

Environmental impact analysis of landfilling system in Irkutsk on basis of life cycle assessment method

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Abstract. Irkutsk is the center of Eastern Siberia with a population of about 600,000 people. At present, the waste management system of Irkutsk is represented by the processes of collection and disposal of MSW. Only 4% of all waste produced by the city are collected separately and transported for a recycling. Most of the wastes are concentrated on a landfill, located 10 km from the city center. The paper describes modeling of the current and alternative future scenarios for waste management in the Irkutsk. We applied the Life Cycle Assessment method using EASETECH. We focused on landfilling which completely dominates the waste management system and on greenhouse gas emissions quantified in terms of CO₂-equivalents. The study shows that the introduction of a modern landfill technology can significantly improve the global warming contribution from the waste management in Irkutsk.

1. Introduction

Currently, one of the factors of technogenic risk is a landfill disposal of municipal solid waste (MSW). The specific feature of Russia in comparison with Western countries is that the absolute majority of municipal wastes (96-98%) are dumped to landfills, most of which were built many years ago and do not meet modern requirements [1].

Conducted research was based on environmental assessment of the current waste management system in Irkutsk, carried out using the Life Cycle Assessment method (LCA). The use of the LCA method allows assessing the impact of the existing system on the environment as well as to determine ways to reduce this impact.

The purpose of the study was to investigate the possibility of reducing the environmental impact of the waste disposal by a building a new modern MSW landfill meeting all modern requirements, including the collection and neutralization the leachate, as well as the collection and subsequent use of landfill gas. The analysis can lead to the development of alternative waste management options with improved environmental performance.

2. Objects and Methods

2.1. Old landfill

The old city's landfill is located 10 km from the center of Irkutsk. The landfill area is 420 000 m² and the average filling depth is 30 m. The bulk density is estimated to 0.67 ton/m³ since compaction is by



dozer. The landfill receives annually approximately 500 000 tons of MSW and the capacity is expected to be exhausted within 5-6 years. The landfill was constructed in 1963 and has no leachate and no gas collection system. The design of the landfill provides for passive degassing with vertical gas migration, in which the landfill gas is moved by its own pressure and thereby released into the atmosphere through the degassing pipe. We assume that 20% of the methane is oxidized. The oxidation rate is considered low because the methane flux out of the landfill is relative high since no gas is collected.

2.2. *New landfill*

The research was aimed at assessing the environment impact of a new landfill equipped with modern technology for control of landfill gas and leachate. Up to 80% of landfill gas is collected within the first 30 years to produce electricity. Next 10 years, gas is still collected but because of the low methane concentration it will be burned. The remaining gas is escaping through the soil cover of the landfill while subject to 50% oxidation of the methane. The fact that the flux of escaping methane now is low allows for assuming a higher methane oxidation rate in the top cover. The collected leachate is purified and then discarded into open water.

In order to assess the robustness of our modelling of the new landfill we performed a sensitivity analysis in terms of changing key parameters regarding the gas generation and gas management:

- Gas generation rate - degradation rate for cold and semi-dry regions was changed to temperate climate gas generation rate.
- Methane oxidation in the top cover - a top cover oxidation of the non-collected methane was changed from 50% to 20% so it was comparable to oxidation in the old landfill.
- Gas collection period- the collection period was changed from 30 years to 45 years, which means that a smaller amount of fugitive methane is released

2.3. *Life-Cycle Assessment (LCA)*

Today, the method of Life Cycle Assessment is one of the leading environmental management tools in the European Union, based on a series of ISO-standards and designed to evaluate the ecological, economic, social aspects and environmental impacts of production systems or disposal of waste [2-4].

EASETECH model was used in the LCA modelling. EASETECH is an LCA-model for assessment of environmental technologies developed at the Technical University of Denmark. The environmental impact assessment is done according to the EU-JRC's recommendations for Life Cycle Impact Assessment in a European context since there is no specific assessment method for Russia [5-7].

3. Results and discussion

3.1. *Inventory analysis*

The inventory of the current landfilling system in Irkutsk is based on various official reports from the regional authorities and from researches done at the National Research Irkutsk Technical University. Some information has been obtained from the literature.

Waste. According to the city administration, each resident of Irkutsk produces an average of 3.12 m³ of MSW, including 0.78 m³ of bulky waste every year. Annually about 500 000 tons of wastes are generated in Irkutsk. The volume of municipal waste generation in the city consists of the following streams: from the housing stock (40% of all waste), industrial enterprises, commercial, public organizations and other institutions [6].

For a complete picture of the fractional composition of municipal waste coming to the landfill, special studies were conducted at the city's landfill. Random garbage trucks were selected, waste was manually sorted and each fraction was weighed. Data on the properties of each fraction were taken from literature (Table 1) [8-11].

Table 1. Composition of MSW in Irkutsk.

