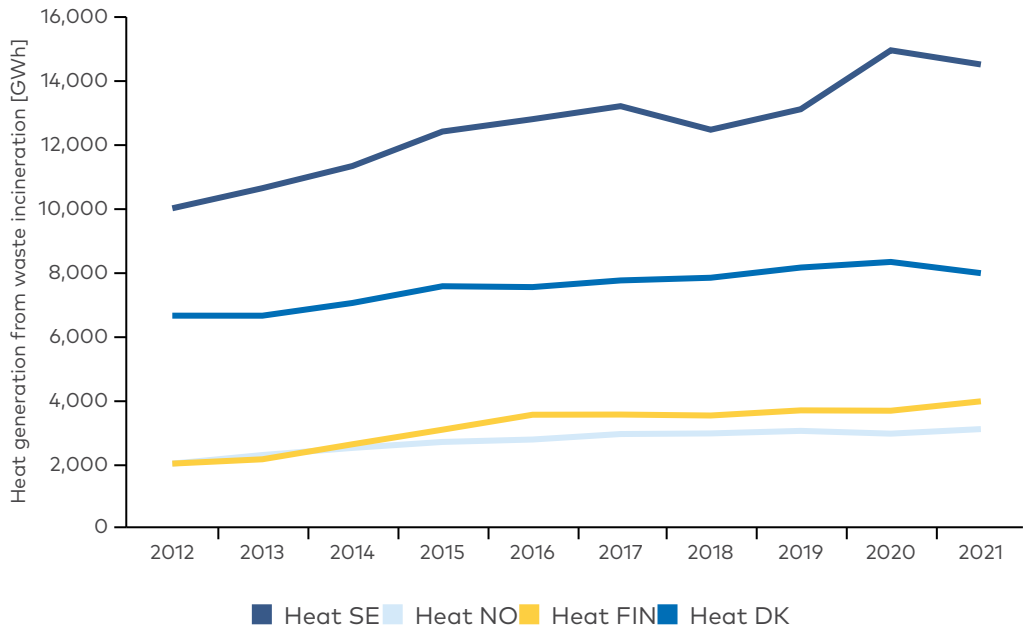

Figure 18 Heat generation from waste incineration to the district heating networks for Sweden, Norway, Denmark and Finland.

Concerning electricity production, other power sources dominate in the Nordic countries. However, waste incineration generates around 1–4% of the total electricity supply while contributing to grid stability due to their constructive layout using turbines with high inertia, a trait they share with other heat-to-power technologies.

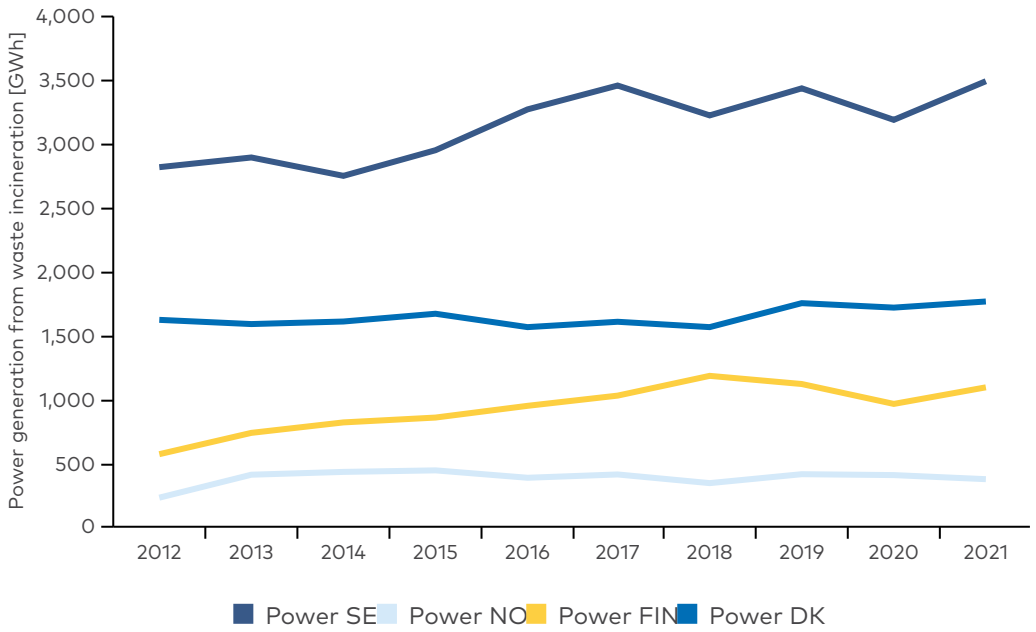

Figure 19 Power generation from waste incineration for Sweden, Norway, Denmark and Finland.

2. Legislative frameworks and circular economy impacts

2.1 In the Nordics

2.1.1 Norway

ETS

Emissions from waste incineration are included in the EU ETS if they result from "the combustion of fuels in installations with a total rated thermal input exceeding 20 MW (except in installations for the incineration of hazardous or municipal waste)".[69] Hazardous and municipal waste incinerators, as determined by the competent national authority in accordance with the relevant definitions under Directive 10/75/EU on industrial emissions (Industrial Emissions Directive or IED), are therefore excluded from the scope of the EU ETS.[70] Only waste incineration installations qualifying as 'waste co-incineration plant' under Article 3(41) IED, whose main purpose is the generation of energy or production of material products, are included. That way, two Norwegian incineration installations are currently covered by the ETS (Frevar and Sarpsborg).

Taxes & Fees

Emissions from Norwegian municipal waste incinerators outside the EU ETS fall within the scope of the ESR, which establishes emissions reduction targets for non-ETS sectors. Under the climate agreement with the EU, Norway has agreed to cut its non-ETS emissions by 40% by 2030 compared to the 2005 level. This target can be achieved either through national cuts in emissions and/ or by using the flexibility mechanisms set out in the ESR. According to the National Climate Action Plan (Klimaplan), the Norwegian government plans to exceed the non-ETS target of 40%, aiming to reduce non-ETS emissions by 45% through domestic measures.[71] Concerning non-ETS emissions from waste incineration, the main strategy is to achieve emission reductions through taxation and the implementation of Carbon Capture and Storage (CCS). In addition to national policies and regulations related

69. Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC (Text with EEA relevance), EP, CONSIL, 275 OJ L (2003). http://data.europa.eu/eli/dir/2003/87/oj/eng , Annex I (ETS Directive)
70. Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) (recast) (Text with EEA relevance), EP, CONSIL, 334 OJ L (2010). http://data.europa.eu/eli/dir/2010/75/oj/eng
71. Meld. St. 13 (2020–2021) Report to the Storting (white paper) Norway's Climate Action Plan for 2021–2030, 3.7.3.3.

to climate impacts, the Industrial Emissions Directive provides EU environmental standards for waste incinerators, allowing to further limit environmental impacts.[72]

As of January 2022, Norwegian waste incineration installations pay a mandatory waste incineration tax that covers emissions to air of fossil CO_2 when burning waste and is calculated by multiplying the amount of waste delivered to the incineration facility measured in tons by a factor of 0.5498 ton fossil CO_2 per ton of waste, with the option to apply for facility-specific factors.[73] Tax exemptions are available for hazardous waste or where CO_2 from waste is captured and stored (Carbon Capture and Storage or CCS). The tax on waste incineration was implemented at the level of 192 NOK/t CO_2 and recently increased to 238 NOK/t CO_2 in 2023. Until 2030, the Norwegian Government plans to gradually increase the tax rate for waste incineration along with the standard tax rate for non-ETS emissions to about NOK2000 per ton of CO_2eq.[74] While the two waste incinerations installations currently covered under the ETS scheme are also covered by the waste incineration tax, the Norwegian government plans to consider rises in carbon tax rates in conjunction with the price of emission allowances in the EU ETS (see graph). For 2023, differentiated tax rates for ETS and non-ETS incinerators have been decided. Accordingly, facilities covered by the EU ETS pay 50% less tax compared to 2022, thus, NOK95/t CO_2 whereas the differentiated tax rate for facilities not subject to the EU ETS has been increased by 141%, to NOK476/tCO_2. The time for the decision to take effect has not been set.

