Country Report – Denmark

Landfilling Practices and Regulation Situation in Denmark

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In Denmark more than 15.000 potential contaminated sites has been registered and mapped. Info on the sites and locations etc. can be found at: http://internet.miljoeportal.dk/Sider/Forside.aspx

I 1982 a mapping of landfill done by the Danish EPA was done which resulted in 3.115 landfill sites. Most of these are dumpsites without permits, liner- and leachate collection systems and approximately 500 is a potential threat to the environment and has a content of hazardous chemical substances.

Since 1982 there has been no new mapping but all landfills has to be registered as ”contaminated sites” and put in to the database. Very little information on what has been landfilled, size etc. has been generated and is actually accessible.

Since 1992 all “new” landfills have to be owned by public authorities (municipalities) Public owned landfills cannot earn money (due to the “self-cost principle”). In 2014; 41 landfills met the EU landfill legislation; this number was 105 in 2007, and has since the adoption of the Landfill Directive been decreasing.

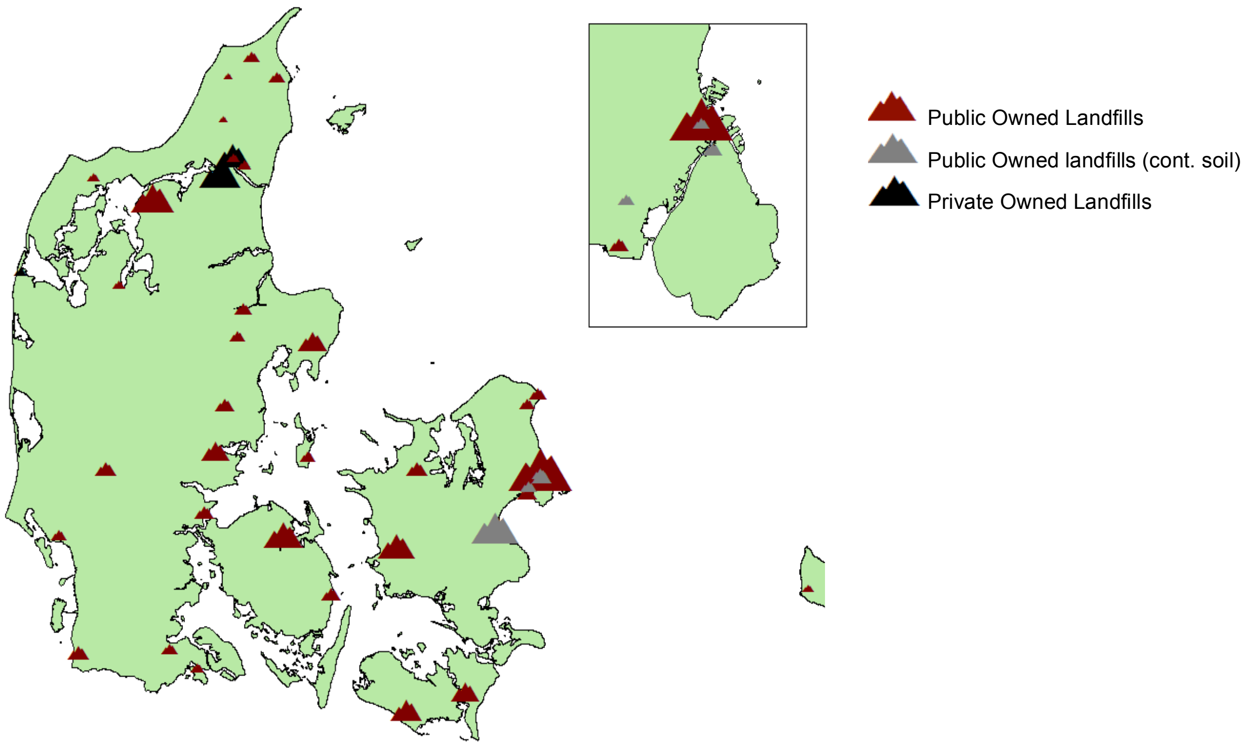


Figure 1: Location of on-going landfills in Denmark (BEATE 2013)

2. Current landfilling concepts

Danish landfills are unique because they are left uncapped which allows water to flow through the landfill. This accelerates the dilution of chemicals in leachate and thus the emissions potential of the landfill is reduced. Danish legislation requires that the aftercare period be 30 years, or however long it takes for the surrounding groundwater to fall below set substance concentration limits. This legislation is based on the concept that each generation should deal with their own problems.

The Technical Adaption Committee (TAC) appointed by the EU council, has created standards for acceptable criteria for waste, which if met can be landfilled. If not the waste has to undergo further treatment before landfilling in order to meet the criteria. Current Danish legislation is stricter and has standards with respect to acceptable chemical concentrations in the groundwater. In addition, the Danish government has established a set of “acceptable criteria” for waste entering landfills to determine whether or not waste is suitable for landfilling. Unfortunately, the legislation does not seem to reflect the reality of the necessary length for the aftercare period.