Fractions	% Wet weight	Heating value, LVH (MJ/kg)	Ash (%Ash/TS)	Volatile solids (%VS/TS)
Organics	30			
<i>Vegetable food waste</i>	25.0	2.5	5.2	94.8
<i>Animal food waste</i>	5.0	9.2	8.7	91.3
Paper	23.5			
<i>Newspaper</i>	1.5	14.6	8.2	91.8
<i>Magazines</i>	3.0	10.6	34.0	76.0
<i>Office paper</i>	1.3	11.2	20.7	87.8
<i>Dirty paper</i>	6.7	13.2	8.9	91.1
<i>Cardboard</i>	11.0	12.2	14.0	86.0
Glass	11.3			
<i>Glass-clear</i>	5.7	-0.3	100	0
<i>Glass-green</i>	2.8	-0.1	100	0
<i>Glass-brown</i>	2.3	-0.1	100	0
<i>Glass-other</i>	0.5	-0.2	100	0
Plastics	15.8			
<i>Bottles</i>	3.0	32.5	6.1	93.9
<i>Soft plastic</i>	8.0	34.1	4.4	95.6
<i>Hard plastic</i>	2.4	36.1	2.2	97.8
<i>Non-recyclable</i>	2.4	29.2	5.5	94.5
Textile	7	18.5	3.6	96.4
Metal	2.6			
<i>Steel containers</i>	1.0	-0.3	100	0
<i>Aluminum containers</i>	0.4	-0.2	100	0
<i>Other of metal</i>	1.2	-0.2	100	0
Rubber	1.2	27.2	9.7	90.3
Leather	1	22.9	12.6	87.4
Wood	1	15.6	10.0	90.0
Others	6.6	-0.8	97.7	2.3
Total	100			

Leachate. The chemical analysis of the leachate composition was carried out. The results are shown in Table 2. The leachate generation is not known, but an estimate can be obtained from general data on annual precipitation (465 mm) and actual evapotranspiration (350mm) [12].

Table 2. Composition of the leachate.

Parameter	Concentration (Mg/l)	Uncertainty (Mg/l)	Parameter	Concentration (Mg/l)	Uncertainty (Mg/l)
Iron	2,0	0,4	COD	> 800	-
Aluminium	0,48	0,14	Solids content	4389	439
Chloride (Cl ⁻)	> 250	-	Calcium	50	8
Sulfate (SO ₄ ⁻)	< 30	-	Petroleum products	1,89	0,45
Nitrite (NO ₂ ⁻)	0,07	0,01	Zinc	0,45	0,009
Nitrate (NO ₃ ⁻)	0,91	0,31	Lead	0,0079	0,0028
Phosphate (PO ₄)	4,5	0,6	Cooper	0,0029	0,0012
Ammonium (NH ₄ ⁺)	> 4	-	Manganese	0,13	0,003
Suspended solids	86	9	Chromium	0,009	0,0032
pH	8,3	0,2	Mercury	0,00065	0,00026
BOD ₅	> 300	-	Cadmium	0,00028	0,0001
SAS	0,2	0,04	Arsenic	0,0052	0,0018

Landfill gas. When MSW is placed in the landfill, the products of destruction of its organic part are released into the atmosphere [13]. The main mass emission occurs at temperatures above 0 ° C, when the degradation processes are most active (Table 3). The percentage of waste subject to intensive destruction is 65.9% (329 500 t/year).

Table 3. Emissions from the landfill.

Parameters	Maximum one-time emission (gram/sec)	Annual emission (t/year)
Nitrogen dioxide (NO ₂)	0.3733203	6.414792
Ammonia (NH ₃)	2.2323456	38.358566
Nitrogen oxide (NO)	0.0606646	1.042404
Sulphur dioxide (SO ₂)	0.2943384	5.057639
Hydrogen sulphide (H ₂ S)	0.1092874	1.877893
Carbon monoxide (CO)	1.0553272	18.133769
Methane (CH ₄)	221.5610553	3807.1000656
Toluene	3.0268582	52.010736
Ethylbenzene	0.3992677	6.860648
Formaldehyde	0.4036258	6.935533

3.2. LCA result

Landfilling –existing facility. For environmental impact analysis the following categories were selected: Climate change (GWP); Ozone depletion (OD); Photochemical ozone formation (POFP); Acidity (AC); Eutrophication terrestrial (EP); Freshwater eutrophication (FEP); Human toxicity-carcinogenic (HuTcar); Human toxicity non – carcinogenic (Hu Toc Noncar); Ecotoxicity (Eco Tox) [14-15].

Figure 1 shows the normalized potential impacts for all 500 000 tons of waste annually managed.

