Critical factors for landfill mining

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LANDSS landfill aftercare forum

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What turns landfilled materials into resources?

MAN WHO ‘THREW AWAY’ BITCOIN HAUL NOW WORTH OVER $80M WANTS TO DIG UP LANDFILL SITE

'It’s a big, expensive and risky project,' says James Howells, from Newport

Source: Independent, accessed on 08.12.2017
Introduction
- Historical development & background
- Landfills as anthropogenic resources: MINEA
- Landfill mining in theory & practice

What drives the economy of landfill mining?
- Goal & Scope
- Modeling approach
- Results & Discussion

Summary
- Critical factors for the economy of landfill mining
Introduction

• No commonly accepted definition
  • … excavate, process, recycle and treat previously deposited materials

• 500,000 (or so) landfills in Europe, which require post-closure management
  • Landfill mining as an alternative

• Overall research trends
  • From solving local landfill problems to emphasis on resource recovery
  • From simple mobile equipment to more technically advanced solutions
  • An emerging system perspective – societal impacts and synergies
Recent developments: Enhanced landfill mining

... combining remediation with recovery of deposited materials, energy carriers and land resources
Landfill mining from a circular economy perspective

- A stepping stone for building future capacity for a circular economy
  - In many regions, an exploitation of landfills could double the available amounts of some secondary resources for decades

- A possible seed-bed for development of new, more resource-effective separation and recycling technologies
What share of anthropogenic materials can be designated as a resource?

- Availability of secondary raw materials from anthropogenic sources such as landfills, mine tailings, buildings, infrastructure, etc.

- Classification in line with geological resource classifications
MINEA – WG 2.2 „Resources in landfills“

Working group leader: Joakim Krook

Which landfills are most suitable for LFM? Based on what?

How to assess LFM & its multiple impacts

How to classify resources in landfills?

Clear incentives rely on indirect benefits or avoided alternative costs

Cost & Benefits
To whom?

Values

What can be recovered and at what quality level? Now and in the years to come...

How to handle conflicts between circular economy and non-toxic environment?

Environmental externalities?

Policy & regulations

How to best organize such projects?
How to distribute costs and benefits among different actors?

Organization

Markets

Demand & prices for resources from landfills?
Waste markets based on gate-fees and disposal costs

Local settings

Technology

Evaluation frameworks

Site-specifics

Conditions & motives for Landfill Mining
LFM in practice: former dumpsite in Kössen

Motivation:
Site heavily affected by flooding & area required for flood protection measures

Mining period:
07/2014 – 06/2015

LFM in practice: Excavation & sorting at Kössen site

Simple technology.

LFM in practice: Output materials


80% re-landfill

Little „recovery“.
LFM in practice: Economy of the Kössen project

- Project economy
  - Total costs: 1.5 Million Euro
  - Total revenues: 90,000 Euro
  - Net result: -1.4 Million Euro

  → Specific costs of 17.5 Euro per ton of deposited waste
  → Specific costs of 100 Euro per m² of reclaimed land

Material recovery (alone) does not justify the LFM project....

Poor economy.

Landfill mining in theory: review of economic assessments

- 10 recent case studies in peer reviewed journals
  - different regions, project sizes, objectives and complexities

- Reported hot-spots in terms of main costs (-) and benefits (+) in the reviewed assessments

Krook et al. (2018): Science to support circular economy symposium
Landfill mining in theory: methodological issues

Studied landfills
- Low-grade MSW
- Low reference costs
Analytical concerns
- Implications of site-specifics?

Employed processing schemes
- From simple to advanced technologies
- Often only one processing line/scenario
Analytical concerns
- Selection criteria? Alternatives?
- Processes treated as black boxes

Assumptions of marketability
- Exhumed resources salable
- Full substitution
Analytical concerns
- Implications of marketability constraints?

Exploration → Excavation → Separation → Treatment & Recovery → WtE, WtM & Disposal

Specificity and quality of applied data
- High/Moderate
- Low

Main origin of data
- Adjacent knowledge fields, industry estimates & small-scale trials

Analytical concerns
- Applicability of high separation and recovery efficiencies?

Handling of data uncertainties
- Mainly input parameters as single estimated values

Analytical concerns
- Implications on performance of stochastic variations & epistemological uncertainties?

Krook et al. (2018): Science to support circular economy symposium
Landfill mining in theory: validity and uncertainty of results

- Recent assessments target deterministic results on economic feasibility
  - Net outcome for a specific scenario
  - Provide little knowledge on what builds up performance of landfill mining

- Ignoring scenario & data uncertainties provide simplified results, but are they valid and useful?
  - High implicit uncertainties
  - Miss out potentials for improvement
  - Difficult to identify critical factors

Krook et al. (2018): Science to support circular economy symposium
What drives the economy of landfill mining?