Denmark modifies these definitions slightly by using four waste categories instead of the LFD’s three categories. Denmark divides non-hazardous waste into two subcategories: mixed Municipal Solid Waste (MSW) and mineral waste.

The goal of landfill design is to optimize waste disposal capacity while minimizing environmental impacts on the community. It is the responsibility of the design engineers to consider all potential environmental impacts, future use of the space after remediation, and economic feasibility.

Each landfills’ unique characteristics, such as climate, clay, bedrock quality, and location relative to groundwater and ocean, must be considered during the design process. The landfills must adhere to best design practices as well as all legal requirements. Every landfill uses several methods to protect the surrounding environment: liner, leachate and gas collection, and groundwater testing. The design of the liner system is often considered the most critical aspect of sustainable landfilling because it is the primary protection for the environment.

The bottom liner has a projected lifespan of 80 years in Denmark; therefore it is beneficial to mitigate the potential impacts of contamination while the liner is still effective. Denmark’s active approach of leaving landfills “uncapped” does just this and benefits the environment in the long run. Danish landfills allow rainwater to percolate through the waste and actively dilute the leachate, thus reducing future environmental impacts and avoiding environmental and economic catastrophe when the liner eventually breaks. When the bottom liner finally breaks, the natural degradation of the surrounding clay should protect the groundwater from contamination.

Complex liner and barrier systems have many layers, each with a specific purpose. The bottom liner of a Danish landfill must include a geological barrier, leachate collection system (gravel and piping network), geotextile, impermeable polymer, and clay.

Each layer within the liner has a specific function to prevent seepage of percolate into groundwater. The geological barrier prevents contamination of the surrounding soil and surface water. There are strict requirements for permeability and film thickness of geological barriers, which vary by landfill type. A thinner, less permeable liner is allowed for inert waste versus hazardous waste. These requirements for thickness are adjustable if a synthetic liner is used rather than a clay liner, but an equivalent amount of protection must be maintained- a minimum thickness of 0.5 meters of synthetic liner is required. With artificial barriers, the stability of the underlying layer must be verified to prevent damage to the geological barrier.

The most commonly used geological barriers include: bedrock “with low permeability and without voids”, natural clay, and artificial barriers [21]. With the development of new technologies in the past few decades, artificial barriers have improved significantly and are currently well accepted in the waste management industry, with high density polyethylene (HDPE) liners being the current industry standard. The negative side of HDPE liners is that they are susceptible to heat generated from the exothermic processes of waste, corrosion caused by leachate, and cracking in cold conditions .

A leachate collection system is necessary to properly remove leachate produced by the landfill. This drainage system includes a series of pipes and pumps to evacuate leachate collected by the pipe network and a layer of gravel, which allows leachate to flow under the waste. The bottom of the landfill is graded so that leachate flows naturally to the pipes due to gravity.

Engineers must consider many factors to design an effective leachate collection system. The system must be able to handle anticipated amounts of leachate without accumulation at the bottom of the landfill over time. All components need to withstand the pressures and aggressive chemical nature of leachate. Piping and pumps should be capable of functioning properly even in a reduced capacity as the hydraulic conductivity of the system decreases over time. Leachate will inevitably deposit materials on the insides of piping systems, which will build up over time and impede the flow of fluid. Systems are typically installed to clean these pipes but this process is rather expensive.

Below the leachate collection system is the geotextile layer; its purpose is to prevent sharp-edged gravel from puncturing the impermeable polymer layer below due to high pressure. This pressure is created by the weight of the above waste and the compaction process. The geotextile also filters suspended solid particles in the percolate that can erode the polymer layer.

The impermeable polymer layer is considered the most important element of the seepage prevention defense line because of its leachate resistant nature. The layer is mainly synthetic bituminous polymers that carpet the landfill bed, with a strong seal between separately installed sections. The hydrophobic nature of these polymers prevents wetting and permeation by percolate.

Clay defines the bed of a landfill and it is used as a barrier between the rest of the liner and the surrounding soil and groundwater table. The clay should have an appropriate water content and be installed with proper compaction techniques in optimum weather conditions. If these factors are taken into consideration, many long term problems, such as reactions with any leaking percolate, can be avoided .The attenuation properties of this clay are very important to prevent groundwater contamination upon breakage of the liner.

In Denmark there is a very specific protocol for sending waste to landfills. Both the waste producer and the landfill owner hold responsibilities in this process and must comply with Danish waste management regulations. The waste producer must create a fundamental characterization, which is a document that outlines all information regarding specific waste, such as information regarding the waste’s classification and special precautions necessary at the landfill.