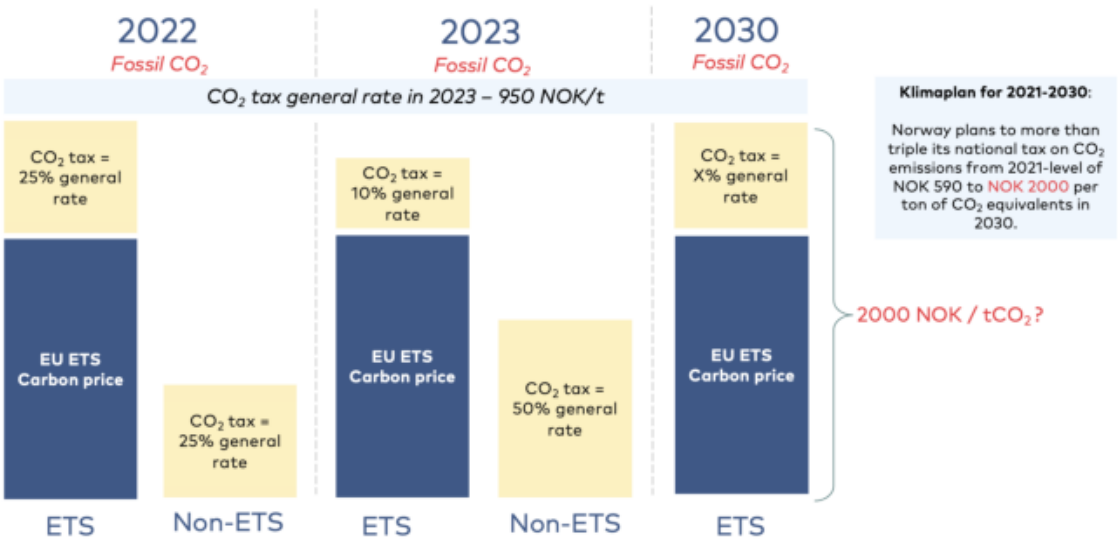

Figure 20 WtE: EU ETS and CO_2 tax – Possible Scenario

72. Commission Implementing Decision (EU) 2019/2010 of 12 November 2019 establishing the best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council, for waste incineration, OJ/L 312/55. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019D2010&from=EN
73. Waste incineration tax. (n.d.). The Norwegian Tax Administration. Retrieved October 12, 2023, from https://www.skatteetaten.no/en/business-and-organisation/vat-and-duties/excise-duties/about-the-excise-duties/avfallsforbrenning/
74. Climate Action Plan for 2021–2030

2.1.2 Denmark

ETS

As of 1 January 2013, waste incineration plants which are primarily used for district heating were included in the EU ETS in Denmark.[75] Today, most Danish waste incineration plants are covered by the ETS. As such, they pay the emissions allowance price for fossil emissions from waste incineration. Incineration installations covered by the ETS also pay the Danish CO_2 tax.

Taxes & Fees

In Denmark, several taxes apply to incineration. A waste heat tax is levied on the amount of heat produced from waste incineration, including heat used at the plant for indoor and water heating (20.7 DDK/GJ in 2022).[76] The waste heat tax is coupled with an additional tax charged per GJ produced heat, calculated, in principle, based on the energy content of combustible waste (31.8 DKK/GJ in 2022).[77] Together, these taxes correspond to the energy tax on other fossil fuels. Biogenic waste in clean loads, like biomass, is exempt for the waste heat tax and additional charge. However, biogenic waste mixed with fossil waste is, in practice, subject to both waste heat tax and additional tax. Moreover, a CO_2-tax is levied on emissions from incinerated non-biodegradable waste (179.2 DKK/tCO_2 in 2022).[78] Emissions from waste incineration are also subject to NO_x and sulfur taxes. The taxes are mainly designed to ensure a level playing field in the energy sector and to help divert waste toward recycling. Given the different tax bases for the taxation elements, the taxes on waste incineration cannot easily be translated into a tax per ton of waste. According to estimations of the European Environment Agency in 2022, assuming an energy content of 10.6GJ/t, the incineration tax would have been around 557 DKK/t, corresponding to 75 EUR/t. In June 2022, the Danish Parliament agreed on a Green Tax Reform, planning a conversion of the current taxes into a higher and more uniform CO_2 tax. According to the Danish Ministry for Climate, Energy and Utilities, the expert group for the green tax report is scheduled to publish their final report Autum 2023.[79]

75. EU Energy Union – Denmark's National Energy and Climate Plan (NECP). (2020, January 13). Energistyrelsen. https://ens.dk/en/our-responsibilities/energy-climate-politics/eu-energy-union-denmarks-national-energy-and-climate , Annex 8
76. European Environmental Agency. (2022). Early warning assessment related to the 2025 targets for municipal waste and packaging waste—Denmark. https://www.eea.europa.eu/publications/many-eu-member-states/denmark/view
77. European Environmental Agency. (2022). Early warning assessment related to the 2025 targets for municipal waste and packaging waste—Denmark. https://www.eea.europa.eu/publications/many-eu-member-states/denmark/view
78. European Environmental Agency. (2022). Early warning assessment related to the 2025 targets for municipal waste and packaging waste—Denmark. https://www.eea.europa.eu/publications/many-eu-member-states/denmark/view
79. Ekspertgruppen for en grøn skattereform—1. Delrapport. (n.d.). Skatteministeriet. Retrieved October 23, 2023, from https://www.skm.dk/aktuelt/publikationer/rapporter/ekspertgruppen-for-en-groen-skattereform-1-delrapport/

2.1.3 Sweden

ETS

According to Article 24 of the EU ETS Directive, Member States may introduce additional institutions and emissions into the trading system, provided that the Commission and Member States give their approval.[80] Sweden has availed itself (as only EU country apart from Denmark and Lithuania) to that option by (1) unilaterally including waste incineration installations with a capacity below the EU threshold of 20 megawatts since the first EU ETS trading period, if they are connected to a district heating network with a total effect of 20 megawatt and (2) extending the definition of eligible installations by the government in 2006, which meant that more installations were included in the ETS.[81] This was approved by the Commission in 2004 and 2007 respectively.[82] It seems that all the waste incineration plants were included in the ETS trading scheme from the 3rd trading period which started in 2013. The reason for this is an interpretation of the Commission's guidance on co-combustion waste incineration plants, stating that their primary aim is to produce heat and power. Following this interpretation, the sector must be included in the ETS scheme.

Taxes and fees

Until recently, the CHP-sector, and thus also waste incineration, was burdened with a separate tax of 125 SEK per ton. The tax was waived with effect from January 2023, arguing that the intended control effects had not materialized. Without the tax, the government hopes that necessary investments in maintaining existing and building new CHP capacity will become more cost-effective.

Including the sector in the ETS scheme has led to a higher cost per ton incinerated waste as emission allowances increased in price. In 2022, the average cost was 740 SEK/ton, a 12% increase from 2021.

As mentioned above, not a lot of waste is landfilled anymore in Sweden. Apart from a landfill ban on sorted combustible waste in 2005, a ban on organic waste landfilling in 2005, and obligatory collection of food waste, a landfill tax has been in place since the year 2000, which in 2023 amounts to 634 SEK/ton.

80. Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC (Text with EEA relevance), EP, CONSIL, 275 OJ L (2003). http://data.europa.eu/eli/dir/2003/87/oj/eng
81. Emission Trading Ordinance (2004:1205); Bill 2005/06:184
82. COMMISSION DECISION of 7 July 2004 concerning the national allocation plan for the allocation of greenhouse gas emission allowances notified by Sweden in accordance with Directive 2003/87/EC of the European Parliament and of the Council, (2004). https://climate.ec.europa.eu/system/files/2016-11/sweden_final_en.pdf; COMMISSION DECISION of 23/01/2007 concerning the unilateral inclusion of additional activities by Sweden in the Community emissions allowance trading scheme pursuant to Article 24 of Directive 2003/87/EC of the European Parliament and of the Council, (2007). https://climate.ec.europa.eu/system/files/2016-11/sv2ndexclusions_en.pdf

Sector goals

Swedens national waste strategy defines a number of goals that will impact the waste incineration sector:

- By 2025, reuse and recycling of municipal waste shall increase to 55% by weight, with a further increase to 60% in 2030 and 65% in 2035, respectively. For 2020, around 40% were reached.[83]
- For non-hazardous building material, the corresponding goal is 70% by weight (up from 52% in 2020).
- The policy focus is therefore on reducing waste streams, increased reuse and more effective sorting and recycling. The role of waste incineration in the long term is thus limited to handling reject streams from sorting facilities, treating hazardous materials and provide end-of-use energy recovery from materials that cannot be recycled anymore.

In addition, the branch goal defined by Avfall Sverige in 2019 is to cut fossil emissions in half by 2030 and reduce them to close to zero by 2045.

2.1.4 Finland

Waste incineration and its emissions, as well as emissions of co-incineration are subject to regulation in Finland. Waste legislation is largely based on EU legislation but is stricter in some cases.[84]

General Waste legislation:

- Waste Act (646/2021)
- Waste Decree (978/2021)

The environmental impacts of waste are also addressed in legislation on environmental protection:

- Environmental Protection Act (527/2014)
- Environmental Protection Decree (713/2014)

Finland has also a National Waste Plan to 2027 that sets objectives for waste management and waste prevention.[85] The plan sets a goal to recycle 57% of municipal waste and 65% of bio-waste for 2027. A ban on landfilling of organic waste has also been implemented in 2016.

83. *Svensk Avfallshantering 2022.* Avfall Sverige
84. *Legislation and instruments.* (n.d.). EastCham Finland ry. Retrieved October 17, 2023, from https://www.eastcham.fi/finnishwastemanagement/municipal-solid-waste/legislation-and-instruments/
85. *National Waste Plan.* (n.d.). Ministry of the Environment. Retrieved October 17, 2023, from https://ym.fi/en/national-waste-plan

In a report,[86] various measures were studied. The analysis shows that a waste incineration tax (at the analyzed levels) does not result in significant recycling or emissions impacts. The expectation is that the cost of the tax will be transferred from waste-to-energy plant operators via the gate fees to household waste fees. The cost impact on households is marginal and thus does not provide sufficient incentive for improving the sorting of household waste. A tax would not result in significant changes in district heating prices or plant investments. However, the suggested tax levels were relatively low, and higher taxes may lead different results.