Systematic assessment of critical factors for the economic performance of landfill mining in Europe

by members of the MINEA working group 2.2

David Laner, John Laurence Esguerra, Joakim Krook, Mika Horttanainen, Mait Kripsalu, Rene Moller Rosendahl, and Nemanja Stanisavljevic

Manuscript submitted to Waste Management
Investigation of critical factors for the economy of LFM

• Goal:
  Assess generically important factors for the business case of landfill mining in consideration of regional differences within Europe
  → Analyse under what specific conditions and settings landfill mining could be economically justified and identify key economic drivers in these cases

• Scope:
  The spatial and temporal scope of the study involves MSW landfills in Europe with current regional variations in price settings and waste management and treatment practices.
### Modeling approach

**Factors & Data sets**

<table>
<thead>
<tr>
<th>Factor</th>
<th>Set 0-1</th>
<th>Set 0-2</th>
<th>Set 0-3</th>
</tr>
</thead>
<tbody>
<tr>
<td>F0: Variation in excavation &amp; sorting costs</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F1: Landfill settings</td>
<td>1-1</td>
<td>1-2</td>
<td>1-3</td>
</tr>
<tr>
<td>F2: Landfill composition</td>
<td>2-1</td>
<td>2-2</td>
<td>2-3</td>
</tr>
<tr>
<td>F3: Reference scenario</td>
<td>3-1</td>
<td>3-2</td>
<td>3-3</td>
</tr>
<tr>
<td>F4: Project drivers</td>
<td>4-1</td>
<td>4-2</td>
<td>4-3</td>
</tr>
<tr>
<td>F5: Excavation &amp; sorting technology</td>
<td>5-1</td>
<td>5-2</td>
<td>5-3</td>
</tr>
<tr>
<td>F6: Waste-to-Energy</td>
<td>6-1</td>
<td>6-2</td>
<td>6-3</td>
</tr>
<tr>
<td>F7: Markets for materials and energy</td>
<td>7-1</td>
<td>7-2</td>
<td>7-3</td>
</tr>
<tr>
<td>F8: Value of recovered land or void space</td>
<td>8-1</td>
<td>8-2</td>
<td>8-3</td>
</tr>
<tr>
<td>F9: Disposal and transport costs</td>
<td>9-1</td>
<td>9-2</td>
<td>9-3</td>
</tr>
<tr>
<td>F10: Transport distances</td>
<td>10-1</td>
<td>10-2</td>
<td>10-3</td>
</tr>
<tr>
<td>F11: Financial accounting</td>
<td>11-1</td>
<td>11-2</td>
<td>11-3</td>
</tr>
</tbody>
</table>

12 factors with 3 alternative sets

**3^{12} combinations = 531,441 combinations**

**Economic model**

- **1 Mg waste excavated**
- **Physical flow model**
- **Evaluation of costs and revenues (Discounted cash flow analysis)**
- **Net present value [€/Mg]**
  - Project total
  - Selected cost and revenue items

**Scenarios**

- **Scenario 1**
  - (1-1,2-1,3-1,4-1,5-1,6-1, 7-1,8-1,9-1,10-1,11-1)
- **Scenario 2**
  - (1-1,2-1,3-1,4-1,5-1,6-1, 7-1,8-1,9-1,10-1,11-2)
- **Scenario 531,441**
  - (0-3,1-3,2-3,3-3,4-3,5-3, 6-3,7-3,8-3,9-3,10-3,11-3)

**Global sensitivity analysis**

→ critical factors for economic performance
## Selected factors and datasets

<table>
<thead>
<tr>
<th>#</th>
<th>Level</th>
<th>Description</th>
<th>Set 1</th>
<th>Set 2</th>
<th>Set 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>F0</td>
<td>System</td>
<td>Regional variations in excavation &amp; sorting costs (investment, labour and maintenance)</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>F1</td>
<td>Site/Project</td>
<td>Landfill settings</td>
<td>Small-scale landfill, short project duration</td>
<td>Medium-scale landfill, medium project duration</td>
<td>Large-scale landfill, long project duration</td>
</tr>
<tr>
<td>F2</td>
<td>Site</td>
<td>Landfill composition</td>
<td>Rich MSW landfill</td>
<td>Average MSW landfill</td>
<td>Poor MSW landfill</td>
</tr>
<tr>
<td>F3</td>
<td>Site/System</td>
<td>Reference scenario</td>
<td>Do nothing</td>
<td>Medium intensity aftercare</td>
<td>High intensity aftercare or remediation</td>
</tr>
<tr>
<td>F4</td>
<td>Project</td>
<td>Project drivers</td>
<td>Resource recovery</td>
<td>Resource recovery &amp; land reclamation</td>
<td>Resource recovery &amp; void space recovery</td>
</tr>
<tr>
<td>F5</td>
<td>Project</td>
<td>Excavation &amp; sorting technology</td>
<td>Mobile sorting (on-site)</td>
<td>Conventional tech. stationary sorting (off-site)</td>
<td>BAT stationary sorting (off-site)</td>
</tr>
<tr>
<td>F6</td>
<td>System</td>
<td>Waste-to-energy (WtE)</td>
<td>Low gate fee</td>
<td>Medium gate fee</td>
<td>High gate fee</td>
</tr>
<tr>
<td>F7</td>
<td>System</td>
<td>Markets for material and energy</td>
<td>Low-level prices</td>
<td>Medium-level prices</td>
<td>High-level prices</td>
</tr>
<tr>
<td>F8</td>
<td>Site/System</td>
<td>Value of reclaimed land or landfill void space</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>F9</td>
<td>System</td>
<td>Waste treatment, disposal, and transport costs</td>
<td>Low</td>
<td>Medium</td>
<td>High</td>
</tr>
<tr>
<td>F10</td>
<td>System/Site</td>
<td>Transport distances</td>
<td>Short</td>
<td>Average</td>
<td>Long</td>
</tr>
<tr>
<td>F11</td>
<td>System</td>
<td>Financial accounting</td>
<td>Low risk</td>
<td>Medium risk</td>
<td>High risk</td>
</tr>
</tbody>
</table>
Regional archetypes