The fundamental characterization includes the results of the leaching test designed to identify any potentially environmentally harmful substances. The leaching test is used for the first year waste is deposited by a waste producer while the compliance test is used for each following consecutive year. The initial leaching test is a more in depth test than the subsequent annual compliance tests.

In Denmark, the LFD's non-hazardous category is further divided into "mineral waste" and "municipal solid waste". Municipal Solid Waste (MSW) is unique in that testing is not required for landfilling because of the high variability and high heterogeneity of its composition. The other three categories of waste (inert, mineral, and hazardous) must be tested before being approved for landfilling. To test the waste, waste is sampled in a manner such that it is the best representation of the entire waste streams. The samples are placed in a testing column and water is run through it over a long period of time.

The fundamental characterization test results are sent to the landfill where they are compared to the acceptance parameters set upon initial characterization results (determined on site by the landfill staff). The landfill staff then determines if the waste is appropriate for the specific site. The staff's decision is relayed back to the waste producer and the waste is dealt with accordingly. If the waste is not accepted by the landfill, pre-treatment may be required. The landfill must keep characterization information on file for a minimum of 10 years.

Upon arrival of waste at a landfill, the weight (in tonnes) is determined, and a visual inspection may be performed, by a trained professional. The purpose of this inspection is to ensure that the waste is sorted and does not contain combustible or recyclable material. If the waste passes inspection, a written receipt is sent to the waste producer. However, if the waste does not pass this inspection, the landfill must issue a written rejection notice with a reason for denial to the waste producer and home municipality of the waste

Once waste is approved for landfilling, it is compacted into cells, which are the volume occupied by the compacted waste over a short period of time, typically every few days. Cells are arranged in rows and layers and are efficiently compacted by tractors and bulldozers to minimize the volume occupied by the waste. They are then covered by soil (the daily cover) and further compacted. Waste is usually screened for bulky material like mattresses and upholstery to ensure maximum compaction. Unfortunately, firmly packed layers of waste can pose a significant obstacle for leachate flow, which can inhibit the decomposition process. Air space, the volume of space on an entire landfill site which is permitted for waste disposal, is one of the most important factors in defining the capacity and lifetime of a landfill.

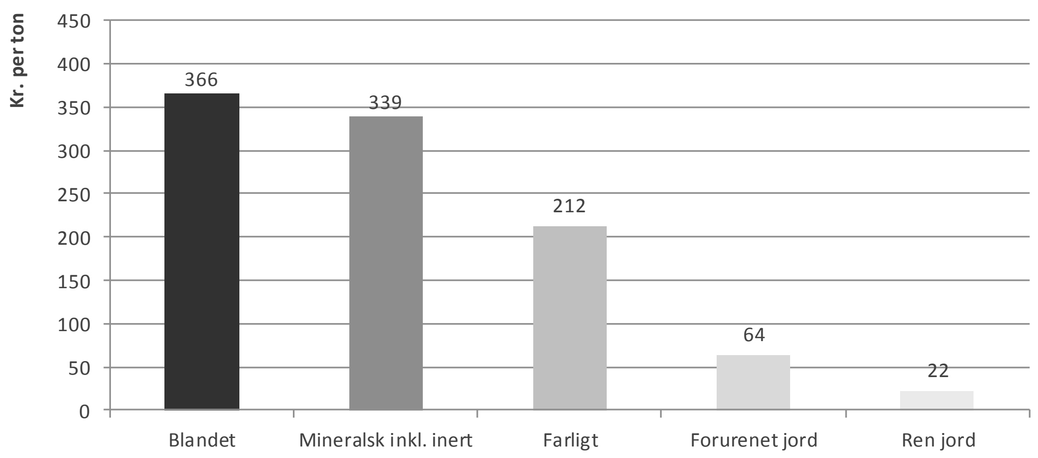
There is strict legislation pertaining to the financial security of Danish landfill owners (as well as EU landfill owners). Owners must provide collateral to prevent abandonment of landfills, which would represent a serious environmental concern. This collateral must be in the form of either a "bank guarantee from a bank, surety insurance policy, or deposit of cash in an escrow account in a bank" to obtain approval for a new landfill [20]. These forms of insurance should be proportional to the potential costs of landfill operation and monitoring throughout its entire lifetime, including the aftercare period. The Danish Environmental Protection Agency (DEPA) prepared a spreadsheet that helps determine how much it costs to deposit waste, by tons of waste and dependent on waste type. This needs to be adjusted every year according to the waste flow and available capacity.

