Manual

“Online Tool for the Economic and Ecologic Evaluation of Landfill Mining Projects“

OnToL

Version 1.2.4 (September 2019)

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General Information

OnToL (Online Tool for the Economic and Ecologic Evaluation of Landfill Mining) is a tool that allows the user to assess the economic and environmental performance of landfill mining projects in comparison to the reference case, where the landfill is not mined. In addition, the user has the possibility to assess also the economic impact of an intermediate use of the landfill (for instance as a parking lot, for solar panels or other) prior its mining.

OnToL builds on existing mathematical models to determine the environmental (Laner et al. 2016) and economic (Winterstetter, 2016) performance of landfill mining. As an example, the structure of the model for evaluating the climate impact of landfill mining for diverse model set-ups and conditions is shown in Figure 1. In essence, the model keeps track of all the material flows out of the landfill and connects them to direct or indirect emissions (in the case of the economic model: to costs) and to avoided emissions due to useful outputs (in the case of the economic model: revenues due to material sales or savings due to avoided costs). In this model, seven processes (see Figure 1) are considered relevant for the material flows, costs and climate impact of the landfill mining project:

A. Landfill characteristics (waste composition, landfill management, landfill emissions during time of mining);
B. Excavation, Sorting and Upgrading of the waste (excavation, sorting and upgrading technology, costs and energy demand of the technologies)
C. Thermal Utilization of combustibles (thermal utilization technology, costs and energy demand/production, operating resources)
D. Solid Residues Processing of incineration ashes (technology for the processing of incineration residues, costs and energy demand of the technology)
E. Material Recycling of metals, minerals and plastics (climate impact of material recycling, prices and quality aspects of recyclables)
F. Landfill receiving waste/residues from the mining project (landfill management, landfill emissions, disposal costs)
R. Reference case for landfill (describing the scenario where the landfill was not mined, including information about the long term landfill management, emission and costs)

1 Time prior mining
2 Landfill, which is to be mined.
3 Transfer coefficients for the material excavated and sorted
4 Recovery of metals and or minerals out of waste incineration ashes
5 Subsequently called “Landfill – New”
Figure 1  Structure of the model to calculate the economic and climate impact of landfill mining illustrating physical flows

The input mask of OnToL is structured as follows:

For each of the seven processes

- **GENERAL DATA AND DATA ABOUT THE PHYSICAL MODEL** (describing the material and waste flows) are to be inserted - subsequently summarized under **A-Material**

- **DATA ABOUT ENERGY, TRANSPORT AND CONSUMABLES** (describing the demand of energy and consumables of each processes as wells as the transport of waste and thereof derived residues and recyclables) – subsequently summarized under **B-Energy**

- **GREENHOUSE GAS EMISSION DATA** (describing the specific greenhouse gas emissions related to the processes) – subsequently summarized under **C-Climate**

- **ECONOMIC DATA** (describing economic costs and revenues of the different processes) – subsequently summarized under **D-Economy**
Registration and Login at OnToL

In order to use OnToL, registration of the user with an email address is required. (create new account).

After clicking “create new account” the registration window opens, where the user is requested to type in his email address. After clicking “register” an email is sent to the user which contains the password for the login.
Subsequently email address and the corresponding password are used to login.
Creation of new projects

After login, the following page opens (see below), which allows the user to create new landfill mining projects to be evaluated (by entering a new project name and using the button Create). Besides the creation of new projects, the user has the possibility to test one already existing project (named LFM – Test case), which describes the landfill mining project for a Municipal Solid Waste landfill containing about 100,000 tons of waste.

By clicking on the project name (e.g. LFM – Test case, name of the new created project), the project can be altered (see Definition of Projects in OnToL – page 9).

In case all necessary data for the landfill mining project have already been defined, the results of the landfill mining evaluation (results of OnToL) can be displayed by clicking the buttons HTML, XLSX or JSON. If data is missing, the buttons HTML, XLSX or JSON are not available for the respective project.

For HTML, a new tab opens, which summarizes the results of the evaluation of the landfill mining project (see Results of OnToL - page 58). XLSX and JSON give the same results in Excel format and in JavaScript Object Notation, respectively.
Renaming, Copying, Exporting, Importing and Deleting of Projects

By clicking the icon below the project name, the project can be renamed.

Projects can also be copied (button Copy), deleted (button Delete), exported (button Exported) and imported (button Import). Copying projects allows the user to assess different scenarios for the same projects, as all input data are copied to a new project, which can easily be altered.

For the import of projects, a file (*.json) needs to be selected. By exporting and importing OnToL files, it is possible to share projects among different users (the file format for exporting and importing is *.json).
Definition of Projects in OnToL

In the following, the entry mask for projects defined in OnToL is explained in detail. The entry mask for the project can be accessed by clicking on the project name given in the list of the projects (created by the user).

Besides the explanation of each input parameter, default values for the different parameter are suggested (if reasonable). This default values are given in light grey colour and should be overwritten by the user.

In general, the current version of OnToL requires the specification of all input data, even if they are relevant for the landfill mining project to be evaluated (e.g. data about thermal utilization, even if no material is thermal utilized).
A-Material

General data about the landfill mining project and all data defining the physical flows of wastes and related products are to be defined.

A - General landfill data

In a first step general landfill data (size, area, tonnage of landfill, disposal period, installation of landfill cover, annual precipitation, leachate generation rate, waste composition, …) are to be defined. Furthermore, it has to be specified whether the landfill (which is to be mined) is equipped with a landfill gas collection and leachate collection system.

Information related to the leachate emissions (such as annual precipitation rate, or leachate generation prior and after final cover installation) can only be defined, if the landfill is equipped with a leachate collection system. All data are saved automatically.

Information about the leachate generation rate before final cover installation \([\text{m}^3 \text{ leachate/m}^3 \text{ precipitation}]\) together with the annual precipitation rate \([\text{m}^3 \text{ precipitation/m}^2 \text{ landfill surface}]\) is used to determine the amount of leachate \([\text{m}^3/\text{year}]\) to be treated during the mining project, whereas the

---

6 In most cases old landfill do have not a gas and leachate collection system
leachate generation rate after final cover installation is used for the reference case (case where the landfill is not mined and landfill is equipped with a final cover).

Click on button 2 in the right upper corner (right next to A-Landfill) to enter data on the landfill’s waste composition:

MF ... Mass fraction of the given material [kg/kg wet matter] the sum of all MFs should be 1!

Please note that preferable for each mass fraction a value different than 0 should be inserted, even if the mass fraction is not known or 0 (In case it is 0, please use a very small value, such as 0.0001). Otherwise, calculation errors (internal server error) could occur!

WatC ... Water content of the respective mass fraction [kg H2O/kg wet matter of the respective fraction]

AshC ... Ash content of the respective mass fraction [kg ash/kg dry matter of the respective fraction]

CarC .... Carbon content of the respective mass fraction [kg C/kg wet matter of the respective fraction]

LHV ... Lower heating value of the respective mass fraction [MJ/kg wet matter of the respective fraction]
The following default values for the water and ash content of the different fractions are suggested, if no detailed information from waste sampling and analysis is available.

<table>
<thead>
<tr>
<th></th>
<th>Water content</th>
<th>Ash content</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>WatC</td>
<td>AshC</td>
</tr>
<tr>
<td></td>
<td>kg H2O/g wet matter</td>
<td>ID</td>
</tr>
<tr>
<td>soil material + fines</td>
<td>0.3 aw1</td>
<td>0.94 aa1</td>
</tr>
<tr>
<td>paper</td>
<td>0.3 aw2</td>
<td>0.2 aa2</td>
</tr>
<tr>
<td>plastics</td>
<td>0.1 aw3</td>
<td>0.1 aa3</td>
</tr>
<tr>
<td>wood</td>
<td>0.3 aw4</td>
<td>0.05 aa4</td>
</tr>
<tr>
<td>textiles</td>
<td>0.3 aw5</td>
<td>0.1 aa5</td>
</tr>
<tr>
<td>stones &amp; inert</td>
<td>0.1 aw6</td>
<td>1 aa6</td>
</tr>
<tr>
<td>degradable organics</td>
<td>0.5 aw7</td>
<td>0.2 aa7</td>
</tr>
<tr>
<td>Fe metals</td>
<td>0.01 aw8</td>
<td>1 aa8</td>
</tr>
<tr>
<td>Al</td>
<td>0.01 aw9</td>
<td>1 aa9</td>
</tr>
<tr>
<td>Cu</td>
<td>0.01 aw10</td>
<td>1 aa10</td>
</tr>
<tr>
<td>Hazardous</td>
<td>0.05 aw11</td>
<td>0.9 aa11</td>
</tr>
</tbody>
</table>

If there is no information available on the Carbon content (CarC) and the lower heating value (LHV), these data can be calculated using the buttons “Calculate (overwrite) CarC from WatC + AshC” or “Calculate (overwrite) LHV from WatC + AshC”.

Click on button 3 in the right upper corner (right next to A-Landfill) to enter general data about the mining project.