There have been negotiations about voluntary agreements (i.e., green deal) for waste incineration companies to decrease emissions, but it looks like the companies are willing to utilize new technologies to decrease emissions in the future.

A study on the impacts of inclusion of waste incineration in the EU ETS has been carried out. The report suggests that the ETS would not necessarily give the desired results on reducing incineration, minimizing production of wastes and improving recycling.[87] Co-combustion plants are already in the emission trade system.

2.1.5 Iceland

Iceland is a member of the EEA, which binds it to implement EU environmental directives. The country has a Waste Management Law no. 55/2003 and a Regulation no 737/2003 on waste treatment, which aim to decrease the quantity of waste by preventing the generation of waste, increase recycling, and recovery and reduce the quantity of waste deposited in landfills. Further regulation (no. 738/2003) provides for a ban on landfill and no. 739/2003 frames the incineration of waste. So far in the research, nothing pointed out that the waste incineration sector is included in the EU ETS.

2.2 European (and global) legislative framework

EU Legislation Specifically Applicable to Waste Incineration

Directive 2010/75/EU on industrial emissions (Industrial Emissions Directive or IED) lays down rules on integrated prevention, control or reduction of pollution arising from industrial activities, including waste management activities and energy industries.[88] Installations undertaking the industrial activities listed in Annex I of the Directive are required to operate with a permit that is granted by the competent national authorities. The IED also sets mandatory requirements on environmental inspections and secures the public's rights to information and

86. *Possibilities to impact CO2 emissions and to promote circular economy by different policy instruments targeting waste incineration.* http://urn.fi/URN:ISBN:978-952-383-093-6
87. *Including waste incineration in emission trading*, Finnish Ministry of Economic Affairs and Employment 2023
88. Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) (recast) (Text with EEA relevance), EP, CONSIL, 334 OJ L (2010). http://data.europa.eu/eli/dir/2010/75/oj/eng

participation. Regarding incineration activities, the IED differentiates between waste incineration plants and co-incineration plants (Article 3(40) and (41). The former are defined as "any stationary or mobile technical unit and equipment dedicated to the thermal treatment of waste, with or without recovery of the combustion heat generated (...)" whereas the latter covers stationary or mobile technical units "whose main purpose is the generation of energy or production of material products and which uses waste as a regular or additional fuel". Operators of waste incineration or co-incineration plants must seek prior authorizations in the form of a permit (Article 44). Permit conditions must be based on environmental performance and Best Available Techniques (BAT), more specifically, the BAT conclusions adopted by the EU Commission.[89] For waste incineration and co-incineration operations the IED furthermore sets out rules for the control and monitoring of emissions as well as other technical specifications. Pollutants for waste incineration and co-incineration, including emissions to air, are also subject to EU wide emission limit values set out in Annex VI. Emissions data is reported by EU countries through the European Pollutant Release and Transfer Register (E-PRTR).

The EU ETS was established by the ETS Directive.[90] Under the ETS, operators of certain activities must purchase emission allowances. However, free allowances are allocated to heat generation for district heating.[91] The activities which fall under the ETS are listed in Annex I of the ETS Directive. Emissions from waste incineration are included in the EU ETS if they result from "the combustion of fuels in installations with a total rated thermal input exceeding 20 MW (except in installations for the incineration of hazardous or municipal waste)".[92] Hazardous and municipal waste incinerators, as determined by the competent national authority in accordance with the relevant definitions under the IED, are thus excluded from the scope of the EU ETS.[93] Only waste incineration installations qualifying as 'waste co-incineration plant' under Article 3(41) IED, whose main purpose is the generation of energy or production of material products, are included.

In the first half of 2023, important amendments were adopted to reform the EU ETS. As part of these developments, in June 2022, the European Parliament approved an inclusion of the municipal waste incineration sector in the ETS as of

89. Commission Implementing Decision (EU) 2019/2010 of 12 November 2019 establishing the best available techniques (BAT) conclusions, under Directive 2010/75/EU of the European Parliament and of the Council, for waste incineration (notified under document C(2019) 7987) (Text with EEA relevance), 312 OJ L (2019). http://data.europa.eu/eli/dec_impl/2019/2010/oj/eng
90. Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC (Text with EEA relevance), EP, CONSIL, 275 OJ L (2003). http://data.europa.eu/eli/dir/2003/87/oj/eng
91. European Commission. (2019). COMMISSION DELEGATED REGULATION (EU) 2019/ 331 determining transitional Union-wide rules for harmonised free allocation of emission allowances pursuant to Article 10a of Directive 2003/ 87/ EC of the European Parliament and of the Council. 62.
92. Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC (Text with EEA relevance), EP, CONSIL, 275 OJ L (2003). http://data.europa.eu/eli/dir/2003/87/oj/eng , Annex I (ETS Directive)
93. Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) (recast) (Text with EEA relevance), EP, CONSIL, 334 OJ L (2010). http://data.europa.eu/eli/dir/2010/75/oj/eng

2026, pricing waste incinerator's fossil CO_2 emissions with the aim of levelling the playing field within national ETS systems already covering the sector and incentivizing further decarbonization.[94] The EU Commission is to submit an impact assessment report on the feasibility of including incineration installations in the ETS from 2028 by 31January of 2026. While, thus, strong signals for the inclusion of the municipal waste incineration sector in the EU ETS exist, the timeline remains uncertain. However, the amendment of Annex I to the ETS Directive already includes installations for the incineration of municipal waste from 1 January 2024 for the purpose of monitoring, reporting, verification, and accreditation of verifiers. The Monitoring and Reporting Regulation has been amended to take this new development into account.[95]

Other EU Laws Affecting Waste Incineration

Directive 2008/98/EC on waste (Waste Framework Directive or WFD) establishes the legal framework for treating waste in the EU. According to the WFD, the EU's approach to waste management builds on the waste hierarchy defined in Article 4 of the WFD, which sets the following priority order: prevention, preparing for re-use, recycling, other recovery (i.e. energy recovery), and lastly, disposal.[96] Among other things, the Directive also emphasizes the 'polluter-pays principle', the concept of 'extended producer responsibility', requires competent national authorities to establish waste-management plans and waste prevention programs, and introduces recycling and recovery targets. For example, as part of a package of measures on the circular economy, the WFD has been amended to set new municipal-waste-recycling targets, increasing the share of municipal waste prepared for reuse or recycled to 55% of all municipal waste generated by 2025, 60% by 2030 and 65% by 2035.[97] The amendment also encourages EU countries to introduce charges and restrictions for the incineration of waste to provide economic incentives for waste prevention and recycling.[98]

Directive 1999/31/EC on the landfill of waste (Landfill Directive) introduces stringent technical requirements to prevent, or reduce as much as possible, any negative impact from landfill. In addition, EU countries are required to implement national strategies to progressively reduce the amount of biodegradable waste

94. Amendments adopted by the European Parliament on 22 June 2022 on the proposal for a directive of the European Parliament and of the Council amending Directive 2003/87/EC establishing a system for greenhouse gas emission allowance trading within the Union, Decision (EU) 2015/1814 concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme and Regulation (EU) 2015/757 (COM(2021)0551 – C9-0318/2021 – 2021/0211(COD)). Retrieved October 12, 2023, from https://www.europarl.europa.eu/doceo/document/TA-9-2022-0246_EN.html
95. EUR-Lex—32023R2122—EN - EUR-Lex. (n.d.). Retrieved November 28, 2023, from https://eur-lex.europa.eu/eli/reg_impl/2023/2122/oj
96. Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Text with EEA relevance), EP, CONSIL, 312 OJ L (2008). http://data.europa.eu/eli/dir/2008/98/oj/eng, art. 4
97. Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste (Text with EEA relevance), CONSIL, EP, 150 OJ L (2018). http://data.europa.eu/eli/dir/2018/851/oj/eng
98. Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste (Text with EEA relevance), CONSIL, EP, 150 OJ L (2018). http://data.europa.eu/eli/dir/2018/851/oj/eng, Annex IVa.

sent to landfills. In 2018, amendments to the Landfill Directive introduced restrictions on landfilling from 2030 of all waste that is suitable for recycling or energy recovery, limited the share of municipal waste landfilled to less than 10% by 2035.[99] The EU legislation on waste management and landfills has the practical consequence of diverting waste from landfills to material and energy recovery, underlining the EUs Circular Economy Action Plan under the European Green Deal while potentially bringing more feedstock to waste incinerators.

Currently, the European Parliament and the Council are also discussing a proposal to update the EU legislation of cross-border waste shipments.[100] So far, Regulation (EC) No 1013/2006 on shipments of waste primarily aims at aligning EU law on cross-border shipments of waste compliant with the Basel Convention of 22 March 1989 on the Control of Transboundary Movements of Hazardous Waste and their Disposal. Under the new rules, waste exports to non-OECD countries would be restricted and only allowed if third countries are willing and able to receive and manage certain wastes sustainably. In addition, the proposal aims to make the intra-EU transport of waste easier and to better tackle illegal shipments. Taken together, these measures may have potential impacts for waste incineration operators in the EU as they may obtain more waste as feedstock at a lower price.