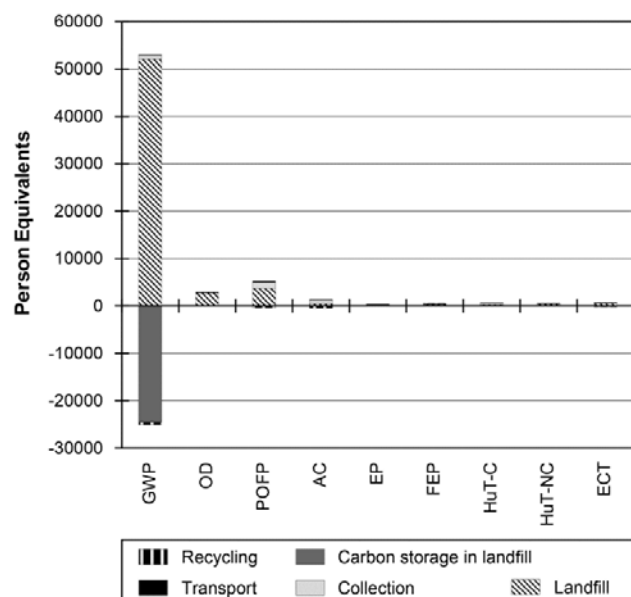


Figure 1. Environmental impacts (person equivalents) estimated for old landfilling system.

The disposal of waste at the old landfill shows very significant Global Warming impacts: a net load of 28 000 person-equivalent (PE, PE = 7700 kg CO₂-equivalents) or about 800kg of CO₂ per ton of waste landfilled. The landfill is totally dominating this impact since collection and transport of the waste contribute less than 1000 PE. The impact is due to a load and a saving: the load is from CH₄ escaping through the top cover of the landfill into the atmosphere – about 50 000 PEs – and a saving

caused by the storage of biogenic carbon in the landfill beyond the 100-year period considered – about 25 000 PEs. The toxicity impacts are low (300 PEs), while Ozone Depletion (2800 PEs) and Ozone Formation (7100 PEs) are significant [16].

Landfilling – new facility. Establishing a new landfill with technological control of the gas emission and utilization of the collected gas dramatically improves the environmental performance. The net Global Warming contribution is now reduced to 0% of the impact of the current waste management system with the old landfill; actually a minor net saving is observed. The landfill is still the dominating factor: The direct emission of CH₄ is significantly reduced to 22 000 PEs, the savings from the stored biogenic carbon after 100 years is unaltered, while using the gas for electricity production provides savings of 5000 PE, since otherwise coal would have been used for production of the same amount of electricity.

The sensitive analysis showed that the changing of standard decay rates is minor with a net difference of 16% (Figure 1) [17]. The 30-year methane collection time is not sufficient for the cold Siberian climate, so it is necessary to extend the period. The level of methane oxidation in the top cover is critical for the impact of the landfill. Therefore, in the operation of a new landfill, great attention must be paid to the collection of landfill gas. How this gas is utilized is a secondary task.

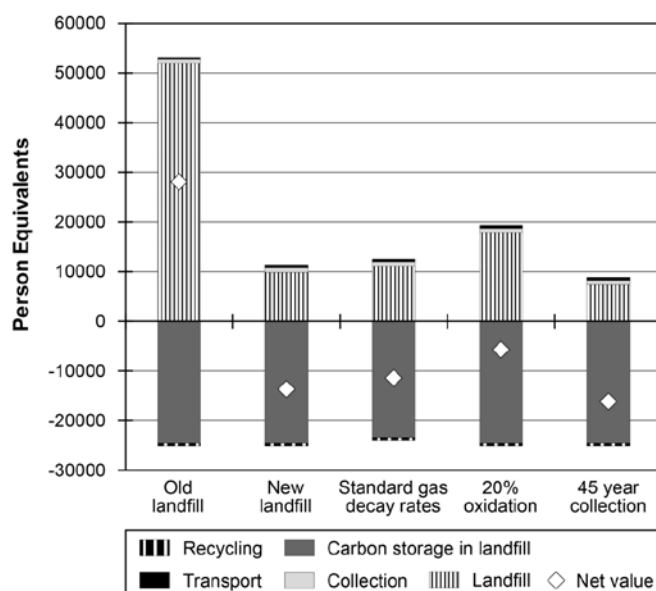


Figure 2. Global Warming impact from landfilling system. The left bar represents the old landfill with no gas management system while the other bars represent a new landfill with various assumptions regarding gas generation, collection and oxidation.

4. Conclusion

As a result of chemical analysis of the leachate of the existing landfill, as well as the calculations to determine the composition and amount of landfill gas, the necessary for LCA data were obtained. On the basis of this assessment, a modern technology of waste disposal was proposed. The assessment of the impact of the landfilling has shown that the construction and operation of the new sanitary landfill will considerably reduce the negative impact of these wastes on the environment. The load on Global Warming will be significantly weakened by the decreasing of the amount of greenhouse gases released into the atmosphere. From an environmental point of view, the existing waste management system does not meet the requirements of modern word waste management systems [19-21]. Opening the modern landfill with the system for collecting and utilizing landfill gas and leachate can significantly improve the ecological characteristics of the Irkutsk waste management system.

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