Assess the status of the project, from a very early project planning phase to high maturity of the project:

- **Pre-exploration phase** (first idea about landfill mining concept, rough assessment of waste composition based on historical data from landfill operation, no test excavations are available yet)
- **Exploration phase** (test excavations, sorting, sampling, (pre-)feasibility studies)
- **Approval phase** (feasibility studies concluded, but not all required permits obtained yet)
- **Mining phase** (feasibility studies concluded, all permits obtained, excavation activities have started).

Confidence of knowledge on waste composition:

- **very low** (only rough estimates about the composition exist)
• **low** (a few waste samples have been analysed)
• **medium** (a significant number of waste samples has been analysed)
• **high** (systematic test excavations and sorting analysis have been conducted).

**Whole landfill is excavated:** Yes/No. No is to be selected, if only a part of the landfill is excavated. *(THE PRESENT VERSION of OnToL allows only the option, that all the waste is landfilled – option YES)*

If the landfill is only partially excavated, then the *share of excavated landfill* is to be specified. *(THE PRESENT VERSION of OnToL allows only the option, that all the waste is landfilled – share equals 1)*

Are parts of the excavated materials re-deposited onsite): Yes/No *(THE PRESENT VERSION of OnToL allows no re-deposition of the waste onsite – option NO)*

If parts of the waste are re-deposited onsite, the *density of the re-deposited waste* as well as the *average height of the re-deposited materials* are to be defined, in order to evaluate how much landfill area and space is gained *(THE PRESENT VERSION of OnToL allows no re-deposition of the waste onsite, hence the density of the re-deposited waste as well as the average height of the re-deposited materials is irrelevant)*

**Duration of the mining project** is to be specified in years.

Project drivers are to be selected, the user can select one out of four options:

- material recovery
- material & land recovery
- material & void space recovery
- land recovery only.

If an *intermediate use of the landfill* 7 (e.g. solar panels, wind mills, parking lot, park, ...) prior to the mining project should be evaluated, the user has to specify this by selecting Yes.

If an intermediate use of the landfill was selected, the *duration of the intermediate use* has to be specified (in years).

Costs and revenues (see D-general data) related to the intermediate use are assumed to start “immediately” (in the first year of evaluation).

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7 Prior to mining, the landfill (area) will be used for another purpose (e.g. parking lot, park, installation of solar panels)
A - Excavation, Sorting and Upgrading

By selecting **A – Excavation, Sorting and Upgrading**, as shown on the left of the picture under A – Landfill, the user can specify the processing steps of the landfilled waste after excavation. In particular, the transfer coefficients of the sorting and upgrading are to be specified. They define how the input into the sorting plant is divided into the different output streams. The input into the sorting plant is the excavated waste, while the outputs of the plant are:

- **Co**: Combustibles (waste which is sent for incineration)
- **Fe**: Ferrous metals separated and sent for recycling
- **NFe**: Non-ferrous metals separated and sent for recycling
- **Agg**: Aggregates (stones, gravel and sand, which are used for recycling in the construction sector)
- **Haz**: Hazardous materials which are sent for special treatment
- **RdO**: Residues disposed of at another landfill site
- **RdR**: Residues re-deposited at the landfill site which is mined (need to be set to 0 for the current version of OnToL)
- **Pla**: Plastics sent for recycling
The transfer coefficients are to be defined for each waste fraction, such as SMF (soil material and fines), paper, plastics, and so on. The user can select also predefined values for different types of sorting plants, i.e. mobile plant, stationary plant and advanced stationary plant. While the former is associated with lower efficiencies, the latter has the highest recovery efficiencies. The different options (mobile plant, stationary plant and advanced stationary plant) are also linked to different default costs for the sorting (not implement in the current version!).

Characteristics of pre-defined sorting plants:

<table>
<thead>
<tr>
<th>Separation steps</th>
<th>Mobile plant</th>
<th>Stationary plant</th>
<th>Advanced stationary plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sieving (waste screening)</td>
<td>Simple sieves (e.g., trammel screen)</td>
<td>Several sieving &amp; subsequent sorting steps</td>
<td>Several sieving &amp; subsequent sorting steps</td>
</tr>
<tr>
<td>Sorting</td>
<td>by sieves (and eventually manual separation)</td>
<td>Sieves, air separation for different grains sizes (and eventually manual separation)</td>
<td>Sieves, air separation, film grabber, sensor technology (and eventually manual separation)</td>
</tr>
<tr>
<td>Separation of ferrous metals</td>
<td>One magnetic separator</td>
<td>magnetic separators for or two different grains sizes</td>
<td>magnetic separators for different grains sizes</td>
</tr>
<tr>
<td>Separation of non-ferrous metals</td>
<td>One eddy current separator</td>
<td>eddy current separator for or two different grains sizes</td>
<td>eddy current separator for different grains sizes</td>
</tr>
</tbody>
</table>

Note: A transfer coefficient of 0.5 for Co and paper means, that 50% of the paper present in the excavated waste is transferred to the combustibles (Co), which are sent for incineration. A transfer coefficient of 0.8 for SMF and RdO means that 80% of the soil materials and fines present in the excavated waste are transferred to the residues (RdO), which are disposed of at another landfill.
A - Thermal Utilization

By selecting A – Thermal Utilization, as shown on the left of the picture under A – Excavation, Sorting, Upgrading, the user can specify the percentage of burnable materials in residues (burnout in kg/kg) and the proportion of hazardous solid residues (fly ash & APC residues) in relation to the total amount of solid residues generated during thermal utilization). The latter depends on the combustion technology and the type of air pollution control APC.

In general, all waste/material directed to Combustibles Co (transfer coefficient to Co – defined in A - Excavation, Sorting, Upgrading) is sent to Thermal Utilization. If the user would like to exclude any thermal utilization, the transfer coefficient to Combustibles Co should be set to 0!

Note: A default value for the percentage of burnable materials in residues of 0 kg/kg is recommended (complete combustion of the waste), and for the fraction of fly ash and APC residues a value of 0.05 kg/kg ash is recommended for grate incinerators with wet APC system. For incineration plants with dry or semidry APC systems the fraction of fly ash and APC residues may amount up to 0.10 kg/kg ash.

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8 The proportion of fly ash and APC residues is in particular of interest for the disposal costs of the incineration residues.
### GENERAL DATA AND PHYSICAL MODEL

<table>
<thead>
<tr>
<th>A — Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>B — Energy</td>
</tr>
<tr>
<td>C — Climate</td>
</tr>
<tr>
<td>D — Economy</td>
</tr>
</tbody>
</table>

#### A — Thermal Utilization

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage of burnable materials in residues</td>
<td>0</td>
<td>%</td>
</tr>
<tr>
<td>Fly ash &amp; APC residues (fraction of solid residues)</td>
<td>0.05</td>
<td>kg/kg Ash</td>
</tr>
</tbody>
</table>

#### A — Landfill

#### A — Excavation, Sorting, Upgrading

#### A — Thermal Utilization

#### A — Solid Residues Proc.

#### A — Material Recycling

#### A — Landfill New

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A - Solid Residues Processing

By selecting A – Solid Residues Processing as shown on the left of the picture under A – Thermal Utilization, the user can specify the transfer coefficients for the processing of the incineration residues. In particular, the separation efficiencies for Fe, Al und Cu can be specified. In addition, the utilization of part of the mineral fraction of the incineration residues as construction material (aggregates) can be defined.

Note: A Fe separation efficiency of 0.8 kg out/kg in means that 80% of the Fe metals present in the incineration residues is recovered and sent for recycling. A value of 0.2 kg/kg bottom ash for Bottom ash residues (use as aggregates) means, that 20% of the bottom ash is recycled as aggregates in the construction sector, a value 0 means that no recycling of the bottom ash in the construction sector takes place.
A – Material Recycling

By selecting A – Material Recycling, as shown on the left of the picture under A – Solid Residues Proc, the user can specify the substitution rate (quality factor) of metals, aggregates and plastics that are eventually recycled during the landfill mining project.

Fe1 ... Ferrous metals recovered after sorting the excavated waste
Fe2 ... Ferrous metals recovered after processing the incineration residues
NFe1 ... Non-ferrous metals recovered after sorting the excavated waste
NFe2 ... Non-ferrous metals recovered after processing the incineration residues
Aggregates (CM) ... Stones, gravel and sand recovered after sorting the excavated waste
Plastics (Ro) ... Plastics recovered/recycled after sorting the excavated waste
Aggregates from Ash (RtR) ... Stones, gravel and sand recovered during the processing of the incineration residues.

The quality factor (substitution rate) is used to evaluate how much primary material (Fe, NFe, aggregates, plastics) is saved by recycling materials gained from the mining operations. This is of importance for evaluating the climate impact of the project. Due to quality constraints of secondary materials the substitution rate is usually < 1. However, for simplicity a quality factor of 1 can be assumed. If no recycling is conducted the quality factors are not used for the subsequent calculations, however they have be specified in order to run the tool.

Note: A quality factor of 1 for Fe1 means that 1 kg of ferrous metals derived from the sorting of the waste substitutes 1 kg or ferrous metals produced from primary resources (iron ores).
A – Landfill New

Landfill New represents the landfill where residues of the mining processes are landfilled. By selecting A – Landfill New, as shown on the left of the picture under A – Material Recycling, the user can specify information on the “new” landfill, which receives waste/residues from the landfill mining project.