Danish landfills are prohibited from making any profit, with the cost of landfill operation and monitoring during the active phase and aftercare period covered by waste producers. This cost is paid in the form of a landfill fee (per ton); a simple formula is used to determine this landfill fee:

The government waste tax is a fixed 475DKK fee per ton for all Danish landfills regardless of waste type, size, etc. The landfill operation cost includes the cost of all elements required to successfully operate the landfill, such as equipment, employee wages, and construction. The purpose of the security collateral is to set money aside for the closure and aftercare of the landfill. A complex process is used to calculate the security collateral for landfills. The calculations take many factors into account, such as residual capacity, annual volume of waste, waste type, and inflation. The landfill operation cost and security collateral vary by site. Both are calculated for the entire landfill and then divided by the predicted capacity (in tons) which gives the price in cost per ton [.Although there should not be a major profit, any extra funds contribute to the following year's expenses and are accounted for when the following year's cost per ton is determined.

The cost to landfill waste (per ton) varies by landfill and there is a wide distribution of costs between landfill sites, as shown in Figure 11 (does not include government waste tax). Danish legislation prohibits waste producers from transporting their waste to less expensive landfills outside their respective municipality or inter-municipality, even though the operational efficiency tends to be greater at larger landfills resulting in lower cost per ton, compared to smaller landfills.

Gate Fee (2012) – mixed waste (non-haz), Mineral(inert), Hazardous, Cont. Soil and clean soil



- *Figure 2: Avg. Gate fee DKR (excl. Tax) 2012 (1 Euro ~ 7.5 DKR)*

Landfill life in Denmark begins with thorough planning. The Danish Government must approve the operational plans and the plans to mitigate potential environmental impacts of each landfill. An in depth assessment of these impacts is performed to determine the required monitoring frequency.

Testing may be required on a monthly basis to assure impacts are minimal, specifically contamination of the water table. Many factors influence the monitoring requirements, such as topography of the land, surface and groundwater flow, locations of drinking water supplies, and proximity to bodies of water. Based on data, ground water wells must be drilled to monitor chemical concentrations. There is a set minimum of three wells, one installed in the upstream region and two downstream based on the hydrology of the groundwater table.

There are specific practices pertaining to landfill daily operations. Waste is added, to specified cells on a daily basis (for a MSW landfill). The MSW is then compacted and covered with a thin layer of soil to reduce the odor and prevent animals and insects from getting into the landfill. This operation continues until the landfill meets its waste capacity. Regular monitoring is necessary as material is added to each different cell during the active stage of the landfill's life.

As the landfill's useful life comes to a close, a second planning stage for the aftercare period begins. Plans must be made for the closure of facilities and aftercare operation, which includes leachate processing, gas venting, and monitoring, as well as demolition of temporary roads and maintenance buildings. In most other European and US landfills, a sealed cap would be installed on top of the landfill to prevent precipitate from percolating through the body of the landfill. Denmark does not cap their landfills. Denmark covers landfills with a thin, permeable soil layer, which allows as much percolate to flow through as possible.

Landfills can have a wide range of environmental impacts ranging from groundwater contamination to odor and noise pollution. During landfill operation, heavy machinery is used to place waste in each landfilling cell, and noise produced by this machinery may be heard by nearby establishments. When waste is exposed to air, there is a natural tendency for the odors it produces to travel to surrounding areas and subject those nearby to unpleasant smells. These factors and the general unsightly nature of landfilling may lower nearby land value and desirability, especially with MSW landfills.

A major cause for concern is the possibility of groundwater contamination. As water percolates through the landfill, it draws chemicals into solution, which may then contaminate the surrounding environment when leaks form in the lining system of the landfills. Some landfills that are classified as inert landfills may possess no liner at all, relying on low chemical concentrations and natural groundwater attenuation, but with this system comes the risk of major consequences should improper material enter the landfill. When contaminates enter the groundwater system, they pose a threat to anything downstream that is fed by the groundwater. This can include wells, springs, and regions of upwelling of groundwater, rivers and shorelines. Danish regulations set thresholds to the allowable concentrations of pollutants in groundwater due to landfilling. Landfill owners must monitor these substances throughout the life of the landfill, which includes the aftercare period. This monitoring is based largely on the contents of the landfill.

Groundwater monitoring is important to assure a landfill is not contaminating the water table. The natural groundwater and hydrology near a landfill is an integral factor during the design and construction and placement of monitoring wells. This is to assure that the landfill does not contaminate sources of drinking water and sensitive environmental areas, and that this contamination can be measured if present. The criteria for concentrations of chemicals in groundwater are stricter in Denmark that the EU requirements because Denmark uses its groundwater extensively for drinking water. Maximum allowable values of pollutants, and chemicals are specified by each landfills permit and if these values are exceeded, remediation action must be taken. These acceptable limits must be reached at a distance within 100m downstream of the landfill, or the Point of Compliance (POC).

