INTRODUCING AN APPROACH TO ASSESS ENVIRONMENTAL PRESSURES FROM INTEGRATED REMEDIATION AND LANDFILL MINING

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Abstract

The aim of the paper is to introduce an approach for evaluating integrated remediation and landfill mining scenarios. Since completed projects with similar scope and goals mostly have been pilot studies or projects with little emphasis on resource extraction, there is very little real case data to access. Thus, scenarios for three different routes have been established: Remediation only; Remediation combined with resource extraction using a mobile separation plant; and finally Remediation combined with resource extraction using a large stationary separation plant. Furthermore, the approach uses Monte Carlo simulations to address the uncertainties attached to each of the different steps of the scenarios, such as separation efficiencies, transport distances and recycling benefits. The approach can be used to assess the probability of results for the different scenarios, as well to study the influences of major parameters. In the future, the approach will be broadened to include economic parameters, and a large effort will be put on validating and analyzing the model parameters and assumptions. For instance, there is a need to study the dependency between different parameters to see if they are positively correlated; otherwise, the uncertainty could be overestimated. Furthermore, scenario uncertainties need to be added and studied.

Keywords

Landfill mining, Remediation, Environmental Assessment, Monte Carlo Simulation, Life Cycle Approach

1. Introduction

In Sweden, there are more than 4,000 landfills, and these waste deposits are related to several environmental implications. Degradation of organic waste in the landfills generates long-term methane emissions, which in fact is the largest source of climate gas emissions from the waste sector. Over the years, hazardous materials and substances have also accumulated in the deposits, exhibiting pollution concerns due to leaching processes. Since most Swedish landfills are old and therefore lack pollution prevention technologies, there is an ever ongoing debate about the need for remediation. The landfills are, however, also related to resource issues, since they contain huge amounts, i.e. several hundred million tonnes, of discarded materials (Lifset et al., 2002; Kapur and Graedel, 2006; Müller et al., 2006). Such material stocks are indeed available for collection and recovery. Although the amount of recyclable resources may vary among the landfills, a significant share often constitutes recyclable materials (e.g. metals, plastic and construction materials) and combustibles that can be used for energy recovery (cf. Lifset et al., 2002; Zhao et al., 2007).

Landfill mining means the excavation, processing, treatment and/or recycling of materials that over the years have been dumped in waste deposits. Throughout the world, more than fifty such projects have been performed, mainly in the USA but also in Europe and Asia (cf Krook et al, 2010). For the absolute majority of these projects, the initiative has come from authorities aiming to solve a specific problem for a region such as conservation of landfill space or remediation preventing pollution of land, air and water (Dickinson, 1995; Hogland et al., 1995; Cossu et al., 1996; Reeves and Murray, 1996; 1997; Hylands, 1998). There are, however, also projects that instead have emphasized resource recovery from landfills, although this is much more uncommon (Rettenberger, 1995; Obermeier et al., 1997; Hino et al., 1998). Even more uncommon are projects that apply an integrated approach, aiming to solve local space and/or pollution problems, and at the same time obtaining a more efficient use of material and energy resources on the regional and global scales.

In the past, landfill mining has seldom involved any real attempt to obtain efficient recovery of deposited resources. As a consequence, resource implications of such initiatives have been disregarded. Instead, emphasis has been on local risks during excavation, such as the leaching of hazardous substances or formation of explosive gases (e.g. Krogmann and Qu, 1997; Hogland, 2002; Zhao et al., 2007). Although this has been a necessary approach, it is also insufficient because environmental impacts could arise on different spatial and temporal scales (cf. Udo de Haes et al., 2000; Finnveden and Moberg, 2005). Since most of the studies have focused on the movement of hazardous substances, there is a knowledge gap regarding how these kinds of projects may affect the environment when it comes to other types of impacts, such as for instance climate change or acidification.

Resource recovery from landfills displays environmental potential in terms of, for example, mitigation of global warming and recovery of scarce materials. The realization of this potential, however, relies on several factors, such as the capacity of waste separation technologies and the resource demand for excavation, processing, transportation and recycling processes. Previous research has shown that landfills also contain large amounts of valuable materials such as metals, which in turn constitute an important driving force for resource recovery (Krook et al, 2010). In contrast, remediation projects always come with huge societal costs, and the available funding in Sweden is largely insufficient (SEPA, 2002; SEPA, 2003). Applying an integrated approach where landfill mining is used for both profitable resource recovery and remediation could, therefore, offer a more viable and efficient strategy than conducting sole remediation projects alone.

1.1 Aim

The aim of this paper is to introduce an approach for handling the environmental assessment of an integration of remediation and resource extraction through landfill mining. We will describe the approach and give examples of its uses. It is important to note that the results shown in this paper should be seen as an indicator of how the approach can be used, but do not, at this stage, illustrate the environmental pressures of the different scenarios.

2 Method

Implementation of remediation combined with landfill mining can be done in many different ways. There is also limited access to detailed data for extraction and separation of valuable materials from landfills (Krook et al., 2010). This introduces two different kinds of uncertainties, what Huijbregts et al. (2003) define as “scenario uncertainties” and “parameter uncertainties”. According to these authors, scenario uncertainty is comprised of all the different uncertainties which are introduced with the different assumptions and choices made in order to build the different scenarios, and parameter uncertainties are related to how individual parameters can vary. In order to deal with these characteristics, we have chosen to use an approach where we set up scenarios which provide different routes of implementation and to use Monte Carlo simulations to analyze how uncertainties influence the results.

The scenarios which will be studied are:

- Remediation only
- Remediation combined with resource extraction using a mobile separation plant
- Remediation combined with resource extraction using a large stationary separation plant

The basic outline of the assessment approach is shown in Figure 1. The approach starts by setting the size and assumed material composition for the studied landfill. Each choice of scenario has a corresponding set of processes along with separation efficiencies and resource use factors; these were used to calculate material flows. Every parameter in the approach is accompanied by uncertainties or possibilities for variation. The material flows are then used, together with emissions factors, to estimate the environmental pressure of the scenarios for a certain set of randomized parameters. The randomization and results use the Monte Carlo Simulation technique.