Under A- Landfill New no data has to be specified in the current version of OnToL!

A – Reference Case

By selecting A – Reference case, as shown on the left of the picture (right under A - Landfill New), the user can specify information on the landfill in a “Do-Nothing scenario”, i.e. where the landfill is not mined (here called “reference case”).

Remaining aftercare duration (in years): Duration of the landfill’s aftercare in case the landfill is not mined. The duration refers to the “starting year” of the proposed landfill mining project.

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9 “new” means that the landfill is different from the landfill site to be mined, it receives residues from the landfill mining project.
A—Reference Case

Description | Value | Unit
--- | --- | ---
Remaining aftercare duration (*) | 0 | years

(*) related to the start date of the IFS project.

The reference case refers to the case where the landfill is left untouched (not mixed) and typical aftercare measures (collection and treatment of landfill gas and leachate) are to be realized.
B - Energy

For all processes of the landfill mining project energy related data (e.g. transport distances, electricity demand, heat demand, fuel demand, electricity production, heat production) are to be specified under B-Energy. These data are required for assessing the climate impact and may be also of relevance for the economic evaluation.

B - Landfill

By selecting B – Landfill, as shown on the left of the picture under B – Energy, the user can specify energy related data for the landfill to be mined, at which also waste/residues from the mining project may be re-deposited.

*The present version of OnToL does not allow any re-deposition of the excavated waste.*

**Transport of excavated waste to sorting** (in km): Distance between the landfill to be mined and the sorting plant. If a mobile sorting plant is selected and located at the landfill the transport distance is 0.

**Electricity demand for gas and leachate treatment** (in MJ/Mg.yr): Electricity consumption for collecting and managing the landfill’s leachate and landfill gas. A typical range for the electricity consumption per year is about 0.5 – 4 MJ/Mg.yr (see Manfredi et al. 2009).

**Fuel demand for gas and leachate treatment** (in MJ/Mg.yr): Fuel consumption of the landfill in order to collect and manage leachate and landfill gas. A typical range for the fuel consumption per year is about 0 – 4 MJ/Mg.yr (depending on the system). *In most cases a value of 0 MJ/Mg.yr is to be selected.*

Electricity use for managing re-deposited waste (incl. aftercare) (in MJ/Mg) : Electricity consumption for the re-deposited waste. A typical range for the electricity consumption is about 10 – 80 MJ/Mg. *(as the present version of OnToL does not allow any re-deposition of the waste, this parameter is not used for any calculation and thus and cannot be edited)*

Fuel use for managing re-deposited waste (incl. aftercare) (in MJ/Mg): Fuel consumption for the re-deposited waste. It includes for instance the fuel consumption for the compaction of the waste. A typical range for the fuel consumption is about 20 – 120 MJ/Mg. *(as the present version of OnToL does not allow any re-deposition of the waste, this parameter is not used for any calculation and thus and cannot be edited)*

*Detailed data on fuel and electricity consumption can be found in Manfredi et al. 2009 ([https://pdfs.semanticscholar.org/5abe/2b7e0be8ebf9874220428e064837718aba90.pdf](https://pdfs.semanticscholar.org/5abe/2b7e0be8ebf9874220428e064837718aba90.pdf))*. 
B - Excavation, Sorting and Upgrading

By selecting **B – Excavation, Sorting and Upgrading**, as shown on the left of the picture under B-Landfill, the user can specify energy related data for the excavation, sorting and upgrading:

**Excavation - diesel consumption** (in MJ/Mg): Consumption of diesel to excavate 1 ton (Mg) of waste. Typical range: 30 – 50 MJ/Mg.

**Upgrading & sorting - diesel consumption** (in MJ/Mg): Consumption of diesel for upgrading and sorting 1 ton (Mg) of waste. Depending on the type of sorting (mobile, stationary, advanced stationary) diesel consumption may vary between 0 and 60 MJ/Mg.

**Upgrading & sorting - electricity consumption** (in MJ/Mg): Consumption of electricity for upgrading and sorting 1 ton (Mg) of waste. Depending on the type of sorting (mobile, stationary, advanced stationary) electricity consumption may vary between 0 and 50 MJ/Mg.

**Transport distance: Aggregates (ACM) to recycling facility/construction site** (in km): Transport distance of gravel and sand recovered from mining project (by sorting of excavated waste) to recycling facility, soil treatment or construction site.

**Transport distance: Plastics (Ro) to recycling facility** (in km): Transport distance of plastics recovered from mining project (by sorting of excavated waste) to recycling facility.
Transport distance: **NFe-scraps to recycling facility** (in km): Transport distance of NFe-scraps recovered from mining project (by sorting of excavated waste) to recycling facility.

Transport distance: **NFe-scraps to recycling facility** (in km): Transport distance of NFe-scraps recovered from mining project (by sorting of excavated waste) to recycling facility.

Transport distance: **Fe-scraps to recycling facility** (in km): Transport distance of Fe-scraps recovered from mining project (after sorting of excavated waste) to recycling facility.

Transport distance: **Combustibles (CCM) to thermal utilization** (in km): Transport distance of combustibles recovered from mining project (by sorting of excavated waste) to recycling facility.

Transport distance: **Fine material (FMr) to landfill** (in km): Transport distance of fine materials separated by sorting of excavated waste to landfill (to landfill that was mined or new landfill).

Transport distance: **Re-deposited material (RDW) to landfill** (in km) ... Transport distance of material that is re-deposited. (As the current version of OnToL does not allow any re-deposition of waste to the landfill which has been mined, this transport distance is irrelevant and cannot be edited)
B - Thermal Utilization

By selecting **B – Thermal Utilization** as shown on the left of the picture under B- Excavation, Sorting, Upgrading, the user can specify energy related data for the thermal utilization of the combustible waste.

*Default data about thermal utilization have to be inserted into the current version of the tool, even if no waste is combusted.*

**(Net) electricity efficiency** (in MJ out/MJ in): Net electricity efficiency of the waste-to-energy plant, meaning net electricity output referred to energy input via the waste (as lower heating value). If only electricity is produced a maximum net electricity efficiency of 0.3 can be assumed. In case that both electricity and heat are produced a significantly lower value is to be used.

**(Net) heat efficiency** (in MJ out/MJ in): Net heat efficiency of the waste to energy plant, i.e. net heat output referred to energy input via the waste (as lower heating value). If only heat (hot steam) is produced a maximum net heat efficiency of 0.85 can be assumed. If both electricity and heat are produced lower values should be applied. Typical range: net electricity efficiency: 0.15 with net heat efficiency of 0.65.

**Water consumed** (in m³/Mg of input): Specific water consumption of the waste incineration plant. The value depends on the type of flue gas cleaning system e.g., wet, dry or semi-dry air pollution control APC system. For dry APC a value of 0 can be assumed, whereas for wet APC a value between 0.3 to 1 m³/Mg of input is feasible.

**Hydrated lime (Ca(OH)2)** (in kg /Mg of input): Amount of hydrated lime used for the APC system and the associated waste water treatment plant. The consumption depends on the APC system and the wastewater treatment plant. The typical consumption may vary between 0.3 kg/Mg of input (for wet APC) and 15 kg/Mg of input (for dry APC).

**Limestone (CaCO3)** (in kg /Mg of input): Amount of hydrated lime used for associated wastewater treatment plant. The typical consumption may vary between 0 kg/Mg of input (dry APC) and 10 kg/Mg of input (wet APC).

**NH3** (in kg /Mg of input): Amount of ammonia used for the APC system. The consumption depends on the APC system and the wastewater treatment plant. The typical consumption may vary between 1 and 3 kg/Mg of input

**NaOH** (in kg /Mg of input): Amount of the hydrated lime used for the APC system and the associated wastewater treatment plant. The consumption of NaOH depends on the APC system and the wastewater treatment plant. The typical consumption may vary between 0.02 and 0.1 kg/Mg of input.

**Transport distance: Solid residues to ash treatment** (in km: Transport distance between the incineration plant and the (bottom) ash treatment facility.
B - Solid Residues Processing

*Default data about thermal utilization have to be inserted into the current version of OnToL, even if no waste is combusted.*

By selecting **B – Solid Residues Processing**, as shown on the left of the picture under **B-Thermal Utilization**, the user can specify energy related data for the processing of the solid residues generated during thermal waste utilization.

**Electricity consumption for processing** (in MJ/Mg of solid residues): Specific electricity consumption of the processing plant (incl. e.g. conveyer belts, sieves, magnetic separation, eddy current separation) for the incineration residues (e.g. bottom ash). The value may typically range between 30 and 50 MJ/Mg of solid residue (depending on the type of processing).

**Transport distance: NFe-scrap to recycling facility** (in km) refers to the distance between the bottom ash processing plant and the NFe-scrap melting plant.

**Transport distance: Fe-scrap to recycling facility** (in km) refers to the distance between the bottom ash processing plant and the Fe-scrap melting plant (steel industry).
Transport distance: Aggregates (RtR) to recycling (in km) refers to the distance between the bottom ash processing plant and the recycling plant/construction site for the aggregates recovered from bottom ash.

Transport distance: Bottom ash to landfill (AtL) external landfill (in km) refers to the distance between the bottom ash processing plant and the landfill where the bottom ash or part of it is landfilled.