The European Waste incineration sector may also see itself increasingly influenced by EU Climate Law and strategy. In December 2021 the EU Commission published a communication on sustainable carbon cycles, in which it, among other things, highlighted the need to push for innovation to capture CO_2 and use it as feedstock for the production of fuel, chemicals and materials as well as to kick-start and upscale industrial carbon management approaches such as CCS and CDR (carbon dioxide removal) more generally.[101] The Communication forms part of the greater recognition of the important role of CCUS and CDR in hard-to-abate sectors and has been followed by EU legislative initiatives such as the Carbon Removal Certification Framework proposed in 2022, the 2023 proposal for the Net-Zero Industry Act and the Industrial Carbon Management Strategy that is presently being developed by the EU Commission. With respect to the waste incineration sector, these instruments may trigger trends such as an increase in CCUS project activity at waste incineration installations but also greater competition for biogenic feedstock. They will receive further consideration in Section 3.2 of the report.

99. Directive (EU) 2018/850 of the European Parliament and of the Council of 30 May 2018 amending Directive 1999/31/EC on the landfill of waste (Text with EEA relevance), CONSIL, EP, 150 OJ L (2018). http://data.europa.eu/eli/dir/2018/850/oj/eng
100. Waste shipments: Council ready to start talks with Parliament. (n.d.). Retrieved October 13, 2023, from https://www.consilium.europa.eu/en/press/press-releases/2023/05/24/waste-shipments-council-ready-to-start-talks-with-parliament/
101. COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL Sustainable Carbon Cycles, (2021). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2021:800:FIN

2.3 The circular economy framework (with focus on the Nordics)

Turning waste into resources is an essential building block of the circular economy according to the European Commission.

From the point of view of the circular economy, utilization as a material takes precedence over waste incineration. The better the materials are recovered, the smaller proportion of them is burned. The recovery of plastic and wood in particular reduces the share of material with a high calorific value in incinerable waste, while bio-waste is poorly combustible and has a low calorific value due to its high-water content. In general, an improvement in the recycling rate leads to an increase in the proportion of unburnt material and relatively high ash concentrations in combustion.

In general, the share of waste going to incineration will decrease in all the Nordic countries.

On the other hand, valuable raw materials can be obtained from the ashes of waste incineration in the future. Nowadays the metals removed from ash can be calculated as recirculation, but utilization of other components of ash or ash in total cannot.

Table 7 National goals related to the recycling of plastic waste

	Sweden	Norway	Finland	Denmark	Iceland
Waste frame-works and goals	• 60% municipal waste recycled by 2030 • 70% of non-hazardous building material recycled • Reduce waste streams • Increase reuse • More effective sorting and recycling • Sector goal: 50% reduction in fossil emissions by 2030 and close to zero in 2045.	• 65% of reuse and material recycling by 2030 • 70% recycling of packaging by 2030 • 50% reduction in food waste • All food and plastic waste must be sorted out	• 57% of municipal waste recycled • 65% of bio-waste recycled • Ban on organic waste landfilling	• requirement to use 25 % recycled material in plastic bottles in 2025 and 30 % in 2030 • requirement of a minimum of 60 % recycling of collected plastic waste from households by 2022[102]	• Prevent waste generation • Increase recycling • Ban landfilling (for some waste types)

102. *Klimaplan for en grøn affaldssektor og cirkulær økonomi*, https://www.regeringen.dk/media/9591/aftaletekst.pdf

3. Synthesis of results

3.1 Common aspects and potential synergies among the Nordic countries

Waste incineration & district heating – a perfect match?

Common for all Nordic countries is a considerable integration between waste incineration and the district heating sector. A colder climate and being able to use the district heating system as a heat sink (or additional income in economic terms) for waste incineration is a strategic advantage for the Nordic countries that is often raised as an argument in favor of maintaining (or even expanding) the Nordic district heating sector. The waste incineration sector is pointed out to primarily having been established for handling waste streams and minimizing waste volumes and thus landfill, but also to reduce potential toxic or infectious properties.[103] Energy recovery is a bonus that the Nordic countries have and should be making use of.

Waste incineration policies differ between the Nordic countries

The national strategies for the Nordic countries with respect to the waste incineration sector, however, differ to some extent, with the inclusion of the waste incineration sector in Denmark and Sweden in the EU ETS system being one of the most obvious differences. Denmark, in addition, has an active policy goal to reduce the waste incineration capacity. The other countries in the Nordics, on the other hand, currently do not have any goals to reduce their waste incineration capacity. For Finland in particular, waste incineration plants have been installed more recently, resulting in incentives for the energy companies to continue using the existing infrastructure at least for its technical lifetime. A political goal of reducing the capacity in turn would be counteractive to these incentives.

Well-established waste sorting systems

All Nordic countries operate well-established systems for sorting and handling large fractions of waste in particular household waste. The fulfillment of recycling goals and increase in material recycling will lead to decreased domestic generation of waste for incineration and may impact the heating value of waste being incinerated. However, the achievement of the ambitious goals set on material

103. *Waste Incineration and Public Health*, Committee on Health Effects of Waste Incineration, Board on Environmental Studies and Toxicology, 2000

recycling is not self-evident, as impurities in waste, many steps prone to human error (e.g., low sorting performance in complicated sorting systems) being involved in the waste handling process and high costs for handling and sorting waste may lead to lower recycling rates in reality.[104]

Nordic countries waste incineration solution for landfill in Europe?

In addition, there currently are substantial amounts of waste imported to the Nordic countries (and transferred between the Nordic countries) with the Nordic waste incineration sector as alternative to landfill for the rest of Europe. Denmark has set a policy goal to avoid import of waste – in line with their planned decrease in incineration capacity - but within the other Nordics countries, energy and waste management companies still are free to import waste to supply their incineration plants.

As mentioned earlier, Nordic conditions allow for high rates of energy recovery due to cold climate and established district heating networks. However, the focus on national policies sometimes can be considered to suboptimize the waste incineration systems with respect to emission reductions from a European or global perspective: national climate targets and conflicting economic incentives can for example be a barrier for European landfill waste being combusted in the Nordic countries. There are a large number of *existing* landfill sites where climate benefits – from e.g., avoiding methane emissions from these landfills – would motivate the case of transporting and handling the waste in Nordic incineration plants from an environmental (global) perspective.

Waste management market not a transparent business

The varying ownership structure (public/private) of waste incineration plants and waste management companies across the Nordics also has an impact on the opportunities to effectively influencing/changing the sector by policy measures. A common Nordic/European market for waste, as well as an international perspective on emissions caused by waste handling (both from landfill and incineration) could help to address a number of challenges but is of course difficult to realize. Missing data and varying levels of details on statistics across the different countries is also an aspect making international comparisons difficult.

Higher costs for waste handling increase risk for illegal business

Increasing efforts on waste sorting, recycling, improved handling in general, as well as stricter requirements on waste incineration plant operators with respect to emission handling has in general increased waste handling costs. Increasing gate fees, caused by higher environmental and emissions standards operators need to

104.https://klimatledande.lindholmen.se/sites/default/files/2024-03/rapport_plast_plockanalyser_final_jan2024-.pdf

adhere to, also might provide a stronger driving force for illegal actions. Illegal waste handling, both through export and illegal dumping or incineration, has increased notably in Europe since 2018, when China, which until then had been the most important waste importer globally, introduced stricter rules on import of solid waste.[105] In Sweden, for example a waste management abuse scandal - with suspicions on illegal waste disposal, intermediate waste deposits catching fire - indicates that there actually is a risk that the more money there is to make from waste, the higher the risk of questionable actors entering the market. Both energy companies and the police authority in Sweden warn for an increased risk of illegal trade with waste due to the increased costs by policy measures (such as taxes and emission certificates).[106]

Nordic islands may become a show case

The islands in the Nordic countries vary in both population in size, resulting in different challenges with respect to waste management. There are several ambitious strategies for reducing waste generation and improving recycling to move towards a more circular economy. Bornholm in Denmark is such an example, trying to inspire and foster international collaboration for addressing the challenges within the sector with its "Without waste 2032" strategy. Also, the Faroe Islands have ambitious goals with respect to waste management and circularity. There is a potential for collaboration among the Nordic countries to lift waste management and waste incineration related topics for islands to an international level, with the Nordic islands becoming an international show case.

Waste incineration will not become redundant in the foreseeable future

Even if the recycling rates based on the Nordic countries' national plans and EU ambitions and regulations are intended to increase, there will still be massive amounts of plastic waste that can be expected to end up in incineration. The waste incineration sectors (at least in Sweden) does not expect the fossil stream of waste to decrease drastically. A recent study investigating private households' "combustible waste" fraction (after sorting for fractions in the household according to the local rules) showed that there remains a considerable amount of plastic and paper waste in the fraction sent to incineration, indicating that goals set up by the municipalities will hardly be reached in the near future.

Accumulation of impurities in plastic waste streams complicates circularity – hazardous content either needs to be sorted and rejected upstream, selectively cleaned/incapacitated during the process (technologies for this will be hard to find and commercialize) or plastic waste must be divided up into more different streams than today, which is more expensive.