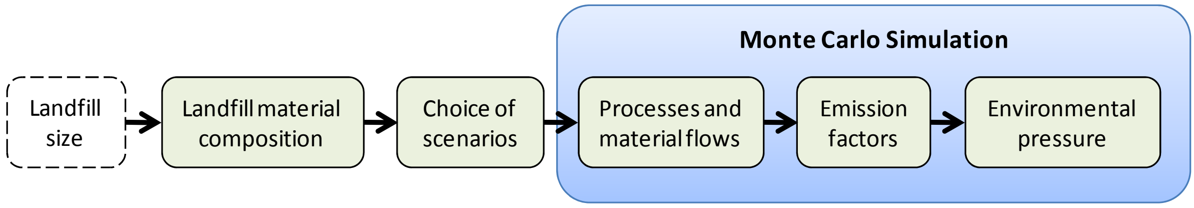

Figure 1. Conceptual drawing of the approach

2.1 Composition of landfills

Reviews of several previous landfill mining cases were conducted with the purpose of gathering information regarding the composition of these landfills. This process resulted in data from a total of 22 cases from different parts of the world.

The different materials that were found in the cases were aggregated into ten material categories: Soil; Paper; Plastic; Wood; Textiles/Rubber/Leather; Inert Materials; Organic Waste; Ferrous Metals; Non-Ferrous Metals and Hazardous. For each category, the mean value and standard deviation was calculated and normalized (i.e. make the sum of the mean values add up to 100%); the result is shown in Table 1 below. The mean values for ferrous and non-ferrous metals are based on the fact that the accumulated consumption of metals in Sweden over time is 80 percent ferrous and 20 percent non-ferrous, so the mean values for these two material types was calculated proportionally (SEPA, 1996).

Table 1. Material composition of landfills based on 22 studies

Material type	Mean value	Std. dev.	Studies (n) [a]
Soil	54,7 %	27 %	17
Paper	6,8 %	88 %	12
Plastic	8,3 %	80 %	17
Wood	6,8 %	64 %	14
Textiles/rubber/leather	6,6 %	106 %	11
Inert materials	10,6 %	96 %	17
Organic waste	2,7 %	73 %	4
Ferrous metals	2,9 %	106 %	14
Non-ferrous metals	0,5 %	106 %	4
Hazardous	0,1 %	77 %	17

[a] Cha et al. (1997); Cossu et al. (1995); Hogland et al. (1995); Hogland et al. (2004); Hull et al. (2005); Krogmann & Qu (1997); Kurian et al. (2003); Mor et al. (2006); Prechthai et al. (2008); Rettenberger (1995); Richard et al. (1996); Stessel & Murphy (1991); Sormunen et al. (2008); Zhao et al. (2007)

2.2 Scenarios, processes and material flows

To develop the scenarios, a panel consisting of experts on separation processes and related material flows was consulted. The task for the expert panel was to establish, together with the researchers, what kind of separation processes should be included in the respective scenarios, and to estimate the separation effectiveness for each of these processes. Each process' energy use also needed to be calculated, which was done in part by the expert panel and in part by the researchers using data from a LCA database. All of these parameters were given uncertainty distributions in the model. These uncertainty distributions were set to rectangular, triangular or log-normal distributions, depending on the type of parameter and its characteristics. Each scenario is explained in greater detail below.

2.2.1 Remediation only (RO)

In this scenario there are only two processes: first the landfill material is excavated, and next the material is redeposited along with the remediation. The resource use for these processes was calculated in the manner explained in the previous section.

2.2.2 Mobile plant (MP)

For the mobile plant scenario, the emphasis was on simplicity; the plant should be transportable and collect a good part of the materials and with minimal time and set up requirements. This approach lead to a mobile plant consisting of four processes: Star Screen; Air Classifier; Magnet; and an Eddy Current Separator (ECS) (see Figure 2 below). The material is excavated and dumped over a coarse screen which separates some of the hazardous and residue material. The rest of the material enters the Star Screen, which produces the Fines and Hazardous fraction. The Air Classifier separates the Combustible fraction and the Magnet, while the ECS separates the Ferrous and the Non-ferrous fractions, respectively. The Ferrous and the Non-ferrous fractions produced by the mobile plant are not clean enough to use for recycling; hence, prior to recycling the fractions must go through additional processes at a stationary plant. These intermediate fractions are noted as Non-Processed Ferrous (NP-Ferrous) and Non-Processed Non-Ferrous (NP-NF) in Figure 2. NP-Ferrous goes through a fragmentation unit to produce a clean Ferrous fraction which is ready to use in recycling. NP-NF is cleaned up by going through a NF-facility. The residue produced in the refinement process of NP-Ferrous and NP-NF are transported back to the landfill and redeposited along with the other Fines, Hazardous and Residue fractions.