Transport distance: Fly ash & APC residues to landfill (FA) (in km) refers to the distance between the waste incineration plant/residue processing plant and the landfill where fly ash & APC residues are landfilled.
B - Material Recycling

No energy related data have been specified.

---

B - Landfill New

By selecting B – Landfill New, as shown on the left of the picture under B-Material Recycling, the user can specify energy related data for the landfilling of waste/residues generated during the mining project at a (new) landfill other than the one mined can be specified.

Electricity use for managing residues (FMr) (incl. aftercare) (in MJ/Mg of waste): Electricity consumption for waste disposed of at a new landfill. Typical range for the electricity consumption: 10 – 40 MJ/Mg.

Fuel use for managing residues (FMr) (incl. aftercare) (in MJ/Mg of waste): Fuel consumption for waste disposed of at a new landfill. Typical range for the fuel consumption: 10 – 40 MJ/Mg.

---

10 “new” means that the landfill is different from the site to be mined

-28-
Fuel use for managing residues (FMr) (incl. aftercare) (in MJ/Mg of waste): Electricity consumption for waste disposed of at a new landfill. It includes for instance the fuel consumption for the compaction of the waste. Typical range for the fuel consumption: 35 – 120 MJ/Mg.

Electricity production efficiency for collected LFG (in MJ out/MJ in): Amount of electricity produced per MJ of lower heating value of the landfill gas collected. If no electricity out of landfill gas is produced at the “new” landfill, a value of 0 is to be used. In case that electricity is produced a value of up to 0.4 might be feasible.

Heat production efficiency for collected LFG (in MJ out/MJ in): Amount of electricity produced per MJ of lower heating value of the landfill gas collected. If no heat out of landfill gas is produced at the “new” landfill, a value of 0 is to be used. If heat is produced a value of up to 0.8 might be feasible.

Detailed data on fuel and electricity consumption can be found in Manfredi et al. 2009 (https://pdfs.semanticscholar.org/5abe/2b7e0be8ebf9874220428e064837718aba90.pdf)
B - Reference Case

**Net electricity production efficiency** (in case of LFG utilization) (in MJ electricity/MJ input): Specific electricity production from landfill gas LFG (referred to the lower heating value of landfill gas) at the landfill which should be mined (in case it is not mined). If landfill gas is not utilized for electricity production, the value is 0. If electricity is produced from the landfill gas collected, a maximum value of 0.4 is suggested.

**Net heat production efficiency (in case of LFG utilization)** (in MJ heat/MJ input): Specific heat production from collected landfill gas LFG (referred to the lower heating value of landfill gas) at the landfill to be mined (in case it is not mined). If landfill gas is not utilized for electricity production, the value is 0. In case that heat is produced out of the landfill gas collected, a maximum value of 0.8 is suggested.

**Electricity use (consumption for LFG and leachate management)** (in MJ/Mg of waste): Electricity consumption of the landfill (which should be mined, but which is not mined in the reference case) in order to collect and manage leachate and landfill gas. Typical range for the electricity consumption per year: 15 – 60 MJ/Mg.

**Fuel use (consumption for LFG and leachate management)** (in MJ/Mg of waste): Fuel (diesel) consumption of the landfill (which should be mined, but which is not mined in the reference case) in order to collect and manage leachate and landfill gas. The fuel consumption may range from 0 to 10 MJ/Mg depending on the landfill system and energy supply.
C-Climate

For all processes of the landfill mining project, climate related data (e.g. emission factors, landfill gas data) are to be specified. These data are required for assessing the climate impact of the landfill mining project.

C - Landfill

By selecting C – Landfill, the user can specify climate related data for the landfill to be mined and at which waste/residues from the mining project may be re-deposited. (The current version of OnToL does not allow any re-deposition of the waste at the landfill, which has been mined)

Annual amount of LFG during mining project (in m³/Mg.¹¹yr): Average annual amount of landfill gas produced during the mining project. Older landfills (landfill closure more than 10 years ago) may still contain significant quantities of organic waste. Therefore the annual amount of LFG may vary between 0.5 and 2 m³/Mg.yr.

If at the landfill, which is to be mined, a landfill gas collection system is in place (see question at A-Landfill – landfill gas collection in place (yes/no)), the user need also to estimate

- How much of the landfill gas generated is collected (landfill gas collection rate (in m³/m³)).
- How much of the collected methane is oxidized (destruction rate for collected methane (in m³/m³))
- What is the net electricity production efficiency (in MJ out/ MJ in)? It gives the amount of electricity produced (MJ out) from landfill gas referred to the lower heating value of the landfill gas collected (MJ in). It may range from 0 to max. 0.4.
- What is the net heat production efficiency (in MJ out/ MJ in)? It gives the amount of heat produced (MJ out) out of landfill gas referred to the lower heating value of the landfill gas collected (MJ in). It may range from 0 to max. 0.8.

Methane oxidation rate (in cover) (in m³/m³): Amount of methane oxidized in the cover layer of the landfill to be mined (referred to the amount of the landfill gas not collected at the landfill to be mined). The value may range between 0 to 0.6 m³/m³ (depending on the methane generation rate at the landfill and the substrate of the cover layer).

Climate impact of transport (in kg CO₂eq/tkm) of the excavated waste gives the specific CO₂ emissions per ton kilometre. It depends on the size of the truck and the density of the waste at the truck. The value may range between 0.17 kg CO₂eq/tkm (Transport, freight, lorry 16-32 metric ton, EURO5) and 0.52 kg CO₂eq/tkm (Transport, freight, lorry 3.5-7.5 metric ton, EURO5).

¹¹ Per Mg of total waste landfilled at the site
Climate impact of electricity production\textsuperscript{12} (in kg CO\textsubscript{2} eq/MJ) Specific CO\textsubscript{2} emissions per MJ of electricity consumed for activities related to landfill mining. It depends on the electricity production system in the respective country/region (e.g. share of hydropower, coal and gas power plants). Values for the climate impact of electricity production may range from 0.024 (high share of renewable energy) to 0.3 kg CO\textsubscript{2} eq/MJ (high share of fossil energy).

Climate impact of fuel combustion (incl. upstream burden) (in kg CO\textsubscript{2} eq/MJ): Specific CO\textsubscript{2} emissions per MJ of fuel (diesel) consumed. For diesel a value of 0.09 kg CO\textsubscript{2} eq/MJ is recommended.

Climate impact of heat production (in kg CO\textsubscript{2} eq/MJ): Specific CO\textsubscript{2} emission per MJ of heat consumed. The value depends on the energy system of the respective country/region. It may range between 0.005 kg CO\textsubscript{2} eq/MJ (heat production from wood chips) and 0.147 kg CO\textsubscript{2} eq/MJ (heat production from hard coal).

Landfill gas potential of the re-deposited waste (in m\textsuperscript{3}/Mg): Amount of landfill gas potential of waste/residues re-deposited at the landfill, which has been mined. It depends on the composition and on the age of waste/landfill. The value for waste from landfills containing a significant share of biogenic matter typically ranges from 20 to 60 m\textsuperscript{3}/Mg. (As the current version of OnToL does not allow any re-deposition of waste to the landfill, which has been mined, this transport distance is irrelevant and cannot be edited)

\textsuperscript{12} Data about the CO\textsubscript{2} eq intensity (given in g CO\textsubscript{2} eq/kWh) of electricity production can be found at https://www.eea.europa.eu/data-and-maps/indicators/overview-of-the-electricity-production-2/assessment-4 or https://www.electricitymap.org/?page=map&Solar=false&Remote=true&Wind=false or https://de.statista.com/statistik/daten/studie/233868/umfrage/co2-emissionen-bei-der-stromerzeugung-nach-erzeugungsart/ (data are to be converted to kg CO\textsubscript{2} eq/MJ by dividing the provided figures by 3600)
C - Excavation, Sorting, Upgrading

By selecting **C – Excavation, Sorting, Upgrading** on the picture on the left hand side just below C-Landfill, the user can specify climate related data for the excavation, sorting, upgrading of the mined waste.

**Climate impact of transport** (in kg CO\(_2\) eq/tkm) for

- **ACM** Aggregates derived from sorting of the excavated waste (for transport from sorting plant to material recycling)
- **Ro** Plastics derived from sorting of the excavated waste (for transport from sorting plant to plastics recycling)
- **NFM1** Non-Ferrous metals derived from sorting of the excavated waste (for transport from sorting plant to metal smelter)
- **FM1** Ferrous metals derived from sorting of the excavated waste (for transport from sorting plant to steel industry)
- **CCM** Combustible waste derived from sorting of the excavated waste (for transport from sorting plant to waste incineration plant)
- **FMr** Fine fraction derived from sorting of the excavated waste (for transport from sorting plant to landfill)
- **RDW** Re-deposited waste derived from sorting of the excavated waste (for transport from sorting plant/landfill to landfill) - value may be 0 (in case that sorting plant is located at the landfill which is mined) - *(As the current version of OnToL does not allow any re-deposition of waste to the landfill which has been mined, this transport distance is irrelevant and cannot be edited)*

The values may range between 0.17 kg CO\(_2\)eq/tkm (Transport, freight, lorry 16-32 metric ton, EURO5) and 0.52 kg CO\(_2\)eq/tkm (Transport, freight, lorry 3.5-7.5 metric ton, EURO5).