105. INTERPOL's strategical analysis on emerging criminal trends in the global plastic waste market since January 2018
106. https://second-opinion.se/avfallshantering-lockar-organiserad-brottslighet/

Proximity to potential CO_2 storage sites in Norway (and Denmark)

Norway being a global frontrunner within storage of captured CO_2 also could leverage strategic investments within the waste incineration in the Nordics, given proper conditions. All Nordic countries – except Finland, where companies within the waste incineration sector have focused carbon capture and utilization as there are no domestic sites for CO_2 storage available – have investigations and plans for CCS within the waste incineration sector. Denmark has recently opened up for CCS storage site establishment as well, with three companies having been awarded licenses to store CO_2 in North Sea oil and gas reservoirs, hoping to store up to 13 Mtons of carbon per year.

3.2 The potential role of CCUS

Across the Nordic countries, CCUS is increasingly recognized as a crucial technology for mitigating CO_2 emissions from waste incineration. This development must be seen in the context of European and Nordic climate ambitions. Norway was the first Nordic country to formulate a strategy for CCUS promoting technology development and cost-effectiveness. Also, Sweden, Denmark and Finland mention CCUS in their climate action plans although strategies for promotion and commercialization exist to varying degrees. For all the Nordic countries, the focus is on equipping existing waste incineration facilities, exploring pilot projects, and actively testing CCUS technologies. However, the type and the status of projects, the scope of initiatives beyond waste and the specific approaches to collaboration differ among the countries. For example, in Norway, several waste incineration actors are already testing out CCS technologies and through the Longship Project, the Norwegian government has decided to take an active role in supporting the implementation of a full-scale industrial CCS value chain by making substantial funding commitments to the Hafslund Oslo Celsio waste-to-energy (WtE). To the contrary, Finnish waste incineration installations presently do not plan to introduce CCS, but rather focus on the implementation of CCU while in Sweden industrial pilots for CCS are still at a very early stage.

Despite the few first operational experiences with CCUS, lacking incentives, investment and infrastructures hampered progress across all Nordic countries. As an example, the Danish government decided to reduce its incineration activity by 30% following a decision to stop importing waste from other countries.[107] Before knowing which plant will reduce capacity or close, some actors are reluctant to invest in CCS. At the same time, the implementation of CCS might also help to secure the future of incineration plants.

107. https://stateofgreen.com/en/news/new-political-agreement-to-ensure-a-green-danish-waste-sector-by-2030/

Nevertheless, there are indicators for a change in dynamics. Where countries have chosen to implement carbon taxes and/or include the waste incineration sector in the ETS, waste incineration operators have a clearer incentive to consider the deployment of CCUS technology, given the expected rise of carbon prices. Emissions verified as captured, transported, and permanently stored may eliminate the obligation to surrender emission allowances or pay carbon taxes. This will be harmonized to a larger extent between the Nordic (and European) countries when the waste incineration sector is included in the EU ETS across the whole European Union towards 2030.

A greater role for CCUS is also foreshadowed in recent legislative initiatives at the EU level. The 2023 proposal for the Net-Zero Industry Act (NZIA) now lists CCUS as one of the 8 strategic net-zero technologies for which scaling up manufacturing capacity is critical. NZIA sets out measures and action lines to facilitate strategic CCUS projects which may benefit the introduction of these technologies in waste incineration installations given the hard-to-abate nature of the sector. The adoption of the proposed Carbon Removal Certification Framework (CRCF) may also bring more certainty for waste incineration operators who plan to deliver negative emissions with BECCS. If the CRCF succeeds in establishing a regulatory framework for robust and transparent carbon removal this might not only create a growing market for BECCS credits generated from biogenic waste incineration but could also pave the way to an integration of negative emissions technologies into the EU ETS, adding to the circle of incentives for the waste incineration sector.

All in all, the role of CCUS for the waste incineration industry is to reduce emissions, reduce related taxes and give more operation stability for the plants as they would comply with authorities' goals. CCUS will not influence the amount of waste being sent to incineration. However, if a carbon removal certification scheme is implemented, the price of certificates may incentivize incineration plants to burn a higher share of biomass and compete to a larger extent with other waste treatment alternatives for biomass, depending on the respective market prices for CDRs and biomass.

3.3 The role of circular economy

The incineration of wastes conflicts with targets of circular economy such as reduction, reuse, or recirculation of materials. Reaching recirculation targets would decrease the amounts of materials such as plastics in mixed waste and decrease both amount and heating value of the incinerated waste. An example from Finland for the effects on increase in circularity illustrates these effects:

In 2021 38% of municipal waste was material utilized, which is much less than the targets 55% (2025) or 60% (2023). Assuming the total amount of municipal waste (3.5 Mtons) will not increase, the amounts of waste to incineration should decrease

based on the target to about 560 000 tons and 730 000 tons, respectively. On the other hand, the recirculation rates of package plastics are also far behind targets, being at 34% while targets are 50% and 55% for the years 2025 and 2030, respectively. The content of plastics in mixed waste will decrease with increasing recycling, leading to lower fossil CO_2 emissions but also to a lower heating value (as the share of plastics decrease). This, in turn, may lead to a need for supporting fuel or a need to increase the amount of other waste derived fuels.

The municipal waste companies have recirculation targets, but, on the other hand, they may have long-term contracts with the energy company for delivering waste for incineration. If the amount of municipal waste decreases, there is a strong need for other waste fuels – such as construction waste – for incineration. There will be competition between incineration and material recycling of waste. On the other hand, imported waste may replace some domestic municipal waste.

The material utilization of ash can be considered as recirculation. According to recirculation rate calculation, metals removed from waste incineration ash can be allocated to the recirculation rate, but the rest of the ash cannot.

There has been discussion of calculating products of CCU as recirculation of carbon. The concepts of CCU will produce methanol, which can be used for the production of chemicals or fuels. However, there is no decision on how this will be treated. Fortum Recycling and Waste has a concept to produce plastics from incineration CO_2.[108] If the methanol is used for production of fuel, CO_2 emissions will be the consequence, and fuel production may not be counted as recirculation. In a circular economy, harmful substances must be removed somewhere in the cycle. These include POP (persistent organic pollutant) compounds, which are found, for example, in demolition waste.
Demolition waste can contain, for example, plastic containing polybrominated diphenyl ethers, polyurethane insulation and wood impregnated with wood preservatives. Short chain chlorinated paraffins have been used in paints and in the fire protection of products made of PVC. Hexabromocyclododecane has been used as a fire retardant for polystyrene insulation.[109]

It has been suggested that these substances should be incinerated at high temperatures for destruction, but to date it remains unclear whether waste incineration is effective enough in destroying long-lived pollutants such as PFAS.[110] High temperature incineration may be used also for treatment of other hazardous materials such as potentially infectious medical waste.

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108. https://www.fortum.fi/media/2023/10/fortum-recycling-waste-investoi-hiilidioksidipohjaisten-muovien-tuotantoon
109. https://www.ttl.fi/ajankohtaista/blogi/turvallista-materiaalien-kierrattamista-rakennusalalle
110. Sofie Björklund, Eva Weidemann, Stina Jansson:

Emission of Per- and Polyfluoroalkyl Substances from a Waste-to-Energy Plant — Occurrence in Ashes, Treated Process Water, and First Observation in Flue Gas.

Environmental Science & Technology, 2023

3.4 Considerations on optimal sizing of the waste incineration sector

Although defining an optimal sector size is not within the scope of this report, it can help to find the relevant questions which need to be answered for such a definition. The data found in chapters 1 and 2 points toward a potential conflict between the availability of waste as feedstock in competition with material or chemical recycling, the fulfilment of circular economy goals, and the cost of running waste incineration plants, see Figure 21.

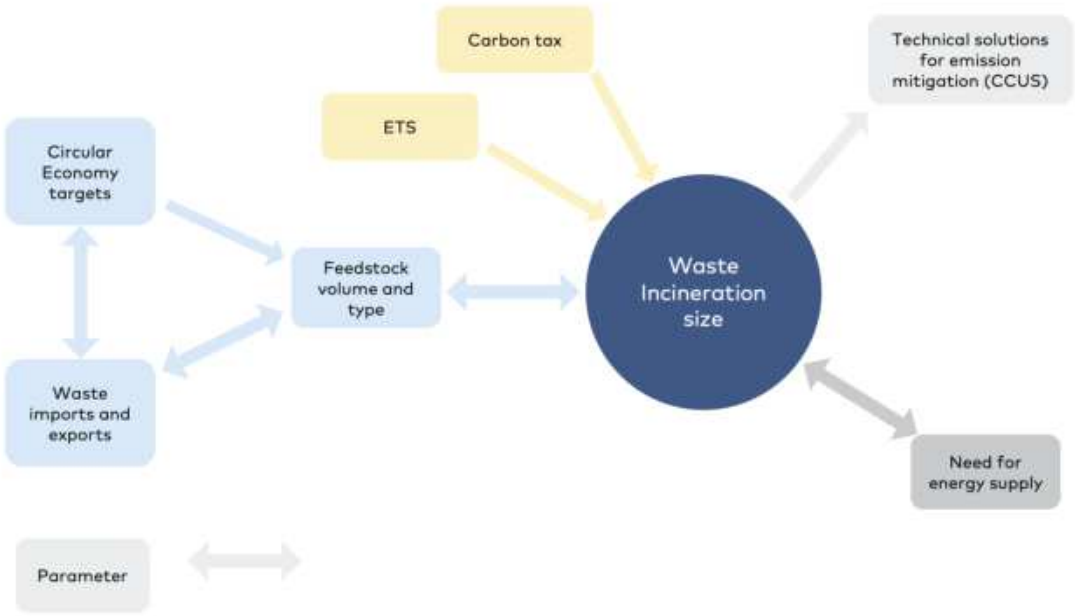


Figure 21 Schematic overview of parameters impacting the waste incineration sector and their interdependence.