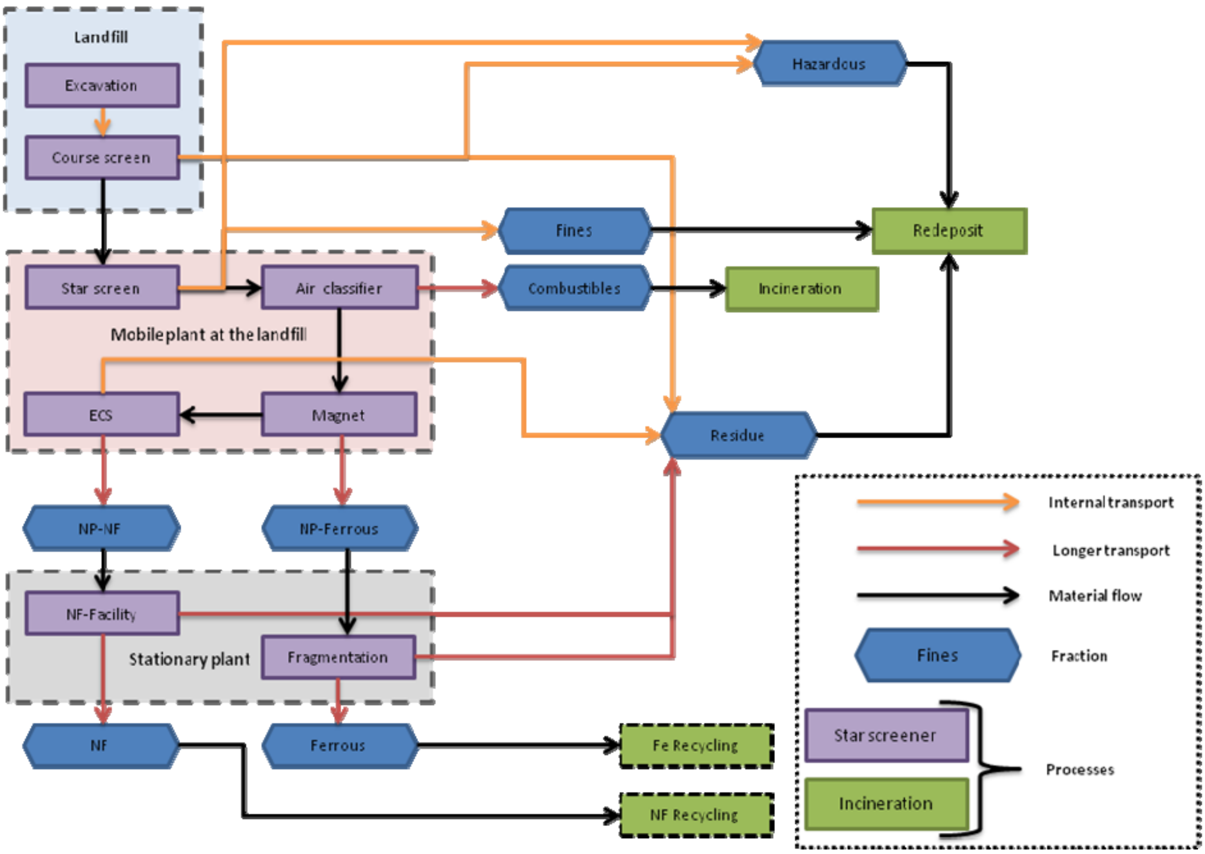

Figure 2. Process model over the mobile plant scenario

2.2.3 Stationary plant (SP)

The plan behind the stationary plant was to make use of state-of-the-art technologies, with the emphasis on collecting the most amount of material possible for recycling. The expert panel designed the scenario as shown in Figure 3 below. At the landfill, the material is excavated and dumped through a coarse screen into a Star Screen, which is placed at the landfill to reduce the transportation of soil from the stationary plant back to the landfill. The processes mentioned above separate hazardous and residue material and a large amount of soil (Fines fraction). The material is then transported to the stationary plant where it enters the NF-Facility, which produces four fractions: Construction Material; Combustibles; Non-Ferrous (NF) and Plastics. The remaining material, which is noted as Non-Processed Ferrous (NP-Ferrous) in Figure 3 below, enters the Fragmentation unit where a clean Ferrous fraction is produced. Four of these five final fractions are transported to different recycling plants, whereas Combustibles are transported to an incineration plant. The stationary plant also produces Hazardous, Fines and Residue which are all transported back to the landfill for redepositing.

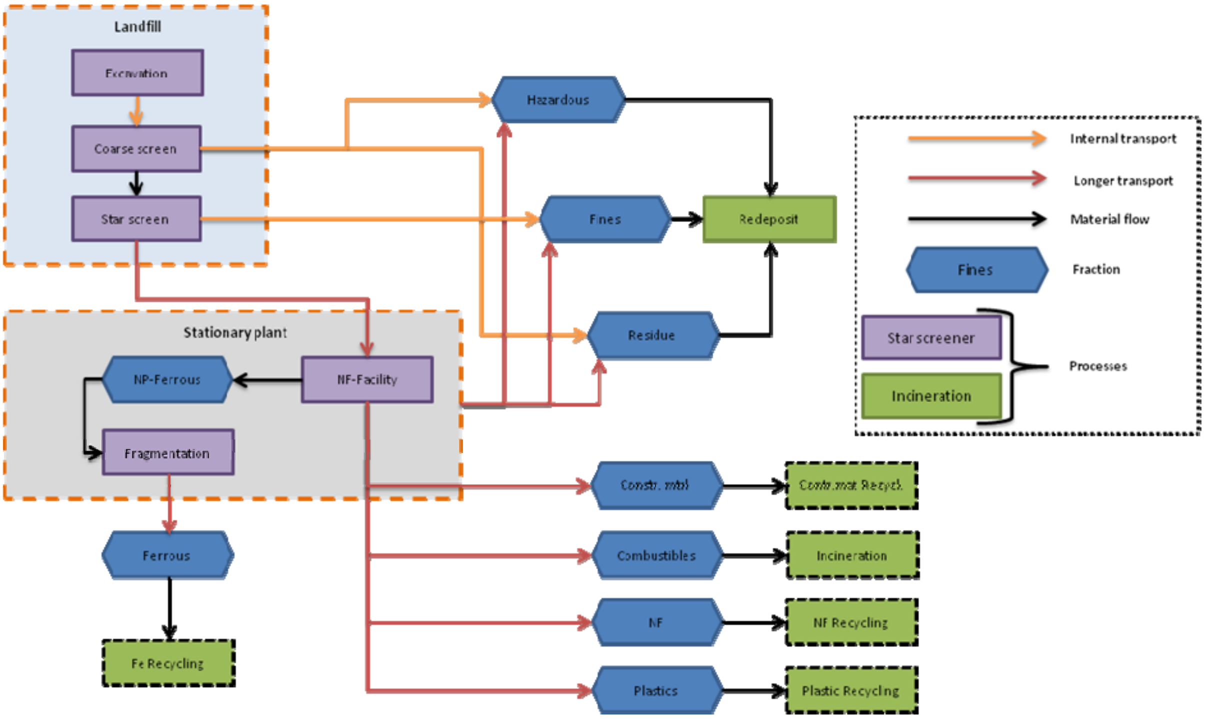

Figure 3. Process model over the stationary plant scenario

2.3 Emissions factors and Environmental Assessment

The environmental assessment is based on a life cycle approach, and the environmental pressures are presented using a range of impact categories shown in Table 2 below; the results presented in this paper, however, will only include global warming potential. Toxicological effects are not included in the life cycle approach, although they might be included at a later stage. The useful materials which are separated out are modeled to be either incinerated or recycled. These processes are assumed to lead to decreased environmental pressures through an avoided burden approach (cf Guineé, 2002). The concept of avoided burdens can be described as the environmental impacts associated with for instance the virgin materials which are avoided when substituted by the introduction of new recyclable materials. If these avoided impacts outweigh the impacts of the recycling process, we get avoided burdens.