3. Legal and Policy Frameworks for landfill

In 1974 the dumpsites in Denmark was banned and requirements on how to run a landfill site in an environmental proper way was introduced because of the first guidance on landfilling was published by the Danish EPA. The guideline introduced the concept "controlled landfilling" and standards for liner systems and collection of leachate

In 1982 the guideline was expanded with a number of technical specifications. The guideline in 1997 introduced discussions on the aftercare and time horizon of a landfill site. The thought of each generation should take care of it´s own waste within a period of 30 years without affecting the surroundings.

During time the focus has changed from only the environmental measures and discharges to the air, soil and water and to look at the characteristics of the waste.

An improvement has been done since the dumpsites and the operation of a landfill today is characterised as a modern environmental plant.

In Denmark the operation of waste management, including landfills, is regulated by The Danish Environmental Protection Agency, which is part of the Danish Ministry of the Environment.

The EU Landfill Directive (99/31/EC) was implemented in Danish legislation by issuing a Statutory Order on landfills in June 2001. The EU Council Decision establishing criteria and procedures for the acceptance of waste at landfills (2003/33/EC) was implemented in Danish legislation in March 2009 by an amendment to the Statutory Order on landfills.

As a general rule the municipalities in Denmark are the permit authority regarding environmental permits on landfills, this will change in 2015. All Danish landfills are as a main rule equipped with liners and leachate collection systems.

In the case of inspection authority, this task is handled by The Danish Environmental Protection Agency as regarding all public owned landfills whereas the municipalities – in general - are the inspection authority regarding private owned landfills.

As part of the implementation of the EU Landfill Directive a Statutory Order on education of all employees at landfills was issued in 2001. The Order requires that all employees at Danish landfills shall obtain a certificate in order to work at a landfill. All operators responsible for the daily tasks at a landfill shall hold an "A-Certificate" while the rest of the employees shall obtain a "B-certificate". Before achieving a certificate the employees have to pass a test on 3 different topics

The landfill directive sets targets for landfilling of biodegradable municipal waste. In 2006 less than

5% of the total amount of biodegradable municipal waste was landfilled in Denmark. A ban on landfilling of biodegradables (organic and household waste for incineration) was launched in 1992.

A large quantity of the total amount of waste produced in Denmark is recycled. Only 6 % of the total amount of waste produced in Denmark is disposed of at landfills.

The Danish Government has – in the national waste management plan - set targets to ensure a large degree of recycling. Furthermore the effort of landfilling constantly smaller amounts of waste should be continued.

All public owned landfills has to be run as a not profit company – they are not allowed to gain an economic profit. During the operation they have to collect a fee for the "collateral damage" that should count for at least 30 years of rehabilitation, monitoring and surveillance.

4. Key Stakeholder in the Waste Sector relating to Landfilling of Waste

Landfill Mining in Denmark is a rather new concept and discussion. As this time there exist no network or consortia's working with this issue.

Some of the key Stakeholders connected to Landfills in Denmark include:

- Ministry of Environment: www.mim.dk
- Danish Environmental Protection Agency: www.mst.dk
- Danish Waste Association (Waste-Union of Danish Municipalities and Waste Companies): www.danskaffaldsforening.dk
- KL (Union of Municipalities): www.kl.dk
- DAKOFA (Waste-Union of Danish Authorities, Municipalities, Consultants, Organizations and Companies): www.dakofa.dk
- DI (Union of Private Waste Companies): www.di.dk
- DEPONET (Network for Sustainable Landfilling): www.deponet.dk
- ERISDA (Electronic Reporting and Information System for Danish Landfills): www.erisda.dk

5. ELFM as a policy transition

In Denmark the experiences from LFM are very poor - only two investigations have been conducted recently. The investigations were undertaken with different aims:

- Excavation of waste for recycling and combustable waste suited for incineration with energy recovery (Project Waste Minimization at Gerringe Landfill)
- Recovery of potential resources from landfilled shredder waste (Simple size fractionation of shredder waste from two mono landfills

A short summary of the two projects are given below.

5.1 Project Waste Minimization at Gerringe Landfill

The 1st of February 2011, the final approval was given by the authorities to "*Project Waste Minimization*" at Gerringe Landfill. The Gerringe Landfill was established in 1973 in the southern part of Seeland. The landfill is designed on a natural clay liner and has a vertical clay liner on the the sides of the landfill. In addition, a drainage system at the inside of the vertical clay liner system has been installed. Parts of the landfill is still in operation. The maximum depth of the waste is approximately 15 meters and the surface area is 12 hectares. The landfill includes 750,000 tonnes of waste in which 50-60 % is concidered biodegradable and mainly landfilled from before 1987. In 1983 an incineration plant was built.