Table 8 shows a scenario for incineration capacity in 2030 in Finland, Norway, Sweden and Denmark, provided that policy and/or sector goals are fulfilled.

Table 8 Waste incineration capacity in 2030 based on policy or sector goals.

Country	Waste incineration capacity required in 2030
Denmark	Plan for 2020–2030: reduction with 480 ktons/year of waste generation, reduction of incineration capacity from 4 to 2.7 Mtons/year.
Sweden	500–670 ktons/year less plastics to incineration 2030 according to 50%-goal set by EU's plastics strategy – concrete recycling projects and sector goals cover only 164 ktons/year.
Norway	Based on national numbers, Norway will have to prepare for reuse and recycling of 65% of household waste and similar waste from the industry. This means that 4% more plastic and 57% more mixed waste will have to be recycled or reused compared to 2021 numbers.
Finland	700 ktons/year less municipal waste to incineration 2030 according to 60%-goal, 26 ktons/year less plastics, 55% goal.

The table clearly shows the ambition to reduce the generation of waste in general and plastic waste in particular, while only Denmark has a clearly stated goal to reduce incineration *capacity*.

What do we optimize for?

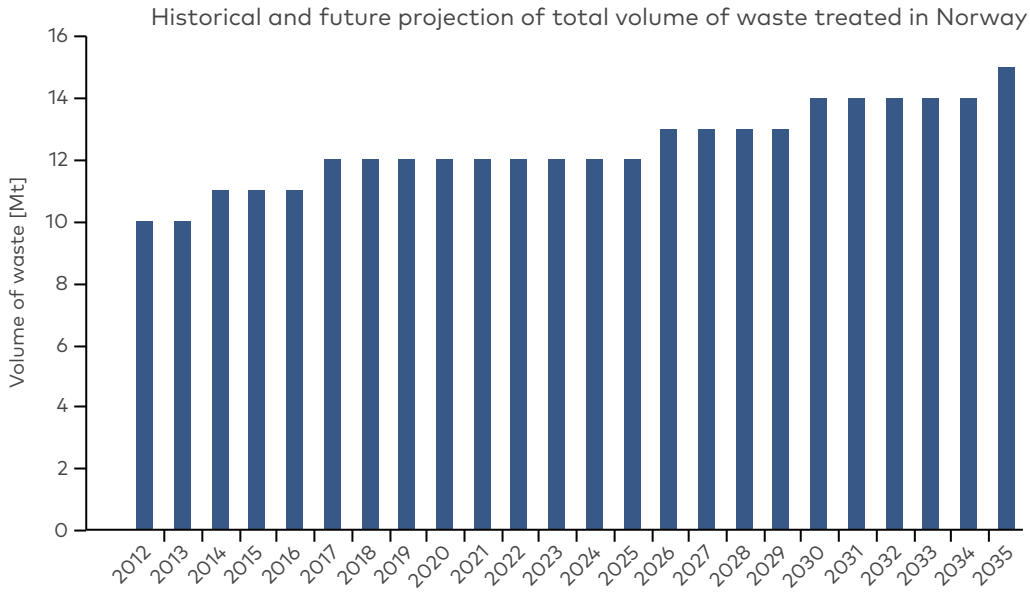
When asking for the optimal size of something, it is important to know what shall be optimized. Depending on whether the optimization shall be directed towards global CO_{2e} emissions, recycling rates, energy use, fossil feedstock utilization, physical footprint, local pollution, or something entirely different, the answer will differ. Assuming that material or chemical recycling in general is preferable to incineration, a first step might be to determine how much waste will be left once an economically viable portion (or what is defined by circularity goals and policies) has been recycled. Any recycling on top of this will only be competitive with incineration if recycling costs can be pressed below the level of incineration.

The availability of biogenic feedstock in plastics production, but also to the economy as a whole, is another important input parameter. Just as recycling rates, it will largely depend on policy measures and the willingness to pay in a free or regulated market.

A potential future carbon tax will also impact the economic feasibility of running a waste incineration plant with reduced availability of feedstock. Such a tax, if introduced, will probably be transferred to municipalities and ultimately consumers, but it remains unclear whether higher fees will be enough for a measurable change in behavior or the deployment of new technologies such as CCS.

3.4.1 High-level estimation of waste volumes sent to incineration: a Norwegian case study.

The objective of this section is to provide an indication of the remaining volume of waste sent to incineration if the national circular economy targets are met, starting with an assumption on the evolution of waste sent to treatment in Norway. Assuming that waste volumes continue to grow at the same rates they have since 2012, the total amount of waste treated has been projected to a 2030–2035-time horizon. To that end, the growth rate observed between 2012 and 2019 has been applied to the 2021 level. 2020 and 2021 have not been considered in the growth rate assessment to exclude the potential pandemic effect on waste streams. Figure 22 shows the resulting projection until 2035, which represents a growth of 21% compared to 2021 levels.



Volume of waste generated in Norway			
	2021	2030	2035
Total	11.6	13.5	14.6

Figure 22 Projected Waste Volumes treated in Norway.

The distribution of waste treatments from the year 2021 was subsequently taken as a reference to estimate the volume of waste that will be sent to material recycling. It was assumed that the pandemic did not influence the way waste was treated. From that reference, the distribution of treatments was modified over time to reach the Circular Economy target of 65% (2030) and 70% (2035) of waste prepared for reuse and material recycling of household waste and similar waste from the industry, assuming that this target would be influencing material recycling, biogas production and composting. Not all waste types are included in this projection. In fact, wastes such as wood, sludge, concrete and brick, slag, dust, bottom ash, fly ash, scraped vehicles, radioactive waste, hazardous waste and lightly polluted masses are assumed to be excluded from the Circular Economy target, keeping the same treatment distribution as in 2021 over the projection period. For those waste categories covered by the target that are already being sent to recycling at a higher percentage than the targets, the same distribution over the projected period has been kept. For those waste types assumed to be influenced by the Circular Economy target which were below the 2030–2035 targets in 2021 (mixed waste, wood waste, plastic and rubber), a linear growth to 65 and 70% was applied to the share sent to recycling.

Finally, the 2021 share of waste sent to incineration was applied to the remaining volumes to obtain the projection for each waste type going to incineration. The results are shown in Figure 23, revealing a total waste stream reduction of 29% in 2030.

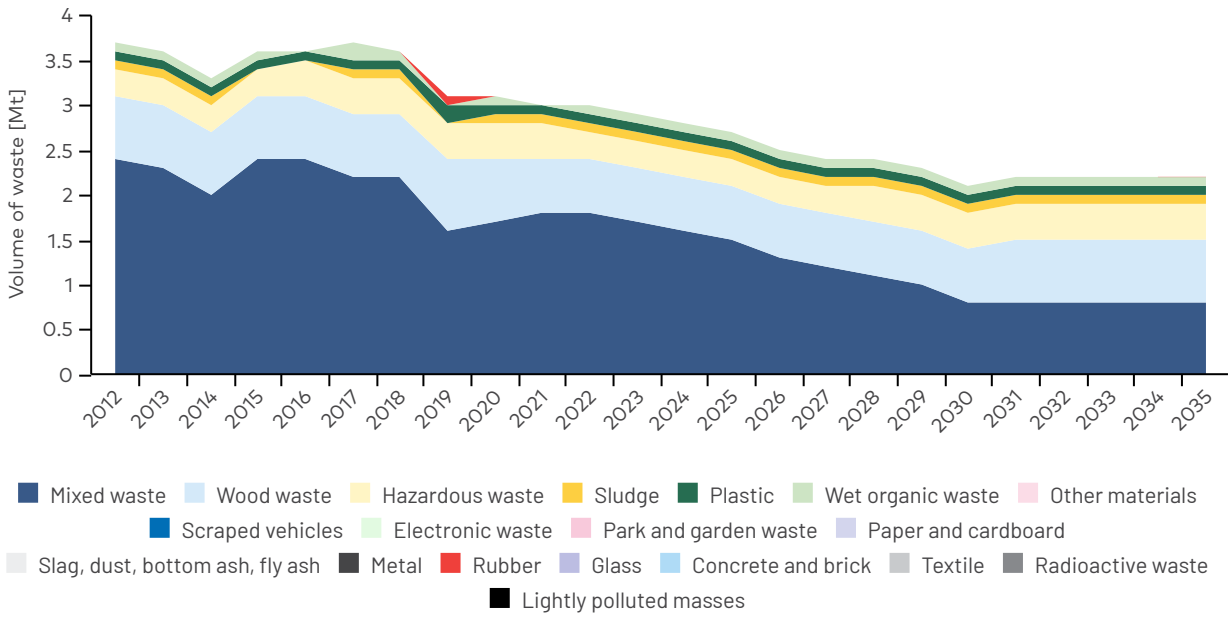


Figure 23 Waste volumes sent to incineration until 2035 in Norway – Scenario 1.

Historical and future projection of volume of waste sent to incineration by type in Norway. Considered target: Preparation for reuse and material recycling of household waste and similar waste from the industry.