In order to calculate the environmental pressures for the different scenarios, we have used emission factors derived from the Ecoinvent databases (Frischknecht & Rebitzer, 2005). Each emission factor is accompanied with a standard deviation. The emissions from incineration and recycling processes are calculated through the variation of energy system for these processes. The energy system is allowed to vary between a coal-based system and a system based on renewable energy sources. To be able to calculate the incineration impacts, the moisture content of the combustibles was set to 30 weight percent (based on Cossu et al., 1995; Hogland et al., 1995; Obermeier et al., 1997; Nimmermark et al., 1998; Hogland et al., 2004). Furthermore, it was assumed that these materials would be incinerated in a combined heat and power plant, with a ratio between produced heat and electricity of 9:1 (The Swedish Waste Association, 2007). Ranges for gross calorific values for each material were then used to estimate the total amount of electricity and heat that could be generated from the combustible materials in the landfills. Climate gas emissions from incineration of the combustibles were calculated based on data from Ecoinvent, but adjusted to apply to the landfilled materials’ slightly higher moisture content (cf. Doka, 2007). At this stage, the approach is modeling that biogenic carbon dioxides are not included in the emissions, although this assumption will be tested in a later version of the approach. Methane from redepositing of organic matter is calculated by attaining carbon content and material composition rates from the Ecoinvent database on landfills (ibid). The amount of methane recovery was allowed to vary between zero and one hundred percent, with the distribution having a bias towards the latter.

Table 2. Impact categories used in the environmental assessment

Impact category	***Unit***
Global Warming	Tonne CO_2-eq
Ozone layer depletion	Tonne CFC11-eq
Photochemical oxidation	Tonne C_2H_4
Acidification	Tonne SO_2-eq
Euthropication	Tonne PO_4^{3-}

2.4 Monte Carlo simulation

Monte Carlo simulation is useful for sensitivity analysis of a system consisting of a large number of variables where every variable has its own distribution of values. The simulation works by generating numerous randomized result samples. These samples are then aggregated into a probability curve which can be graphically presented and analyzed.

Since the model used in this study consists of numerous variables with variations and uncertainties, simulation using the Monte Carlo method was deemed appropriate. For a more in-depth description of the Monte Carlo method, see for example Metropolis and Ulam (1949) or Kalos and Whitlock (2008).

3 Results

This chapter shows the results from the Monte Carlo simulation and includes the following charts: cumulative distribution of the result of each scenario, cumulative distribution of the difference between the results of each scenario and finally cumulative distribution of the variables that have the largest impact on the results.

The results are preliminary and should only be used as indicators of what can be accomplished with the method used in this study. As mentioned above, the results are presented in the form of a chart with a cumulative distribution over the net CO_2-equivalent emissions. The charts show the maximum, minimum and average amount of emissions of that particular scenario/variable, as well as the probability for a positive environmental effect (i.e. negative net CO_2-equivalent emissions).

The results below are based on 40,000 sample runs. While working with the model, the authors have come to realize that the model's rate of convergence is quite fast, despite 231 different variables where many of them are independent. The figures in this chapter acquire largely the same form after only a few hundred runs.

3.1 Results – Scenarios

This section shows the results for each scenario as well as the differences between the three scenarios. These results (which only act as examples) can be used as a guideline for deciding which scenario has the most positive environmental effect, and how the scenarios relate to one another in this aspect.

Figure 4 below contains the cumulative distribution of the net CO_2-equivalent emissions for each scenario. Figure 4 shows that scenario SP has the best potential of the three followed by scenario MP. Scenario SP has a mean value of around -25 Mton CO_2-equivalent and more than an 85 percent probability for negative net CO_2-equivalent emissions. Scenario MP shows negative net CO_2-equivalent emissions 60 percent of the time and a mean value of slightly below zero Mton CO_2-equivalent. Figure 4 also shows that scenario SP has a flatter curve, i.e. a wider range of outcomes, than scenario MP. Scenario RO has a mean value of +20 Mton CO_2-equivalent and no chance of negative net CO2-equivalent emissions (as expected).

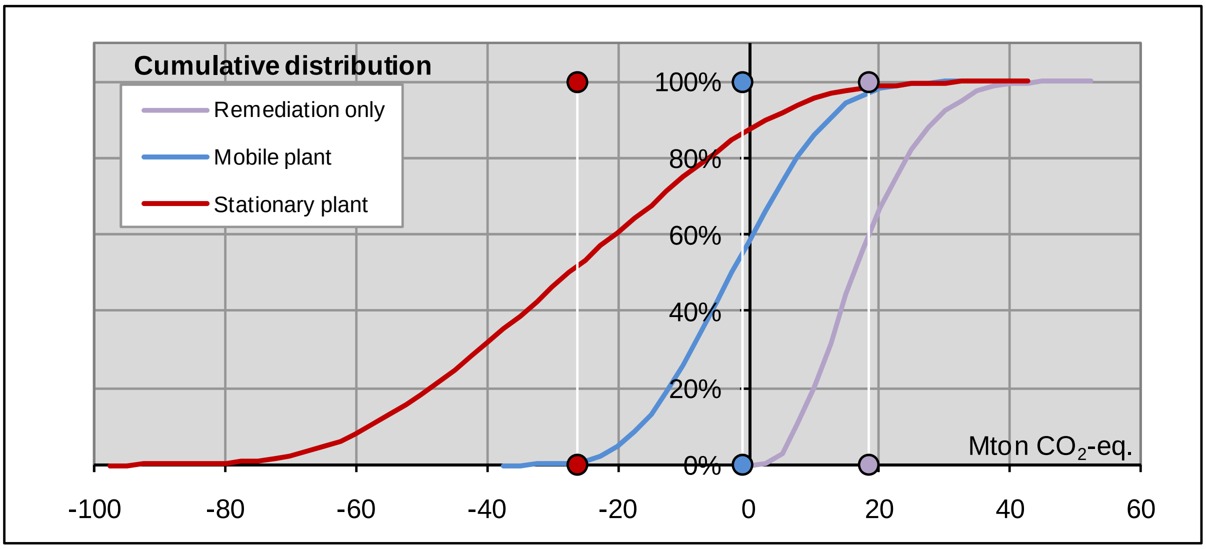

Figure 4. Cumulative distribution for the three scenarios' environmental effects and their respective mean values