**Climate impact of electricity production** (in kg CO\(_2\) eq/MJ): Specific CO\(_2\) emission per MJ of electricity consumed. It depends on the electricity production system in the respective country/region (e.g. share of hydropower, coal and gas power plants). Values for the climate impact of electricity production may range from 0.024 (high share of renewable energy) to 0.3 kg CO\(_2\) eq/MJ (high share of fossil energy). – Typically the same value as used under C-Landfill for the climate impact of electricity production is to be chosen.

**Climate impact of fuel combustion (incl. upstream burden)** (in kg CO\(_2\) eq/MJ) gives the specific CO\(_2\) emission per MJ of fuel (diesel) consumed. For diesel a value of 0.09 kg CO\(_2\) eq/MJ is recommended.
C – Thermal Utilization

By selecting C – Thermal Utilization on the picture on the left hand side, the user can specify climate related data for the thermal utilization of the combustible waste.

**Climate impact of electricity production** (in kg CO₂ eq/MJ) gives the specific CO₂ emission per MJ of electricity consumed\(^\text{13}\). It depends on the electricity production system in the respective country/region (e.g. share of hydropower, coal and gas power plants). Values for the climate impact of electricity production may range from 0.024 (high share of renewable energy) to 0.3 kg CO₂ eq/MJ (high share of fossil energy). – *Typically the same value as used under C-Landfill for the climate impact of electricity production is to be chosen.*

**Climate impact of heat production** (in kg CO₂ eq/MJ) gives the specific CO₂ emission per MJ of heat consumed. The value depends on the energy system of the respective country/region. It may range between 0.005 kg CO₂ eq/MJ (heat production from wood chips) and 0.147 kg CO₂ eq/MJ (heat production from hard coal). *Typically the same value as used under C-Landfill for the climate impact of heaty production is to be chosen.*

\(^{13}\) The actual specific CO₂ emissions of the waste incineration plant are calculated using different data inserted. The data to be edited here, is used to assess the climate impact of the electricity consumption of the plant as well as to assess the net climate impact by comparing the specific CO₂ emissions of the waste incineration plant to the specific CO₂ emissions of the energy system of the respective country/region.
Climate impact of water consumption (in kg CO₂ eq/kg) gives the specific CO₂ emission per kg of water consumed. Depending on the water supply (e.g. pumping), the value may range from 0.001 to 0.005 kg CO₂ eq/kg.

Climate impact of hydrated lime (in kg CO₂ eq/kg) gives the specific CO₂ emission per kg of hydrated lime consumed. A value of 0.1 kg CO₂ eq/kg is recommended.

Climate impact of limestone (in kg CO₂ eq/kg) gives the specific CO₂ emission per kg of limestone consumed. A value of 0.03 kg CO₂ eq/kg is recommended.

Climate impact of ammonia NH₃ (in kg CO₂ eq/kg) gives the specific CO₂ emission per kg of ammonia consumed. A value of 2.9 kg CO₂ eq/kg is recommended.

Climate impact of Sodium hydroxide NaOH (in kg CO₂ eq/kg) gives the specific CO₂ emission per kg of Sodium hydroxide consumed. A value of 0.9 kg CO₂ eq/kg is recommended.

Climate impact of transport: Solid residues (in kg CO₂ eq/tkm) gives the specific CO₂ emission per ton kilometre of solid residues arising from thermal waste utilization. It depends on the size of the truck and the density of the waste at the truck. The value may range between 0.17 kg CO2eq/tkm (Transport, freight, lorry 16-32 metric ton, EURO5) and 0.52 kg CO2eq/tkm (Transport, freight, lorry 3.5-7.5 metric ton, EURO5).
C - Solid Residues Processing

By selecting C – Solid Residues Proc. on the picture on the left hand side, the user can specify climate related data for the processing of the solid residues arising from thermal waste utilization.

Climate impact of electricity production (in kg CO₂ eq/MJ) gives the specific CO₂ emission per MJ of electricity consumed. It depends on the electricity production system in the respective country/region (e.g. share of hydropower, coal and gas power plants). Values for the climate impact of electricity production may range from 0.024 (high share of renewable energy) to 0.3 kg CO₂ eq/MJ (high share of fossil energy). – Typically the same value as used under C-Landfill for the climate impact of electricity production is to be chosen.

Climate impact of transport (in kg CO₂ eq/tkm) for

- **NFM2** Non-Ferrous metals derived from processing of the solid residues from thermal waste utilization (for transport from processing to metal smelter)
- **FM2** Ferrous metals derived from processing of the solid residues from thermal waste utilization (for transport from processing to steel industry)
- **RtR** – Mineral fraction (derived processing of the solid residues from thermal waste utilization) sent to recycling (for transport from processing to recycling/construction site)
- **AtL** – Solid residues (derived from processing of the solid residues from thermal waste utilization) sent to landfill (for transport from processing to landfill)
- **FA** – Fly ash (derived from thermal waste utilization) sent to landfill (for transport from incineration plant to landfill)

The values may range between 0.17 kg CO₂ eq/tkm (Transport, freight, lorry 16-32 metric ton, EURO5) and 0.52 kg CO₂ eq/tkm (Transport, freight, lorry 3.5-7.5 metric ton, EURO5).
C - Material Recycling

By selecting **C – Material Recycling** on the picture on the left hand side, the user can specify climate related data for the recycling of materials recovered during the landfill mining project.

The different commodities the following entries for the climate impact (distinguishing between primary and secondary production) are recommended. The data are based on the ecoinvent database.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary steel production</td>
<td>2.21</td>
<td>kg CO2 eq/kg</td>
</tr>
<tr>
<td>Secondary steel production</td>
<td>1.27</td>
<td>kg CO2 eq/kg</td>
</tr>
<tr>
<td>Primary Cu production</td>
<td>4.1</td>
<td>kg CO2 eq/kg</td>
</tr>
<tr>
<td>Secondary Cu production</td>
<td>3.25</td>
<td>kg CO2 eq/kg</td>
</tr>
<tr>
<td>Primary Al production</td>
<td>13.82</td>
<td>kg CO2 eq/kg</td>
</tr>
<tr>
<td>Secondary Al production</td>
<td>2.18</td>
<td>kg CO2 eq/kg</td>
</tr>
<tr>
<td>Primary plastic production</td>
<td>1.88</td>
<td>kg CO2 eq/kg</td>
</tr>
<tr>
<td>Secondary plastic production</td>
<td>0.35</td>
<td>kg CO2 eq/kg</td>
</tr>
<tr>
<td>Gravel production</td>
<td>0.005</td>
<td>kg CO2 eq/kg</td>
</tr>
</tbody>
</table>
C - Landfill New

By selecting C – Landfill New on the picture on the left hand side, the user can specify climate related data for the “new” landfill receiving waste and residues from the landfill mining project.

Landfill gas potential of residues (FMr) (in m³/Mg) gives the amount of landfill gas potential of the fine fraction separated during the sorting of the waste and disposed of at a “new” landfill or at the site where the mining project was conducted. The value for the landfill gas potential of the fine fraction may typically range between 10 to 50 m³/Mg.

*Note: based on the composition of the residues/fines (defined via the composition of the landfilled waste and the transfer coefficients for the excavation, sorting and processing), OnToL assesses a default value for the landfill gas potential of the residues (given as Suggested value from fgc3). The user however, can specify another value.*

Climate impact of electricity production (in kg CO₂ eq/MJ) gives the specific CO₂ emission per MJ of electricity consumed. It depends on the electricity production system in the respective country/region (e.g. share of hydropower, coal and gas power plants). Values for the climate impact of electricity production may range from 0.024 (high share of renewable energy) to 0.3 kg CO₂ eq/MJ (high share of fossil energy). *Typically the same value as used under C-Landfill for the climate impact of electricity production is to be chosen.*

Climate impact of fuel combustion (incl. upstream burden) (in kg CO₂ eq/MJ) gives the specific CO₂ emission per MJ of fuel (diesel) consumed. For diesel a value of 0.09 kg CO₂ eq/MJ is recommended.

Climate impact of heat production (in kg CO₂ eq/MJ) gives the specific CO₂ emission per MJ of heat consumed. The value depends on the energy system of the respective country/region. It may range between 0.005 kg CO₂ eq/MJ (heat production from wood chips) and 0.147 kg CO₂ eq/MJ (heat production from hard coal). *Typically the same value as used under C-Landfill for the climate impact of heat production is to be chosen.*

Climate impact of landfilling of AtL (in kg CO₂ eq/kg) gives the specific CO₂ emission per kg of bottom ash landfilled. A value of 0.0034 kg CO₂ eq/kg bottom ash is recommended.

Climate impact of landfilling of FA (in kg CO₂ eq/kg) gives the specific CO₂ emission per kg of fly ash landfilled. A value of 0.0034 kg CO₂ eq/kg fly ash is recommended.

Collection rate of landfill gas (for residues, FMr) (in m³/m³): Rate of landfill gas collected at the “new” landfill, where the residues of the landfill mining processes are disposed of.