The results suggest that mixed waste will remain the main waste stream going to incineration, with wood waste and hazardous waste following. Moreover, mixed waste is decreasing over time due to the increase in preparation for reuse and recycling, while wood waste and hazardous waste are not impacted by the target and are likely to keep growing in accordance with the total stream of waste generated in Norway.

Furthermore, the projections reveal that even though the target increases by another 5% in 2035, the waste generated actually compensates and increases slightly the waste stream sent to incineration so the actual reduction compared to 2021 will decrease to -28%.

While the aim of the projection was to test the effect of the preparation for reuse and recycling target on the future waste streams, it may also be run for the reduction in food waste target, which specifies a 30% reduction by 2025 and 50% in 2030. A reference year for this target has not been identified and, therefore, was assumed to be 2021. The reduction in food waste streams was applied to the wet organic waste and food waste share of the mixed waste category. To estimate the food waste share in the mixed waste category, the results of the waste picking studies showed earlier in chapter 1 (32.3% and 20.9%) were averaged to represent 27% of mixed waste.

The effect of this additional measure can be seen in Figure 24, where a further 4% reduction is reached.

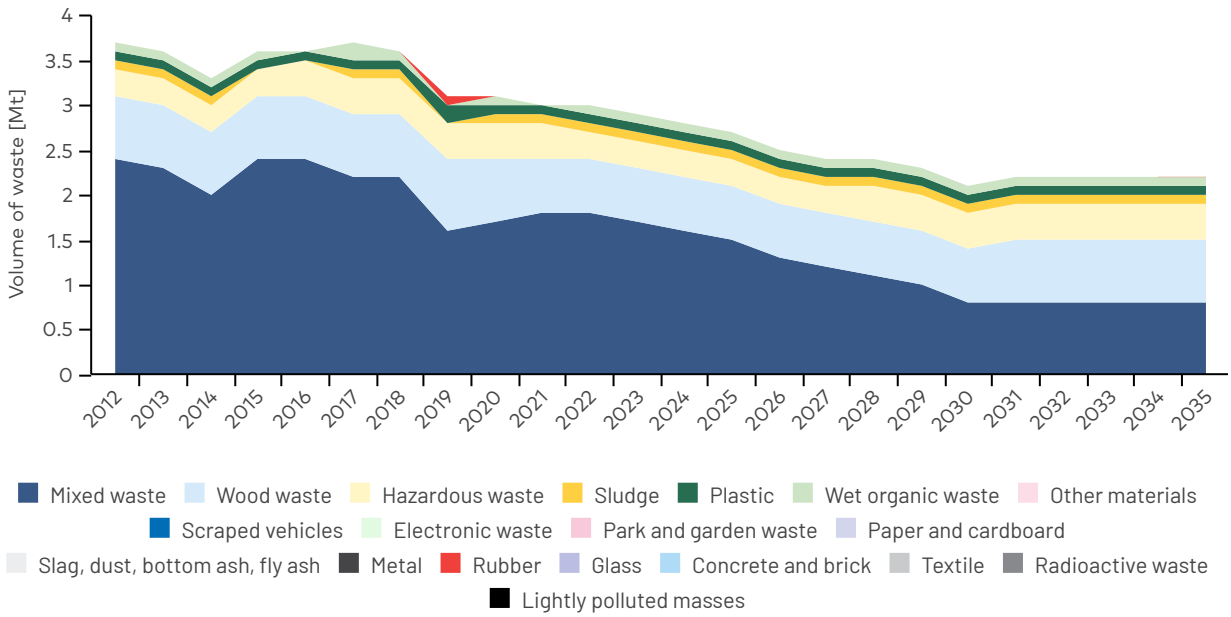


Figure 24 Waste volumes sent to incineration until 2035 in Norway – Scenario 2.

Historical and future projection of volume of waste sent to incineration by type in Norway. Considered target: Preparation for reuse and material recycling of household waste and similar waste from the industry + Reduction in food waste.

The mixed waste category is further reduced, and wood waste actually becomes the main waste stream sent to incineration. All in all, testing the fulfillment of Circular Economy targets shows that the total volume of waste sent to incineration in 2030 could be 2 Mtons. The current incineration capacity in Norway is about 1.7–2 Mtons.[111][112] This means that the amounts of waste delivered to incineration in 2035 will match the current incineration capacity. A dedicated scenario-testing-study led by Mepex in 2020 shows similar results for an equivalent scenario, reaching 1.85Mtons going to incineration in 2035.[113]

The notion of "household waste and similar waste from the industry" remains unclear. The actual waste categories that will be impacted by the targets might slightly differ. However, the assessment captured and highlighted the main forces at play. Mixed waste is one of the main waste feedstocks and the effect of such targets is likely to happen the way it was modelled for this category. On the other hand, if hazardous waste is actually influenced by the target, the effect on the overall volume reduction would be less important than a change in the mixed waste category. The result sensitivity is smaller and to a certain extent unsignificant to other waste categories than mixed and wood waste.

The assessment does not consider the possibility that new types of waste could be sent to incineration in the future. It has been mentioned in chapter 1 that a larger share of hazardous waste could be sent to incineration. The volume compensation that hazardous waste could bring is challenging to estimate within the scope of this study. Moreover, allowing more of this type of waste will depend on the decision of each regional authority but also on the incineration temperature of each plant to ensure a clean incineration of such substances. Another consideration to have after this assessment is to know if the reduction in waste streams will happen everywhere across the country to the same extent or if we observed a regionalization of effects with some facilities that will be more impacted than others.

Another possible phenomenon mentioned in the previous chapter is the increase in plastic waste generation. If that waste stream increased to the same extent it is projected by some sources, it might have a compensating effect on the total volume sent to incineration.

The assessment relies on the assumption that all the waste sent to incineration is generated in Norway. The effect of waste imports and exports is not considered. If waste imports are included in the statistical basis used for this assessment, the effect of Circular Economy targets will be reduced as a waste stream not subject to

111. Sveinung, B., Frode, S., & Andreas, D. (2019). Avfallsmengder fram mot 2035—Energigjenvinningens rolle i sirkulørækonomi (07/2019; p. 32). Mepex Consult AS. https://avfallnorge.no/fagomraader-og-faggrupper/rapporter/avfallsmengder-fram-mot-2035
112. Import og eksport av avfall. (2022, June 20). Miljøstatus. https://miljostatus.miljodirektoratet.no/tema/avfall/import-og-eksport-av-avfall/
113. Sveinung, B., Frode, S., & Andreas, D. (2019). Avfallsmengder fram mot 2035—Energigjenvinningens rolle i sirkulørækonomi (07/2019; p. 32). Mepex Consult AS. https://avfallnorge.no/fagomraader-og-faggrupper/rapporter/avfallsmengder-fram-mot-2035

those targets will still be imported. As Norway mainly imports waste from the UK, the effect of imports on the 2030–35 Norwegian waste volumes also relies on the policy and targets that will be set in the UK.

Finally, under the growth assumption of the total waste generated in Norway, it is possible to foresee that if the 2035 target is reached, the actual amount of waste sent to incineration actually starts to increase again afterwards due to the increase in waste generated. Thus, the reduction in waste volumes might also be a temporary effect of the target. The waste incineration plant would have to deal with that temporary reduction in waste availability.

The likelihood of the second growth of waste streams after 2035 is high. Indeed, increasing the recycling targets above 70% might become more and more challenging as there will always be a share of waste that will not be able to be recycled. Moreover, the waste stream generated in Norway might still grow even with a reduced waste per capita production. Thus, the incineration sector is expected to still play a role in the future.

Perspective of the case study on the optimal sizing of the waste incineration sector

The amount of waste sent to incineration is considered as the most important influencing parameter to be able to estimate the "optimal size" of the waste incineration sector.

The fact that the assessment suggests a 30% reduction in waste volumes sent to incineration is the most important indicator to consider.

The fact that incineration plants play an important role in district heating or electricity generation is secondary; other power generation technologies (electric heated boilers with heat storage, heat pumps,...) could replace them - provided their maturity, ease of implementation and available feedstock.

The implementation of CCS will certainly allow for cleaner power production but will not compensate for the loss of feedstock for incineration plants. The first ones to implement it might be the ones to survive, provided that the loss of feedstock is even across the country or not happening for the given plants.

The influence of carbon taxes and ETS is expected to accelerate the adoption of CCS and influence to a lesser extent the willingness to incinerate waste due to higher taxes. But it will not counterbalance the effect of the feedstock loss for the incineration sector.

4. Outlook

This chapter will sum up and address open questions to be answered in future projects. Some of these questions have not been looked at in depth in this report but are still added as a reminder.

A sector under uncertainty

From a current perspective, it is hard to imagine a world without waste incineration, even in the long run. Assuming landfill as primary handling of waste should stop on a global scale, and with material recycling rates at the desired level, waste incineration capacity still might be needed to take care of hazardous waste streams and/or mixed streams that are difficult to recycle.

The future scale of the sector, however, is unclear and highly dependent on political choices and incentives, which will ultimately have a high impact on the importance of chemical recycling, material recycling and CCS. Investments in these new or expanding technologies have to be made under uncertainty, which highlights the need for clear guidelines and long-term policies.