Figure 5 below shows the differences between the three scenarios' cumulative distribution. The figure shows that between using a stationary plant for resource recovery and using only remediation, the first option shows on average -45 Mton net CO_2-equivalent emissions compared to the latter. The difference between using a mobile plant and using only remediation is on average -20 Mton net CO_2-equivalent emissions.

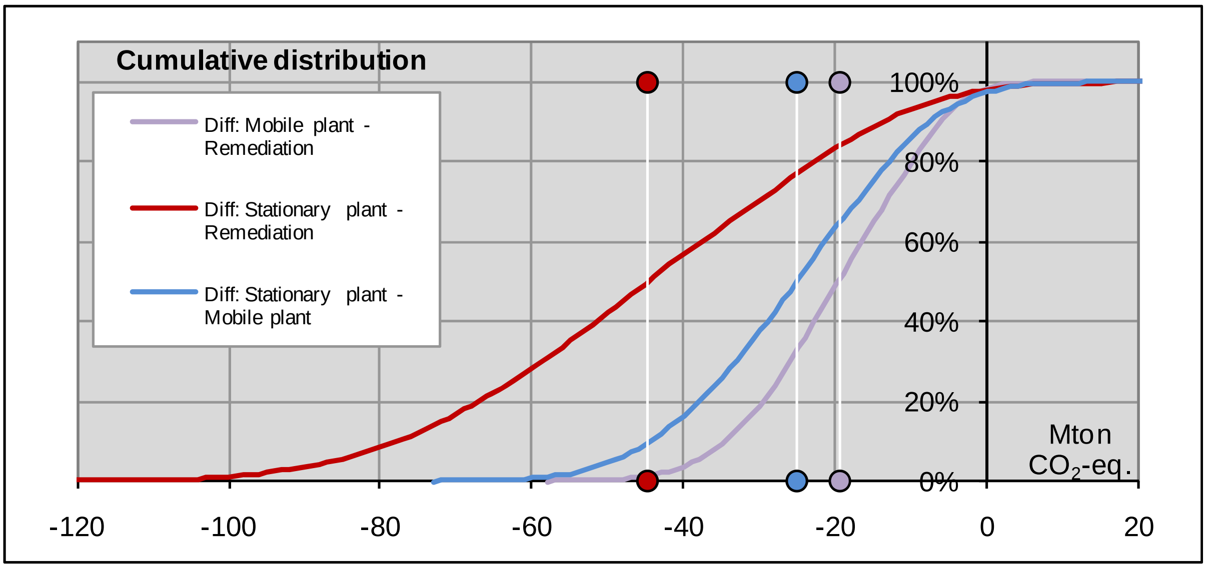

Figure 5. Cumulative distribution for the differences between the three scenarios' environmental effects and their respective mean values

3.2 Results – Variables

This section presents the results for some of the variables that have the biggest impact on the results for the stationary plant scenario. These results should not be taken literally, and serve mostly as an indication of what the possibilities are with the model and the simulation.

As can be seen in Figure 6 below, the type of heat-producing energy system currently used has a very large impact on the final result. This is due to the fact that the Combustible fraction replaces what is currently used as fuel. If the current heat-producing energy system is running on fossil fuel, the net gain can be as much as 100 Mton CO_2-equivalent emissions. If the heat-producing energy system runs on renewable material, the net gain is zero. The electricity-producing energy system has less impact, with a range from -20 Mton to 0 Mton CO_2-equivalent emissions and a mean value of -7 Mton net CO_2-equivalent emissions.
As the model is setup at this stage there is no correlation between the emissions from the heat-producing energy system and the electricity-producing energy system, which might not be realistic. This will be tested in future versions of the model.

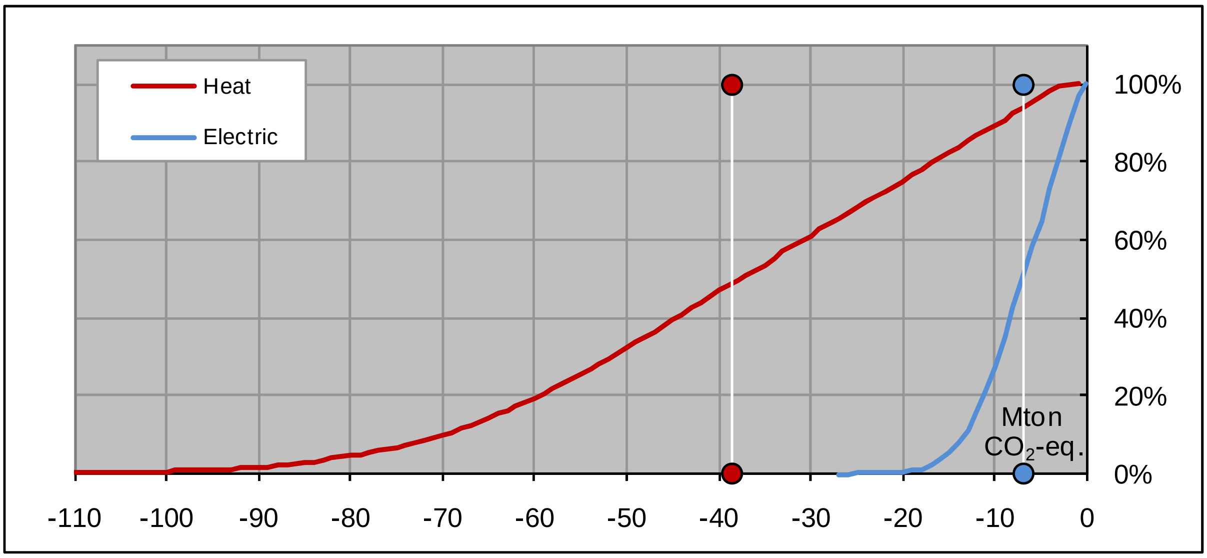

Figure 6. Cumulative distribution of net CO_2-equivalent emissions from the heat-producing and electricity-producing energy system and their respective mean values