The part chosen for excavation was closed in the beginning of the 1990s. The total area chosen for excavation was approximately 6000 m^2 with a capacity of 200 m^3 per day. It did not consist of any biodegradable waste but instead of waste suitable for combustion and recycling. Due to ongoing landfill gas production, the intention was to excavate in the maximum depth of six metres. Thus, it was of most importance not to excavate in biodegradable waste landfilled before 1987.

Excavated waste was separated in the following fractions:

- Combustible Waste, i.e. incineration
- Iron and metal, i.e. sale for re-use
- Bedrocks/demolition waste, i.e. sale for re-use
- Tires, i.e. sale for re-use
- Residual waste, i.e. soil with mixed plast, rubber, and glas for re-landfilling

The excavation was completed within an eight-month period. An entrepreneur was hired to execute the excavation – or rather an agreement was concluded in which he would excavate for free and in return get all materials representing a positive value along with a fee of 14 Euros per tonnes of combustible waste delivered for incineration.

Date	**Residual Waste (re-landfilled) (Tonnes)**	**Combustible Waste (Tonnes)**	**Bedrock/Dem Waste (Tonnes)**	**Tires (Tonnes)**	**Iron/Metal (Tonnes)**
18 Mar		118.78			
01 Apr		300.3			
13 Apr		240.68			
14 Apr		86			
26 May		422.16			
27 May		229.4			
05 Sep		56.96	65.74	38.94	21.16
19 Sep				27.92	
20 Sep				25.84	
21 Sep	1200			24.86	
Total	**1200**	**1454.28**	**65.74**	**117.6**	**21.16**

Table 1: Excerpts of the operating journal

The composition of the waste excavated from the landfill is shown in the figure below.

- 50.9 % Combustible Waste
- 41.9 % Residual Waste
- 4.1 % Tires
- 2.3 % Bedrocks/Demolition Waste
- 0.8 % Iron and metal, i.e. sale for re-use

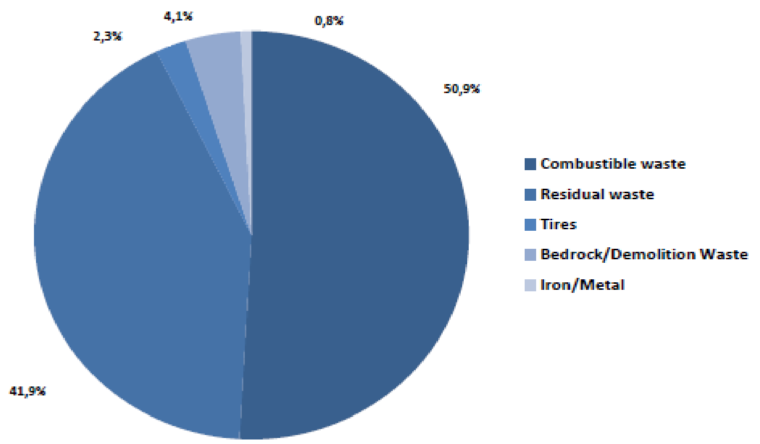


Figure 1: Waste composition - Gerringe Landfill (%)

Table 2 shows the specific financial aspects of the total project.

Activity	Euro/tonnes	Actual Costs/Revenue (Euro)
Costs		
Entrepreneur (combustible waste)	14	20,160
Excavation	18	52,000
Sorting and screening	14	40,000
Transportation	10	16,533
Costs incineration costs	65	94,000
Re-landfilling costs	1.5	1,600
Administration	3	8,000
Revenue		
- Iron and metals - Bedrock/Demolition Waste - Tires (bad quality)	200 0 0	4,234 0 0
Value of new landfill capacity	4	11,436
Tax refusion	63	105,066

- *1 Euro ~ 7.5 DKR*

• *Derivative environmental effects and costs have not been priced but contribute positive in the total environmental gain*

Table 2: Cost-Benefit calculation - Gerringe Landfill

As shown i table 2, an implementation of the LFM project entails more costs than revenues. The cost is rated at 67 Euro per tonnes of waste excavated. If the project should have economical feasible, the metal content should have been considerable higher. However, it is unlikely to locate a landfill site in Denmark that possesses a larger potential than 2-3 % metals. Consequently, one would risk more uncontrolled landfilling etc., chemicals, and hazardous waste when excavating – which might be of prime economic consideration.

Based on the economic evaluation, the entrepreneur must be categorised as the financial looser. The potential of waste for re-use was lower than expected (< 1%), the quality was poor and hard to sell with a profit, and the excavation, i.e. hauling and labor costs, was the most expensive part of the project.

The scenario presented in table 2 is the most realistic of its kind. Nevertheless, it can be regarded in various ways. This would provide certain challenges that have to be carefully considered. One of the major issues is the value of the new landfill capacity.

The proceeds are defined as the value of the volume released when the waste is excavated and the costs per volume. It is calculated on the basis of the community's costs as regards to the establishment of the operating landfill – it should essentially represent the true costs.