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14 “new” means that the landfill is different from the site to be mined
Methane oxidation rate in landfill cover (for residues, FMr) (in m³/m³): Amount of methane oxidized in the cover layer of the new landfill, corresponding to the amount of uncollected landfill gas at the new landfill.

Methane destruction rate (for collected LFG) (in m³/m³): Rate of methane combusted/oxidized at the new landfill in relation to the collected methane amount at this landfill. A methane destruction rate of 1 means that all methane collected is oxidized to CO₂ and H₂O.

C – Reference Case

By selecting **C – Reference case** on the picture on the left hand side, the user can specify climate related data for the landfill that is supposed to be mined. The data entered here refer to the case when the landfill is not mined, so the reference case is used for comparing the landfill mining scenario with the situation of not mining.

Remaining landfill gas potential (in m³/Mg) gives the amount of landfill gas potential of the waste present at the landfill (which is supposed to be mined) at the proposed time of mining. It depends on the composition and on the age of waste/landfill. The value for waste from landfills containing significant amount of biogenic matter may typically range between 20 to 80 m³/Mg waste.
Note: based on the composition of the waste landfilled at the site, which is to be mined, OnToL assesses a default value for the landfill gas potential of the residues (given as Suggested value from rc1). The user however, can specify another value.

**Climate impact of electricity production** (in kg CO₂ eq/MJ) gives the specific CO₂ emission per MJ of electricity consumed. It depends on the electricity production system in the respective country/region (e.g. share of hydropower, coal and gas power plants). Values for the climate impact of electricity production may range from 0.024 (high share of renewable energy) to 0.3 kg CO₂ eq/MJ (high share of fossil energy). – Typically the same value as used under C-Landfill for the climate impact of electricity production is to be chosen.

**Climate impact of fuel combustion (incl. upstream burden)** (in kg CO₂ eq/MJ) gives the specific CO₂ emission per MJ of fuel (diesel) consumed. For diesel a value of 0.09 kg CO₂ eq/MJ is recommended.

**Climate impact of heat production** (in kg CO₂ eq/MJ) gives the specific CO₂ emission per MJ of heat consumed. The value depends on the energy system of the respective country/region. It may range between 0.005 kg CO₂ eq/MJ (heat production from wood chips) and 0.147 kg CO₂ eq/MJ (heat production from hard coal). Typically the same value as used under C-Landfill for the climate impact of heat production is to be chosen.

**Methane content of landfill gas (LFG)** (in m³/m³): Share of methane contained in the landfill gas of the landfill to be mined (usually a value of 0.5 is assumed).

**Collection rate of LFG** (in m³/m³) Rate of landfill gas collected at the landfill to be mined.

**Methane oxidation rate in cover** (in m³/m³): Amount of methane oxidized in the cover layer of the landfill to be mined corresponding to the amount of uncollected landfill gas at this landfill.

**Methane destruction rate of collected LFG** (in m³/m³): Rate of methane combusted/oxidized at the landfill that should be mined in relation to the collected methane amount at this landfill. A methane destruction rate of 1 means that all methane collected is oxidized to CO₂ and H₂O.

Note: If no gas collection system is in place at the landfill to be mined (see input at A-Landfill), the following parameter cannot be edited: **Climate impact of electricity production**, **Climate impact of heat production**, **Collection rate of LFG**, and **Methane destruction rate of collected LFG**.
C – General data

By selecting **C – General data** on the picture on the left hand side, the user can specify the climate impact of different climate gases.

The following characterization factors for 100-year Global Warming Potential GWP are currently recommended (based on IPCC). If shorter time periods (e.g. 20-year GWP) are considered, a significantly higher value for CH4 (82 kg CO2 eq/kg) is to be used.

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Characterization factor: CO2\textsubscript{fossil}</td>
<td>1</td>
<td>kg CO2 eq/kg</td>
</tr>
<tr>
<td>Characterization factor: CO2\textsubscript{biogenic}</td>
<td>0</td>
<td>kg CO2 eq/kg</td>
</tr>
<tr>
<td>Characterization factor: CH4</td>
<td>28</td>
<td>kg CO2 eq/kg</td>
</tr>
<tr>
<td>Characterization factor: N2O</td>
<td>265</td>
<td>kg CO2 eq/kg</td>
</tr>
</tbody>
</table>
D - Economy

Economics (costs and revenues) of the landfill mining project are to be specified.

D - Landfill

By selecting D – Landfill on the picture on the left hand side, the user can specify economic data associated with the landfill to be mined.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Possible values</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land value(^{15})</td>
<td>Price of the regained land (by the mining project) ... depending on the location of the landfill and the land price in the surroundings</td>
<td>50</td>
<td>Euro/m(^2)</td>
</tr>
<tr>
<td>Void space value(^{16})</td>
<td>Price of the regained landfill space (by the mining project)</td>
<td>20</td>
<td>Euro/m(^3)</td>
</tr>
<tr>
<td>Leachate treatment costs</td>
<td>Costs for treating leachate generated at the landfill which is to be mined.</td>
<td>20</td>
<td>Euro/m(^3) of leachate</td>
</tr>
<tr>
<td>Gas collection and treatment costs</td>
<td>Costs for collecting and treating landfill gas generated at the landfill which is to be mined.</td>
<td>0.4</td>
<td>Euro/m(^2) of landfill area and year</td>
</tr>
<tr>
<td>Price of heat (produced)</td>
<td>Selling price for heat generated by utilizing landfill gas at the landfill which is to be mined.</td>
<td>5</td>
<td>Euro/GJ</td>
</tr>
<tr>
<td>Price of electricity (produced)</td>
<td>Selling price for electricity generated by utilizing landfill gas at the landfill which is to be mined.</td>
<td>12</td>
<td>Euro/GJ</td>
</tr>
<tr>
<td>Price of heat (consumed)</td>
<td>Purchasing price for heat at the landfill which is to be mined.</td>
<td>6.25</td>
<td>Euro/GJ</td>
</tr>
<tr>
<td>Price of electricity (consumed)</td>
<td>Purchasing price for electricity at the landfill which is to be mined.</td>
<td>15</td>
<td>Euro/GJ</td>
</tr>
<tr>
<td>Price of diesel</td>
<td>Purchasing price for diesel</td>
<td>1.2</td>
<td>Euro/l</td>
</tr>
<tr>
<td>Transport costs</td>
<td>Price for transporting 1 ton (of waste/material) for 1 km</td>
<td>0.1</td>
<td>Euro/tkm</td>
</tr>
<tr>
<td>Management costs of re-deposition (incl. potential landfill tax)</td>
<td>Specific costs for re-deposition of excavated waste/residues at the landfill</td>
<td>40</td>
<td>Euro/Mg re-deposited</td>
</tr>
</tbody>
</table>

\(^{15}\) Can only be defined, if under A-Landfill (Bottom 3) – project drivers, the options **Material & land recovery** or **Land recovery** were chosen.

\(^{16}\) Can only be defined if under A-Landfill (Bottom 3) – project drivers, the option **Material & Void space recovery** was chosen.
Annual landfill operation (long-term) | Annual operational costs of landfill per m² | 1.5 | Euro/m².yr
---|---|---|---
Cost of final cover for redeposited waste | Specific cost for final cover which is necessary to cover the redeposited waste at the landfill | 50 | Euro/m²

(As the current version of OnToL does not allow any re-deposition of waste to the landfill which has been mined, the last 3 parameter of the table are irrelevant and cannot be edited)

---

D-Excavation, Sorting, Upgrading

By selecting D – Excavation, Sorting, Upgrading on the picture on the left hand side, the user can specify economic data associated with the excavation, sorting and upgrading of the waste mined.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Possible Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excavation - investment</td>
<td>Specific investment costs for excavating the landfill (e.g. costs for excavator, trucks), referred to annual excavation capacity.</td>
<td>8.5 (5 – 20)</td>
<td>Euro/Mg of annual waste excavation capacity</td>
</tr>
<tr>
<td>Description</td>
<td>Specific Operational Costs</td>
<td>Rate</td>
<td>Description</td>
</tr>
<tr>
<td>----------------------------------------------------------------------------</td>
<td>---------------------------</td>
<td>--------------</td>
<td>----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Excavation - Maintenance &amp; Repair, Admin &amp; Insurance (or rental costs in case that existing equipment is rented)</td>
<td>Specific “operational” costs for excavating the landfill <strong>excluding electricity &amp; fuel costs</strong></td>
<td>0.85 (0.5 -2)</td>
<td>In case rental equipment is used the value might be significantly larger than 2</td>
</tr>
<tr>
<td>Excavation - labour costs</td>
<td>Specific labour costs for excavating the landfill</td>
<td>3 (2 – 7)</td>
<td>Euro/Mg excavated</td>
</tr>
<tr>
<td>Upgrading &amp; sorting - investment</td>
<td>Specific investment costs for sorting &amp; upgrading the excavated waste (e.g. costs for sieves, magnetic separator, eddy current separator), referred to annual waste input into the plant.</td>
<td>14/20/28</td>
<td>In case existing plants are rented the value is 0</td>
</tr>
<tr>
<td>Upgrading &amp; sorting - repair &amp; maintenance, Admin &amp; Insurance (or rental costs in case that existing plants are rented)</td>
<td>Specific “operational” costs for sorting &amp; upgrading the excavated waste <strong>excluding electricity &amp; fuel costs</strong></td>
<td>1.4/2/2.8</td>
<td>In case existing plants are rented the value might be in the range of 10 to 40</td>
</tr>
<tr>
<td>Upgrading &amp; sorting - labour costs</td>
<td>Specific labour costs for sorting &amp; upgrading the landfill</td>
<td>2 (1 – 5)</td>
<td>Euro/Mg excavated</td>
</tr>
<tr>
<td>Excavation: share of investment costs related to machinery</td>
<td>gives the share of investment costs for machinery in relation the total investment costs for the excavation. This information is subsequently used to assess the residual value of the machinery at the end of the project.</td>
<td>0.85</td>
<td>In case rental equipment is used the value is 0</td>
</tr>
<tr>
<td>Sorting &amp; Upgrading: share of investment costs related to machinery</td>
<td>gives the share of investment costs for machinery in relation the total investment costs for</td>
<td>0.8</td>
<td>Euro/Euro</td>
</tr>
</tbody>
</table>