A big impact factor is the emissions from incineration of the Textiles/Rubber/Leather fraction, which is dependent on the relationship between the different types of materials in the fraction. There is a large amount of scenario uncertainty when it comes to this fraction, since in this material fraction we have not separated between biogenic and non-biogenic materials. However, in reality the textile part of the fraction would probably consist of at least some biogenic material. In the future, the impact on the results of the inclusion or exclusion of biogenic emissions from incineration will be tested. The net CO_2-equivalent emissions from this fraction vary from zero to 60 Mton, with a mean value of around 20 Mton (see Figure 7).

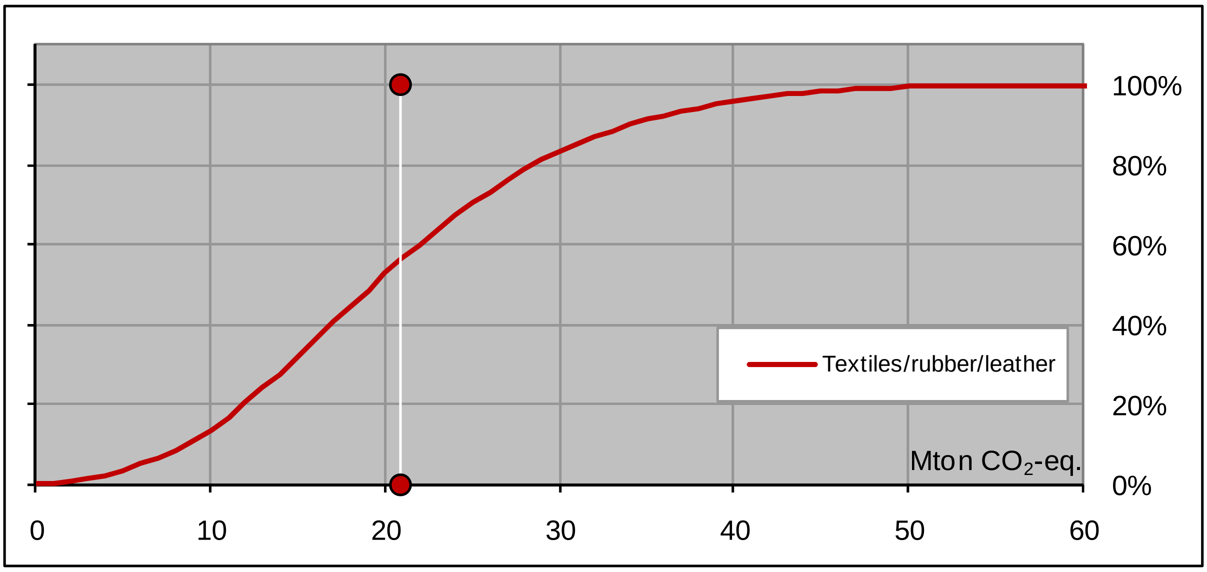

Figure 7. Cumulative distribution of net CO_2-equivalent emissions from the Textiles/Rubber/Leather fraction

Plastics is the material fraction with the biggest impact when it comes to recycling, due to the fact that this fraction is the largest that is sent to recycling. The cumulative distribution of the net CO_2-emissions from Plastics can be seen in Figure 8 below. The emissions varies between -16 Mton CO_2 to -1 Mton CO_2 and the mean value is approximately -8 Mton CO_2.

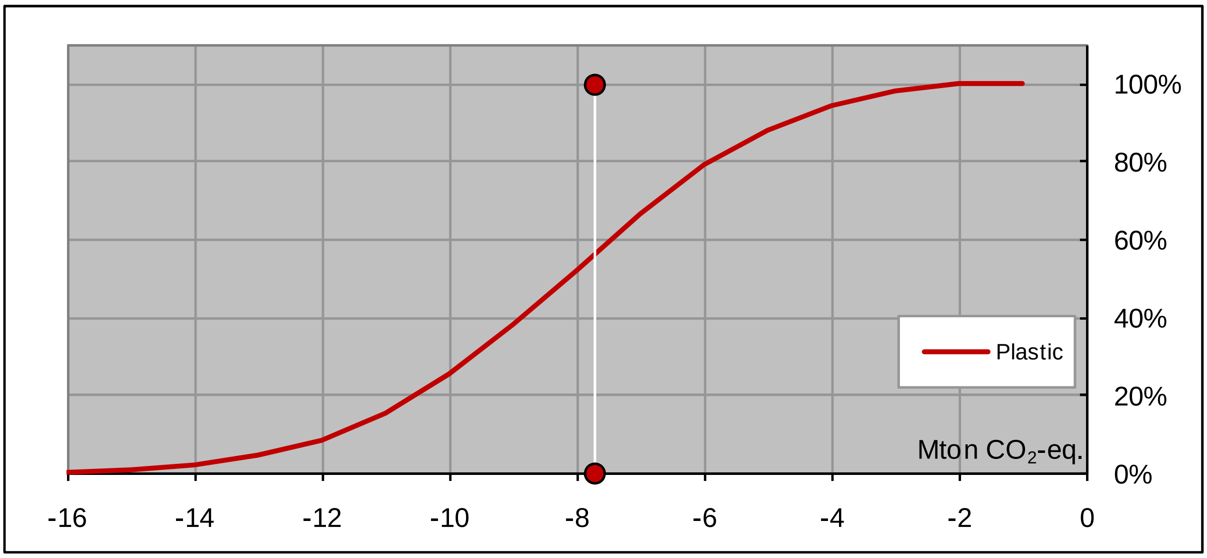

Figure 8. Cumulative distribution of the net CO2-emission when recycling the Plastics fraction