• Archetypal settings
  • Purpose: analyse the economy of landfill mining projects under specified boundary conditions (e.g. regional disparities)
  • Design: fix seven factors on the system level (F0, F3, F6, F7, F8, F9, F11) by choosing one of the three datasets
    → 243 scenarios ($3^5 = 243$) for each setting

• Two extreme settings
  • High income, high waste management standards
    • F0-3, F3-3, F6-3, F7-3, F8-3, F9-3, F11-1
  • Low income, low waste management standards
    • F0-1, F3-1, F6-1, F7-1, F8-1, F9-1, F11-3
NPV of landfill mining scenarios

breakeven: 19% net profitable scenarios

mean

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

0 40 80 120 160

NPV, Euro/Mg

Share of Scenarios, %
Present value of cost and revenue items

- **excavation and sorting costs**: -20.83, -20.61%
- **internal re-landfilling costs**: -15.16, -15.01%
- **external waste treatment costs**: -25.26, -25.00%
- **transport costs**: -2.85, -2.82%
- **avoided landfill management costs**: 16.81, 16.64%
- **revenues from materials**: 9.81, 9.71%
- **revenues from voidspace**: 4.03, 3.99%
- **revenues from machinery**: 3.06, 3.03%
- **revenues from land**: 3.22, 3.19%
- **NPV**: -27.15

Euro/Mg of waste
Sensitivity of project NPV to factor variation

• Variations in 4 factors explain >75% of the results’ variation

1. **F9** - Waste treatment and disposal costs: 34%
2. **F3** - Reference scenario: 21%
3. **F6** - Waste-to-Energy: 12%
4. **F1** - Landfill settings: 10%

Mainly direct effects of variation on results
Mainly indirect effects of variation on results

• Variation in other factors

5. – 8. F5 – Excavation & sorting technology 6%, F4 – Project drivers 5%, F8 – Value of land/void space 5%, F2 – Landfill composition 4%

9. – 12. Variation in F11, F7, F0, and F10 altogether accounts for less than 3% of total variation
Graphical analysis of scenario results
Project economy in the high – high setting
Project economy in the low – low setting
Economy of LFM - Conclusions

- Landfill mining is a challenging business endeavour, which is highly dependent on the specific situation
  - NPV from -139 Euro (deficit) to +127 Euro (profit) per Mg of waste
    - Around 80% of the scenarios result in negative NPVs
  - Most important cost items
    - Treatment and disposal of excavated and processed materials
    - Excavation & sorting costs
  - Most important revenue items
    - Avoided costs of alternative landfill management
    - Material and land or void space recovery (if valorized) of similar importance
  - System-level conditions drive the major cost and revenue items
    - overarching boundary conditions to guide site selection and project development
    - Extreme of high income, high wmgt standards
      - minimize treatment costs more important than maximize material revenues
      - focus on landfills with low mass-to-area ratios → aftercare & land revenue
    - Extreme of low income, low wmgt standards
      - maximize material revenues rather than minimize (already low) treatment costs
      - focus on large landfills rich in valorisable materials
Critical factors for landfill mining… in general

- Landfill mining can offer a sustainable management option for a (small) part of Europe’s landfills
  - If – in economic terms – multiple benefits can be obtained (materials & land & avoided management…)
  - If – from a circular economy perspective – key challenges of material quality and market acceptance can be overcome
  - If – from a societal perspective – diverse impacts on different societal scales and time horizons are better understood and internalized
  - If – from a policy perspective – landfill mining is seen as potential alternative to conventional practices and considered in regulatory frameworks
Outlook: what can we learn from primary production

Prospection:
Which landfills to mine?

Exploration & Production:
How to do it?
(in a long-term learning and institutional perspective)
Thank you for your attention!

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