Cost-driven risk of illegal waste handling

High gate-fees (caused by high CO_2 prices) may open up for less serious actors entering the market. This risk has been highlighted by waste management actors and a recent abuse scandal in Sweden[114] with suspicions of illegal waste disposal. In the wake of this scandal, the police have warned that waste can become one of organized crime's most important sources of income.[115]

Potential impact of CCUS on total incineration capacity

Whether CCUS technologies are deployed on a large scale in waste incineration may be a decisive factor for the sector's future: even if circularity goals are met, the chances for a completely carbon-neutral waste sector seem slim without CCUS, given the predicted hard competition for renewable feedstocks. Once a capture facility is installed and running in at a waste incineration plant, it is fair to assume that this plant has a higher chance of survival even if incineration capacity as a whole should decline, both due to the ability to operate carbon neutral (or, in fact, carbon-negative if biogenic CO_2 is captured and stored permanently instead of reentering the value chain) and considerable capital lock-in effects.

114. https://www.transportarbetaren.se/think-pink-toppen-pa-misstankt-brottsberg/
115. https://www.svd.se/a/yR8EKa/sopimperiet-gick-upp-i-rok-en-komplott

Purity requirements in chemical or material recycling

Due to the potentially long lifetime of plastic materials produced in the past, hazardous impurities in recycling streams will present a problem even when their use should be discontinued in virgin materials. Setting a reasonable threshold to the effort of separating these materials from more benign and thus easily recyclable materials will be an own optimization task.

Human behavior

Ambitions on sorting of municipal household waste are high and reality is way below the set targets in most Nordic countries; progress is necessary to improve the sorting of household waste using a combination of behavioral change, policy measures and technical development. Common efforts in identifying successful measures implemented could be an effective way for the Nordic countries to collaborate. Research projects addressing these aspects include WECOS (Waste-to-Energy in Sweden's circular economy – Collaborative system dynamics modelling), a project which "aims at improving strategic decision-making regarding the production, use, and re-use of household waste and energy infrastructure through a model platform integrated with quantified human behavior.[116]

Plastics

The global plastics market is expected to increase drastically in the coming decades, reaching a level of above 1 billion tons per year,[117] see Figure 25.

116. WECOS: Waste-to-Energy (WtE) in Sweden's circular economy – Collaborative system dynamics modelling https://mesam.se/projekt/wecos-waste-to-energy-wte-in-swedens-circular-economy-collaborative-system-dynamics-modelling/
117. *United Nations Environment Programme (2021). From Pollution to Solution: A global assessment of marine litter and plastic pollution*. Nairobi.

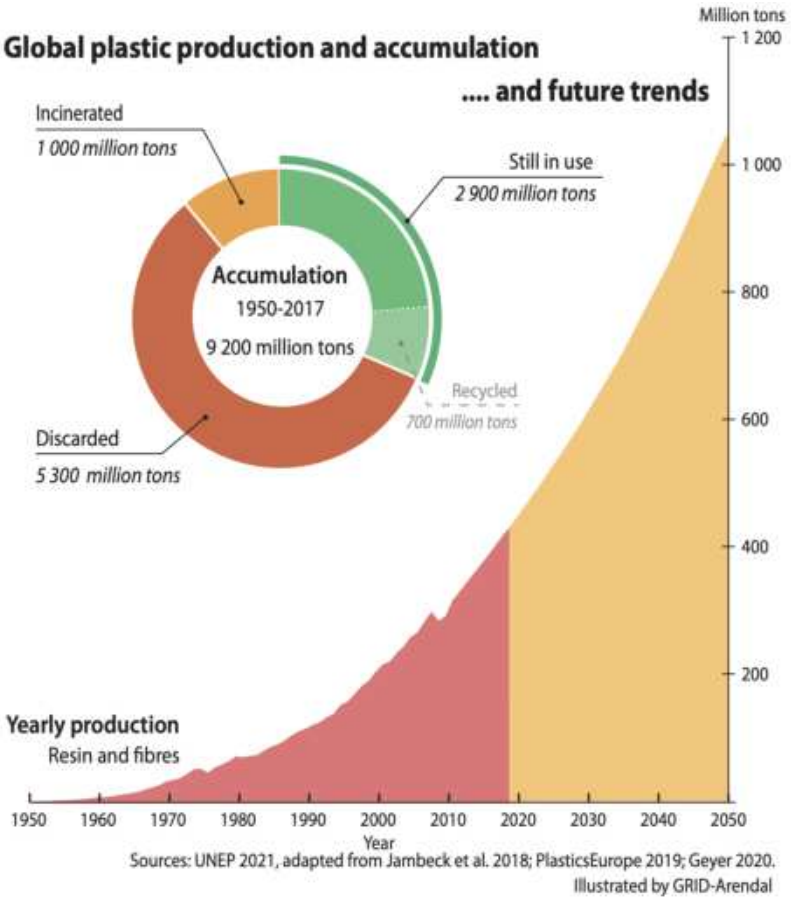


Figure 25 Global plastic production and accumulation - historically and forecast

The cumulative global production of primary plastic between 1950 and 2017 is estimated to 9200 million tons (see Figure 25) and forecast to reach 34 billion tons by 2050.[118]

Plastics cause the highest share of fossil CO_2 emissions from waste incineration – a fact that needs to be addressed if both national, Nordic and EU emission goals are to be reached. Higher recycling rates are the obvious answer to the question of how to reduce said emissions but are hard to achieve without substantial changes in the design, construction and production of new products containing plastics.

To achieve the necessary rates, a series of prerequisites need to be fulfilled:

- Recycling friendly product design.
- Increased (or, in fact, exclusive) use of recycled or biogenic plastics.
- A fair division of the cost incurred by these goals.
- Improved sorting technologies, leading to little or no reject to incineration facilities.

118. Geyer, R. (2020). Production, use, and fate of synthetic polymers. In Plastic Waste and Recycling (pp. 13–32). https://doi.org/10.1016/B978-0-12-817880-5.00002-5

- A controlled way of handling hazardous materials in plastics, e.g., by forbidding these materials in new plastics and using waste incineration or chemical recycling to handle remaining hazardous materials from old plastics

In Denmark and Sweden – where the waste incineration sector is included in the EU ETS system – gate fees for waste management companies are rather high. There is a relatively high burden on materials being of service and use to society (in particular plastics) at the end of the value chain. Extracting fossil fuels for plastics and material production on the other hand is comparatively cheap. In case the cost for producing plastics do not incorporate the whole lifecycle cost in the near term, it can be expected that plastic volumes will increase heavily instead of decline.[119] The packaging EPR (Extended producer responsibility) as defined in EU directive 2019/904 on the reduction of the impact of certain plastic products on the environment[120] aims at incorporating the whole lifecycle cost in the product, which might have a limiting effect on the amount of plastics being used. With this concept, the responsibility to manage the whole lifecycle of packaging, including end-of-life, is shifted to producers or importers, providing an incentive to reduce packaging waste.

To recycle or not to recycle

Current recycling goals are formulated under the assumption that once waste has been produced (i.e., the first steps of the waste pyramid are not applicable), material recycling is the best option from an environmental point of view. Future progress in e.g., chemical recycling technology might challenge that view.

District heating without combustion?

It is, in theory, possible to adapt district heating networks in a way that phases out combustion-based heat supply, e.g., by using heat pumps. In that case, the resulting additional electricity demand and the flow temperatures necessary in a district heating network (typically above 80 °C in existing networks) are challenges to be solved. Generally, the deployment of low-temperature district heating networks will probably be necessary to increase the use of non-combustion heat sources. In that context, the long-term effects of the updated Energy Efficiency Directive[121] and specifically its requirements concerning waste heat utilization need to be taken into consideration as well.

119. Bauer, F., Tilsted, J. P., Deere Birkbeck, C., Skovgaard, J., Rootzén, J., Karltorp, K., Nyberg, T. (2023). Petrochemicals and Climate Change Governance: Powerful Fossil Fuel Lock-Ins and Policy Options for Transformative Change Work Plan. Retrieved from https://portal.research.lu.se/en/publications/petrochemicals-and-climate-change-powerful-fossil-fuel-lock-ins-a
120. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019L0904
121. Directive (EU) 2023/... of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 (recast) (europa.eu)

The economic viability of such systems will have to be evaluated considering the continued delivery of electricity (and thus, availability of relatively high-grade heat) from CHP plants.

The Nordics providing waste services for Europe?

As was pointed out before, the Nordic countries are well-suited for specializing in waste incineration and thus potentially taking care of other countries' waste. However, relying heavily on imports when planning national or Nordic capacity needs is a risk in itself as it is not sure that other European countries would want to rely on the Nordics to solve a strategic national problem. That being said, the current Nordic incineration capacity already exceeds the domestic waste production as mentioned earlier. A situation constituting a substantial amount of waste import would therefore in no way be an unusual one to handle for the Nordic waste incineration sector.

About this publication

Waste incineration in the Nordic countries

A status assessment with regard to emissions and recycling

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TemaNord 2024:524

ISBN 978-92-893-7859-8 (PDF)
ISBN 978-92-893-7860-4 (ONLINE)
http://dx.doi.org/10.6027/temanord2024-524

© Nordic Council of Ministers 2024

Cover photo: Stian Lysberg Solum/Scanpix
Published: 4/6/2024

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