4 Discussion

Studying complex systems such as an integrated remediation and landfill mining project inherently leads to the need for simplifications and assumptions. This is also true for most environmental assessment studies, and there are different ways to handle it. A decision that has environmental consequences should preferably be based on holistic information. This implies that vast amounts of data need to be collected, interpreted and prioritized. Thus, there is a risk for what Hertwich et al. (1997) call an "analytical paralysis", i.e. that the collection of data for the environmental impact evaluation is outside the limits of what can be done within the available budget or time frame. When conducting this kind of assessment, it is necessary to do simplifications without decreasing the relevance and validity of the study. A common way to make these assessments is to assign single values to each parameter in a defined model. However, this has a high probability of leading to a deterministic outcome (Loyd and Ries, 2007). Another common way to address these uncertainties is to use Monte Carlo simulations and attach uncertainties to each parameter used in the model. In a case such as ours this is preferable, since a large amount of uncertainties are present due to the lack of knowledge base to draw data from (cf Krook et al, 2010). However, this technique does not automatically study uncertainties related to assumptions and scenario modeling. Hence, in a complex model such as this it is also necessary to assess the differences between parameter uncertainty and scenario uncertainty. Our approach is at the moment focusing on the parameter uncertainties, but will as it matures also be broadened to be able to assess different kinds of scenario modeling.

Evaluating an integrated remediation and landfill mining project introduces several dilemmas. Since the performed projects mostly have been pilot studies or projects with little emphasis on resource extraction, there is a limited amount of case data to access (Krook et al, 2010). However, before starting to implement projects on a larger scale, a broader study of its environmental impacts is, if not necessary, then at least preferable. By applying an approach as has been presented in this paper, this assessment can be made and presented with all the uncertainties and assumptions clearly visible. The probability figures can be used to see how different parameters influence the result. Apart from the application areas of the present approach, it would be good to expand to also be able to assess breaking points for the different parameters. This could for instance be used to understand how far a larger volume of extracted materials can be transported before the benefits of recycling is offset, or in what type of energy systems the project needs to be located for a positive environmental performance to occur.

Apart from this, there is also a further need to understand the underlying institutional aspects which will influence which routes can be taken in these projects. All of these aspects need to be factored into the scenario uncertainties. As an example, incineration may not be a viable option if the remediation and landfill mining project is carried out by an actor who does not operate an incineration plant. Judging by the current practices, there is a substantial cost attached to leaving your combustibles at an incineration plant, which could jeopardize the entire economic feasibility of the project. Furthermore, there are discussions regarding if the excavated materials should be regarded as new waste; this also has a substantial effect on how the project should be modeled.

4.1 Future development of the approach

As has been stated earlier, this approach is in its initial state of development and there is room for several improvements. The approach will be broadened to include economic parameters, and a large effort will be put on validating and analyzing the model parameters and assumptions. For instance, there is need to study the dependency between different parameters to see if they are positively correlated; otherwise, the uncertainty could be overestimated (Hong et al, 2010). This, for instance, probably occurs in an energy system where it is likely that a highly fossil-based system for electricity is correlated to a fossil-based system for heat. In a complex model such as this, it is also necessary to assess the differences between parameter uncertainty and scenario uncertainty. As has been mentioned earlier, the choice of how we have modeled biogenic carbon release will need to be tested, as well as how some of the transportation distances have been modeled.

Furthermore, we will look into the possibilities of including hazardous substances and how we can model their toxicological effects. This will be important since the occurrences of these substances will be the main reason for starting up the remediation effort in the first case. This could be done by applying a kind of substance flow analysis method and tracking some hazardous materials through the different scenarios.

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References

Cha, M.C., Yoon, B.H., Sung, S.Y., Yoon, S.P., Ra, I.W., 1997. Mining and remediation works at Ulsan landfill site, Korea. Proceedings Sardinia '97, Sixth International Landfill Symposium, Cagliari, Italy, 553–558.

Cossu, R., Hogland, W., Salerni, E., 1996. Landfill mining in Europe and the USA. ISWA Tear Book 1996, 107–114.

Dickinson, W., 1995. Landfill mining comes of age, Solid Waste Technologies 9, 42–47.

Doka G., 2007. Life Cycle Inventories of Waste Treatment Services. Final report Ecoinvent data v2.0. Volume: 13. Swiss Centre for LCI, Empa - TSL. Dübendorf, CH.

Finnveden, G., Moberg, Å., 2005. Environmental systems analysis tools — An overview. Journal of Cleaner Production 13, 1165–1173.

Frischknecht and Gerald, R., Rebitzer (, G., 2005).. The ecoinvent database system: a comprehensive web-based LCA database. Journal of Cleaner Production, Volume 13, Issues 13-14, Pp 1337-1343

Guinée, J.B.; Gorrée, M.; Heijungs, R.; Huppes, G.; Kleijn, R.; Koning, A. de; Oers, L. van; Wegener Sleeswijk, A.; Suh, S.; Udo de Haes, H.A.; Bruijn, H. de; Duin, R. van; Huijbregts, M.A.J., 2002. Handbook on life cycle assessment. Operational guide to the ISO standards. I: LCA in perspective. IIa: Guide. IIb: Operational annex. III: Scientific background. Kluwer Academic Publishers, ISBN 1-4020-0228-9, Dordrecht, 2002, 692 pp.

Hertwich, E. G., Pease W. S., Koshland C., 1997. Evaluating the environmental impact of products and production processes: a comparison of six methods. The Science of the Total Environment 196:13-29.

Hino, J., Miyabayashi, Y., Nagato, T., 1998. Recovery of nonferrous metals from shredder residue by incinerating and smelting. Metallurgical Review of MMIJ (Mining and Metallurgical Institute of Japan) 15, 63–74.

Hogland, W., Jagodzinski, K., Meijer, JE., 1995. Landfill mining tests in Sweden. Proceedings Sardinia '95, Fifth International Landfill Symposium, Cagliari, Italy, 783–794.