17 Mobile plant: 14 Euro/Mg, stationary plan: 20/Euro/Mg and advanced stationary plant: 28 Euro/Mg
18 Mobile plant: 1.4 Euro/Mg, stationary plan: 2.0/Euro/Mg and advanced stationary plant: 2.8 Euro/Mg
the sorting & upgrading. This information is subsequently used to assess the residual value of the machinery at the end of the project.

<table>
<thead>
<tr>
<th><strong>Price of electricity</strong> (consumed)</th>
<th>Purchasing price for electricity at the landfill and/or sorting &amp; upgrading plant</th>
<th>15</th>
<th>(10 – 20)</th>
<th>Euro/GJ</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Price of diesel</strong></td>
<td>Purchasing price for diesel</td>
<td>1.2</td>
<td>(1 – 1.4)</td>
<td>Euro/l</td>
</tr>
<tr>
<td><strong>Transport costs</strong></td>
<td>Price for transporting 1 ton (of waste/material) for 1 km</td>
<td>0.1</td>
<td>(0.05 – 0.2)</td>
<td>Euro/tkm</td>
</tr>
<tr>
<td><strong>Costs for hazardous waste disposal (transport included)</strong></td>
<td>Price for the disposal of hazardous waste excavated (incl. transportation costs)</td>
<td>250</td>
<td>(150 – 400)</td>
<td>Euro/Mg</td>
</tr>
</tbody>
</table>
D - Thermal Utilization

By selecting D – Thermal Utilization on the picture on the left hand side, the user can specify economic data associated with the thermal utilization of the combustible waste derived from the sorting and upgrading of the waste mined.

WtE plant is external (gate fee) or internal (external/internal): the user can specify whether the Waste to Energy WtE plant belongs to the consortium of the landfill mining project (internal) or not (external). In case external is chosen, the user just needs to specify the gate fee for thermal utilization (in Euro/Mg), the other parameter are then not editable. The gate fee may range between 60 to 140 Euro/Mg. The gate fee includes also the processing of the solid residues arising after incineration.

In case internal is chosen, the user needs to specify specific costs and revenues for

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Possible Values</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating &amp; investment costs of WtE</td>
<td>Specific operating and investment costs of WtE plants (referred to Mg of waste input)</td>
<td>120 (100 – 200)</td>
<td>Euro/Mg of input</td>
</tr>
<tr>
<td>Price of heat (produced)</td>
<td>Selling price for the heat generated</td>
<td>5 (3 – 6)</td>
<td>Euro/GJ</td>
</tr>
<tr>
<td>Price of electricity (produced)</td>
<td>Selling price for the electricity generated</td>
<td>12 (8 – 18)</td>
<td>Euro/GJ</td>
</tr>
<tr>
<td>Transport costs</td>
<td>Specific transport costs for solid residues in Euro per ton and kilometre</td>
<td>0.1 (0.05 – 0.2)</td>
<td>Euro/tkm</td>
</tr>
</tbody>
</table>
D - Solid Residues Processing

By selecting **D – Solid Residues Processing** on the picture on the left hand side, the user can specify economic data associated with the processing of solid residues generated during thermal utilization of the combustible waste.

Economic data for **Solid Residues Processing** can only be inserted, if under D-Thermal Utilization the WtE plant has been specified as internal. If external for the WtE plant was chosen, all costs related to the solid residues processing are already considered in the gate fee, specified under D-Thermal Utilization.

If internal for the WtE plant (under D-Thermal Utilization) was chosen, the following specific costs are to defined:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Possible Values</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific costs for ash treatment</td>
<td>Specific treatment costs for incineration residues (bottom ash) - excl. energy costs for running the processing plant</td>
<td>15 (10 – 35)</td>
<td>Euro/Mg</td>
</tr>
<tr>
<td>Price of electricity (consumed)</td>
<td>Purchasing price for electricity at the plant for processing solid residues from thermal waste utilization</td>
<td>15 (10 – 18)</td>
<td>Euro/GJ</td>
</tr>
<tr>
<td>Transport costs</td>
<td>Price for transporting 1 ton (of solid residues from thermal waste utilization) for 1 km</td>
<td>0.1 (0.05 – 0.2)</td>
<td>Euro/tkm</td>
</tr>
</tbody>
</table>

---

19 Such as Fe scrap or Cu scrap
D - Material Recycling

By selecting **D – Material Recycling** on the picture on the left hand side, the user can specify economic data associated with the recycling of different materials recovered during the landfill mining project.

In particular, selling prices for the following materials/commodities are to be specified:

<table>
<thead>
<tr>
<th>Materials</th>
<th>Description</th>
<th>Possible Values</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel scrap</td>
<td>Selling price for steel scrap recovered during waste sorting and/or processing of incineration residues (per ton of steel scrap)</td>
<td>100 (30 – 200)</td>
<td>Euro/Mg</td>
</tr>
<tr>
<td>Al scrap</td>
<td>Selling price for Aluminium scrap recovered during waste sorting and/or processing of incineration residues (per ton of Al scrap)</td>
<td>600 (400 – 1300)</td>
<td>Euro/Mg</td>
</tr>
<tr>
<td>Cu scrap</td>
<td>Selling price for copper scrap recovered during waste sorting and/or processing of incineration residues (per ton of Cu scrap)</td>
<td>3500 (2000 – 6000)</td>
<td>Euro/Mg</td>
</tr>
<tr>
<td>Plastics (recyclable)</td>
<td>Selling price for recyclable plastics (per ton of recyclable plastics)</td>
<td>50 (0 – 200)</td>
<td>Euro/Mg</td>
</tr>
<tr>
<td>Sec. Aggregates</td>
<td>Selling price for secondary aggregates (stones, gravel, sand) recovered from the landfill mining project (per ton of sec. aggregates))</td>
<td>1 (0 – 4)</td>
<td>Euro/Mg</td>
</tr>
</tbody>
</table>

Actual commodities prices for secondary resources (e.g. Fe-scrap) can be accessed at different websites. However, it is recommended not to use actual prices, but long term prices, as commodities prices are very volatile and landfill mining projects usually run over longer time periods.
By selecting **D – Landfill New** on the picture on the left hand side, the user can specify economic data associated with the landfilling of waste/residues from the mining project at a “new” landfill site.

The following specific costs (gate fees) are to be defined:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gate fee - Landfill for fines &amp; residues (FMr)</td>
<td>Gate fee for landfilling fines and residues derived during the sorting of the excavated waste (per ton of waste/residues)</td>
<td>50</td>
<td>Euro/Mg deposited</td>
</tr>
<tr>
<td>Gate fee - Landfill for inert waste (AtL)</td>
<td>Gate fee for landfilling non-hazardous residues (e.g. bottom ash) generated during thermal utilization of the combustible waste (per ton of ash)</td>
<td>50</td>
<td>Euro/Mg deposited</td>
</tr>
<tr>
<td>Gate fee - Landfill for fly ash (FA)</td>
<td>Gate fee for landfilling fly ash generated during thermal utilization of the combustible waste (per ton of fly ash)</td>
<td>200</td>
<td>Euro/Mg deposited</td>
</tr>
</tbody>
</table>

---

20 “new” means that the landfill is different from the site mined.
D - Reference Case