In 1973, the landfill was established with an aggregate area of 11.6 hectares. This results in a total landfill volume of 1,611,409 tonnes/m^3. Deployment costs were approximately 80 Euro per m^2 in 1973. It is equivalent to approximately 6.5 million Euros. Therefore, the value of the new landfill capacity is only 4 Euros/m^3.

For instance, a use of the newly gained landfill capacity and landfill new non-hazardous waste would be equivalent to approximately 1650 tonnes. If the waste company should receive the waste for the current gate fee, it would be 50 Euros plus 63 Euros in tax, whereas, and the costs for collateral damage would represent 9 Euros. Thereby, this scenario would gain revenue of 68,000 Euros and, thus, the waste company would nearly be able to finance the LFM project. Nonetheless, it would still not be feasible.

Some of the questions need clarification. For example, should collateral damage of this type of waste be paid? It is landfilled after 16 July 2009 and the new waste would actually contribute to an extension of the aftercare period in such a way that a need to extend the post closure care and monitoring is probable. In addition, does the landfilling comply with the legislation in the European Landfill Directive and the Council Decision?

5.2 Recycling of resources from landfilled shredder waste by low-tech size fractionation at two mono landfills

It is estimated that more than 1.5 million tons of shredder waste has been deposited in mono landfills in Denmark. In order to recover and exploit potential resources from landfilled shredder waste a treatment concept based on simple size fractionation was established. From two Danish mono landfills (AV Miljø and Odense Nord Miljøcenter) approximately 100 tons of shredder waste was excavated, representing waste of different ages. By means of sieving, the waste were divided into four particle size fractions, > 45 mm, 45-10 mm, 10-5 mm and less than 5 mm, which represented 11-13%, 34-40%, 28-30% and 18-24% of the excavated volume of shredder waste, respectively (figure 2). Chemical analyses were performed on samples from each of the particle size fractions.

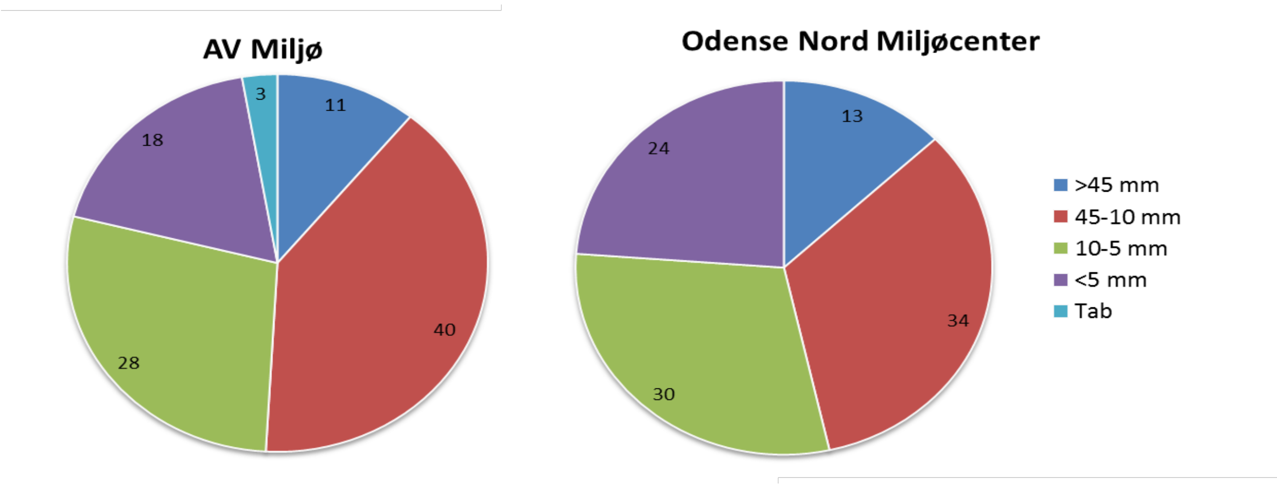


Figure 2: Results of size fractionation of excavated shredder waste (w/w %)

The results of the chemical analyses showed that the metal content of each fraction was between 28% and 37% (based on dry weight). Mass balances based on results of the analyses in combination with assumptions regarding the degree of oxidation of the metals and the occurrence of carbonates and sulfates confirmed the reliability of the results. Overall, the mass balances indicated that for particle size fractions larger than 5 mm, about 50% of the metals are present as pure metals and 50% as metal oxides. The degree of oxidation is increasing for metal present in fractions with smaller particle size (<5 mm).