Hogland, W., 2002. Remediation of an old landfill: soil analysis, leachate quality and gas production. Environ Science & Pollution Research 1, 49–54.

Hogland, W., Marques, M., Nimmermark, S., 2004. Landfill mining and waste characterization: a strategy for remediation of contaminated areas. Journal of Material Cycles and Waste Management 6, 119–124.

Hong, J., Shaked, s., Rosenbaum, R. K., Jolliet, O., 2010. Analytical uncertainty propagation in life cycle inventory and impact assessment: application to an automobile front panel. Int J Life Cycle Assess (2010) 15:499–510

Huijbregts, M. A., Gilijamse, W., Ragas, A. M. J., Reijnders, L., 2003. Evaluating Uncertainty in Environmental Life-Cycle Assessment. A Case Study Comparing Two Insulation Options for a Dutch one-Family Dwelling. Environ. Sci. Technol., vol 37, No 11, pp 2600-2608.

Hull, R.M., Krogmann, U., Strom, P.F., 2005. Composition and Characteristics of Excavated Materials from a New Jersey Landfill. Journal of Environmental Engineering 131, 478-490.

Hylands, K., 1998. Minesweeping. Surveyor 5487, 14–16.

Kalos, M. H., Whitlock, P. A., 2008. Monte Carlo Methods. Wiley-Interscience.

Kapur, A., Graedel, T.E., 2006. Copper mines above and below ground. Estimating the stocks of materials in ore, products, and disposal sites opens up new ways to recycle and reuse valuable resources. Environmental Science & Technology 40, 3135–3141.

Krogmann, U., Qu, M., 1997. Landfill mining in the United States. Proceedings Sardinia '97, Sixth International Landfill Symposium, Cagliari, 543–552.

Krook, J., Svensson, N., Eklund, M., Johansson, N., Frändegård, P., (2010) Landfill Mining: A review of three decades of research. Proceedings The 14th European Roundtable on Sustainable Production and Consumption (ERSCP) and The 6th Environmental Management for Sustainable Universities (EMSU), Delft, The Netherlands.

Kurian, J., Esakku, S., Palanivelu, K., Selvam, A., 2003. Studies on landfill mining at solid waste dumpsites in India. Proceedings Sardinia '03, Ninth International Landfill Symposium, Cagliari, Italy, 248–255.

Lloyd, S. M., Ries, R., 2007. Characterizing, Propagating,and Analyzing Uncertainty in Life-Cycle Assessment- A Survey of Quantitative Approaches. Journal of Industrial Ecology, Volume 11, Issue 1, Pp 161-179

Lifset, R.J., Gordon, R.B., Graedel, T.E., Spatari, S., Bertram, M., 2002. Where has all the copper gone. JOM 54, 21–26.

Metropolis, N., Ulam, S., 1949. The Monte Carlo Method. Journal of the American Statistical Association, Vol. 44, No. 247., pp. 335-341.

Mor, S., Ravindra, K., De Visscher, A., Dahiya, R.P., Chandra, A., 2006. Municipal solid waste characterization and its assessment for potential methane generation: A case study. Science of the Total Environment 371, 1–10.

Müller, D., Wang, T., Duval, B., and Graedel, T.E., 2006. Exploring the engine of anthropogenic iron cycles. PNAS, 103, 16111–16116.

Nimmermark, S., Hogland, W., Larsson. L. and Bladh, H. (1998). Utgrävningar vid deponierna Måslycke och Gladsax Hallar i Simrishamns kommun. Rapport 107, Kalmar University College and Lund University [in Swedish].

Obermeier, T., Hensel, J., Saure, T., 1997. Landfill mining: energy recovery from combustible fractions. Proceedings Sardinia '97, Sixth International Landfill Symposium, Cagliari, Italy, 569–578.

Prechthai, T., Padmasri, M., Visvanathan, C., 2008, Quality assessment of mined MSW from an open dumpsite for recycling potential. Resources, Conservation and Recycling 53, 70–78.

Reeves, T.S., Murray, G.C., 1996. "Mining" used to close rural landfill. Public Works, 50–51.

Reeves, T.S., Murray, G.C., 1997. Landfill mining – a tool for rural landfill management and closure. Proceedings of the Air and Waste Management Association's 90th Annual Meeting and Exhibition, Toronto, Canada.

Rettenberger, G., 1995. Results from a landfill mining demonstration project. Proceedings Sardinia '95, Fifth International Landfill Symposium, Cagliari, Italy, 827–840.

Richard, D., Ambrosie, R., Zavoral, P., Zimmerman, R., 1996. Fargo takes a second look at the old landfill site. Proceedings of the 19th International Madison Waste Conference, University of Wisconsin-Madison/Extension, Madison, WI, USA.

SEPA, 1996. Metaller – materialflöden i samhället. The Swedish Environmental Protection Agency, Report 4506, Stockholm [in Swedish].

SEPA, 2002. Kunskapsförsörjning inom efterbehandling av förorenade områden. The Swedish Environmental Protection Agency, Report 5252, Stockholm [in Swedish].

SEPA, 2003. Förslag till delmål för efterbehandling av förorenade områden 2005-2010 – redovisning av regeringsuppdrag. The Swedish Environmental Protection Agency, Available on www.naturvardsverket.se [in Swedish].

Sormunen, K., Ettala, M., Rintala, J., 2008. Detailed internal characterisation of two Finnish landfills by waste sampling. Waste Management 28, 151–163.

Stessel, R.I., Murphy, R.J., 1991. Processing of material mined from landfills. Proceedings of the National Waste Processing Conference, Publ. by ASME, Detroit, MI, USA, 101–111.

The Swedish Waste Association, 2007. Svensk avfallshantering 2007. Malmö, Sweden. Available at: http://www.avfallsverige.se

Udo de Haes, H., Heijungs, R., Huppes, G., Van det Voet, E., Hettelingh, J-P., 2000. Full mode and attribution mode in environmental analysis. Journal of Industrial Ecology 4, 45–56.

Zhao, Y., Song, L., Huang, R., Song, L., Li, X., 2007. Recycling of aged refuse from a closed landfill. Waste Management Research 25, 130–138.