The potential for recovering resources from excavated shredder waste was evaluated by means of hand sorting experiments and approximately 50 tons of the waste with a particle size larger than 5 mm were re-treated in Danish mechanical metal recovery facilities. From the experiments it can be concluded that it is possible to recover a significant part of the potential of metals in excavated and size fractionated shredder waste by re-treating the largest size fractions in existing mechanical separation facilities. From mass balance considerations and hand sorting experiments it can be assumed that up to 18% of the fractions larger than 5 mm is metal. By mechanical treatment in existing facilities up to 15% of the materials were recovered as metals. The recovery rate was significantly highest from the fractions larger than 45 mm and a lowest from the fractions 10-5 mm.

The potential for energy recovery from the excavated shredder waste increased with increasing particle size fraction. For fractions of shredder waste larger than 10 mm the calorific values were between 7 and 17 MJ/kg after plastics were removed. Including plastics the calorific values were estimated to between 14 and 27 MJ/kg, highest for the fractions larger than 45 mm. Calorific values determined for the fraction 5-10 mm were lower than expected, possibly because of poor separation of the fine fraction.

The fines (less than 5 mm) had a high ash and metal content and a low calorific value and were not suitable for energy recovery. Fines should thus be separated from the rest of the shredder waste before energy recovery.

The feasibility of excavating, treating and recovering resources from landfilled shredder waste was evaluated in form of technical, economic and environmental feasibility. Overall, this evaluation showed that technically it will be necessary to optimize fractionation process in order to obtain an improved particle size fractionation. Environmentally, it is advantageous to excavate and recovery the resources in terms of materials and energy assessed based on life cycle analysis. Financially it depends on the specific situation and circumstances if revenues from sales of materials and value of regained landfill volume could cover the cost for excavation, treatment, recovery and taxes. No regulatory barriers were identified hindering the recovery of resources from landfilled shredder waste.

A preliminary assessment of the financial basis for excavating landfilled shredder waste and recovery of potential resources showed firstly that the site specific circumstances is crucial for the outcome of the analysis - for example, the estimated value of landfill volume varied between 2,7 to 38,7 Euro/ton of material removed from the landfill. Secondly, the environmental taxes, especially on energy recovery, gave rise to substantial financial uncertainty. Energy recovery did not have a direct positive impact on the economy.

Two different scenarios were defined in order to evaluate the economic feasibility of resource recovery from landfilled shredder waste (table 3). The evaluation showed that in scenario 1 the economic balance was positive and it was estimated that 31,9 Euro/ton can be earned. Scenario 2 showed negative balance and it would cost 55,3 Euro/ton of excavated shredder waste. The different outcome of the scenarios is mainly due to differences in assumed environmental taxes. However several uncertainties are related to this evaluation and a detailed site specific evaluation is recommended. In this study it was not possible to draw general conclusions regarding the economic feasibility of recovering resources from landfilled shredder waste.

	Scenario 1	**Scenario 2**
Sorting degree (%)		
Recycling (metals)	5.2	5.2
Incineration	64.8	64.8
Landfill	30	30
Activity	**Euro/tonnes**	**Euro/tonnes**
Costs		

Excavation	1,33	1,33
Sorting and screening	6,66	13,33
	9,33	9,33
Transportation	2,80	2,80
Costs incineration	17,33	38,93
Re-landfilling costs	0,40	25,20
Revenue		
Revenue sale of recovered materials	53,33	26,66
Value of new landfill capacity	9,33	1,86
Tax refusion	0	0
Refusion of collateral damage fee	7,06	7,06
Total cost	**31,9**	**- 55,33**
• *1 Euro ~ 7.5 DKR*		

Table 3: Cost-benefit of excavation of shredder waste and recycling of resources from landfilled shredder waste

5.3 The future perspectives of LFM

In Denmark we have not yet seen full scale landfill mining projects that are feasible, but conclusions from the two projects described above show that especially LFM from mono landfills with high content of valuable material resources may be feasible. The investigations on two mono landfills containing shredder waste from metal scrap showed promising results. However it does require a detailed site specific analysis to determine whether the LFM is economically feasible.

LFM from a traditional MSW landfill is based on the results for the Danish study not considered as feasible, due to too many uncertainties related to excavation and recovery of resources and the poor quality of materials recovered.

In order to get better estimates we need to initiate further projects in order to improve the technologies used to excavate and sort the waste. One obvious option is to establish partnerships between the waste companies in Denmark with the aim of sharing knowledge and reduce costs e.g. for equipment. In addition we need to look into the regulatory barriers (e.g. taxes on energy recovery, environmental taxes etc.) in order to make it attractive to recover resources from landfilled waste. On the other hand if we wait long enough we may in Denmark run out of landfilling capacity and at that time we may be forced to think differently with respect to drivers for landfill mining.

In April 2014 the SHERMAN –project began. A large excavation and sorting of 40.000 tonnes of landfilled shredder waste. No conclusion has yet been published.

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