By selecting **D – Landfill New** on the picture on the left hand side, the user can specify economic data (costs and revenues) associated with the landfill (that should be mined) in case that the landfill is not mined.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Possible Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leachate treatment costs</td>
<td>Costs for treating leachate generated at the landfill (in case it is not</td>
<td>20</td>
<td>Euro/m³ of leachate</td>
</tr>
<tr>
<td></td>
<td>mined).</td>
<td>(0 – 40)</td>
<td></td>
</tr>
<tr>
<td>Gas treatment costs</td>
<td>Annual specific costs for collecting and treating landfill gas generated</td>
<td>0.5</td>
<td>Euro/m² of landfill area and year</td>
</tr>
<tr>
<td></td>
<td>at the landfill (in case it is not mined).</td>
<td>(0 – 1)</td>
<td></td>
</tr>
<tr>
<td>Costs for final cover (and potentially</td>
<td>Specific costs for final cover (if necessary) and potential stabilization</td>
<td>50</td>
<td>Euro/m² of landfill area</td>
</tr>
<tr>
<td>potentially stabilization)</td>
<td>measures at the landfill (in case it is not mined).</td>
<td>(0 – 70)</td>
<td></td>
</tr>
<tr>
<td>Costs for maintenance and monitoring (after</td>
<td>Annual specific cost for maintenance and monitoring of the landfill</td>
<td>1</td>
<td>Euro/m² of landfill area and year</td>
</tr>
<tr>
<td>final closure)</td>
<td>(in case it is not mined).</td>
<td>(0 – 2)</td>
<td></td>
</tr>
<tr>
<td>Price of heat (produced)</td>
<td>Selling price for heat generated by utilizing landfill gas at the landfill</td>
<td>5</td>
<td>Euro/GJ</td>
</tr>
<tr>
<td></td>
<td>(in case it is not mined).</td>
<td>(3 – 6)</td>
<td></td>
</tr>
<tr>
<td>Price of electricity (produced)</td>
<td>Selling price for electricity generated by utilizing landfill gas at the</td>
<td>12</td>
<td>Euro/GJ</td>
</tr>
<tr>
<td></td>
<td>landfill (in case it is not mined).</td>
<td>(8 – 18)</td>
<td></td>
</tr>
</tbody>
</table>

---

21 In case it is planned to install a final cover at the site, if it is not mined.
D- General Data

By selecting **D – General data** on the picture on the left hand side, the user can specify general economic data used for the economic evaluation of the landfill mining project.

In particular, the following parameter are to be defined:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Possible value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Discount rate</strong></td>
<td>Discount rate for the project expenses and revenues (used to assess the net present value(^22) of the landfill mining project). The discount rate depends on the perspective of the project (a private investor will demand a higher discount rate than a public investor)</td>
<td>0.05</td>
<td>Euro/Euro</td>
</tr>
<tr>
<td><strong>Depreciation rate of machinery/equipment</strong></td>
<td>Depreciation rate of the machinery and equipment used for excavating, sorting</td>
<td>0.1</td>
<td>Euro/Euro</td>
</tr>
</tbody>
</table>

\(^{22}\) In case that the project contains an intermediate use of the landfill (prior mining), the net present value is calculated for the first year of intermediate use. In case that there is no intermediate use, the net present values is calculated for the first year of the mining project.
and upgrading of the waste (depends on the life time of the machinery)

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Costs</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permitting costs</td>
<td>Permitting costs of the project (e.g., costs for environmental impact assessment, costs of permitting authorities)</td>
<td>25000 (10000 – 100000)</td>
<td>Euro</td>
</tr>
<tr>
<td>Project planning and preparation costs</td>
<td>Costs for project planning, design (e.g., consultancy work, waste sampling and preparation costs)</td>
<td>50000 (depending on the size and location of the site)</td>
<td>Euro</td>
</tr>
<tr>
<td>Purchase of site</td>
<td>Costs for purchase of site (if necessary) at the beginning of the landfill mining project</td>
<td>depending on the size and location of the site</td>
<td>Euro</td>
</tr>
<tr>
<td>Installations useful for redevelopment</td>
<td>Costs for installations (such as access roads, swage or water networks) useful for redevelopment (after the landfill mining project has been completed)</td>
<td>20000 (depending on the size and location of the site)</td>
<td>Euro</td>
</tr>
<tr>
<td>Costs for Landscaping</td>
<td>Costs for landscaping (after the landfill mining project has been completed)</td>
<td>20000 (depending on the size and location of the site)</td>
<td>Euro</td>
</tr>
<tr>
<td>Env. supervision &amp; overhead costs</td>
<td>Costs for environmental supervision and overhead (after the landfill mining project has been completed)</td>
<td>10000 (0 – 50000)</td>
<td>Euro</td>
</tr>
</tbody>
</table>

In case of intermediate use\(^2\) the following costs have to be defined additionally:

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
<th>Costs</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment costs of intermediate use</td>
<td>Costs for necessary investments to enable the intended intermediate use of the landfill (e.g. costs for the installation of solar panels)</td>
<td></td>
<td>Euro</td>
</tr>
<tr>
<td>Annual costs of intermediate use</td>
<td>Annual costs for the intended intermediate use of the landfill (e.g. costs for maintenance of solar panels)</td>
<td></td>
<td>Euro/year</td>
</tr>
<tr>
<td>Annual revenues of intermediate use</td>
<td>Annual revenues for the intended intermediate use of the landfill (e.g. revenues from the electricity produced by solar panels installed at the landfill)</td>
<td></td>
<td>Euro/year</td>
</tr>
<tr>
<td>End of life costs of intermediate use</td>
<td>End of life costs for the intended intermediate use of the landfill (e.g. costs for the de-installation and disposal of solar panels)</td>
<td></td>
<td>Euro</td>
</tr>
</tbody>
</table>

Site-specific values could be beyond the ranges given in brackets

---

\(^2\) Prior mining, the landfill (area) is used for another purpose (e.g., parking lot, park, installation of solar panels)
Costs and revenues related to the intermediate use are assumed to start “immediately” (in the first year of evaluation).
Additional features (check of input data)

In order to check in the input data, the following features of OnToL can be used.

**Outputs**

By clicking on the button Outputs, the tool displays calculation results directly connected to the input data of the specific sheet (e.g., A-Landfill, B-Thermal Utilization). This function helps to crosscheck the user’s input data. By clicking again on the button Outputs, the calculation results disappear again.
Furthermore, the user can display information about the flows of wastes and different materials (given in tons/year) by pointing with the cursor to the respective flows in the figure.

If all required input data have been specified, the colour of the different processes (A-Landfill, A-Thermal Utilization, C-Excavation, Sorting, Upgrading) turns from grey into green, blue, red, ...
Results of OnToL

By clicking on the button Results, the tool calculates the overall results of the landfill mining project (waste and material flows, greenhouse gas emissions and economy of the project). A new Tab (named: results + name of the project) opens, which summarizes all results.

A new tab (named: results + name of the project) opens, which summarizes all results of the projects.

The results of the evaluation can also be exported as excel spreadsheet via the button XLSX.
1-Results on the physical flows

First, the results with respect to the waste and material flows of the project are summarized. Besides a graph showing the flows of the material and their total quantities, the results sections contains also a table summarizing this information (on an annual basis indicated by Mg/yr and for the whole project duration indicated by Mg).

For instance for the herein presented case study, 76,318 tons of residues are landfilled at an external/new landfill.
2-Results on climate impact

The results on the climate impact of the project are summarized in table form under 2-Results on climate impact.

The burdens and savings of climate gases are expressed in CO₂-equivalents and are given for the different processes of the project. In particular, the flows’ burdens and savings are distinguished:

**Burdens/emissions:**

**Direct emissions** include greenhouse gas emissions GHG that result from the waste itself (e.g. landfill gas).

**Indirect emissions** include GHG emissions that result from the energy supply of the different processes (e.g. energy demand for leachate treatment).

**Avoided savings** include basically GHG emissions that would have been avoided in the reference case (e.g. substituted fossil fuels by utilizing landfill gas).

**Savings:**

**Savings** include avoided GHG emissions by substituting fossil fuel or primary raw materials.

**Avoided direct emissions** include direct emissions (from the waste itself) that are avoided by the LFM project.

**Avoided indirect emissions** include indirect emissions (results from energy supply of the different processes) that are avoided by the LFM project.

*For the herein presented case study, the landfill mining project avoids direct emissions of 48,750 Mg CO₂ eq (results from the reference case). These are emissions of landfill gas (methane), which would have occurred if the landfill would have not been mined. The avoided indirect emissions amount to 340 Mg CO₂ eq. These avoided emissions are associated to the collection and treatment of leachate and landfill gas, in case that the landfill would have not been mined (reference case).*

*During the mining project, direct emissions (in form of landfill gas emitted during the project duration) of 726 Mg CO₂ eq occur. In addition, there are indirect emissions of 72 Mg CO₂ eq (resulting from the energy consumption for leachate and landfill gas collection and treatment) during the period of landfill mining.*
The excavation and sorting of the waste produces (due to fuel and electricity consumption) indirect emissions of 856 Mg CO$_2$ eq.

The thermal utilization of the combustible fraction causes on the one hand direct emissions of 5883 Mg CO$_2$ eq (which refers to the fossil CO$_2$ emissions of the waste to energy plant). In addition, there are indirect emissions of 72 Mg CO$_2$ eq due to the consumption of electricity and additives for the operation of the waste incineration plant. On the other hand, the energy production (heat and/or electricity) of the waste to energy plant saves CO$_2$ emissions of 7496 Mg CO$_2$ eq (due to substitution of other energy carriers required to produce the same amount of heat and/or electricity as the waste to energy plant).

The disposal of the residues/fines of the mining project at the “new” landfill generates 42,714 Mg CO$_2$ eq (due to the emissions of landfill gas). Further, at the “new” landfill indirect emissions (due to the energy demand for leachate and landfill gas collection and treatment) of 626 Mg CO$_2$ eq occur.

The transport of all wastes and materials causes indirect emissions of 730 Mg CO$_2$ eq (due to fuel/diesel consumption).

The total climate burdens amount to about 51,700 Mg CO$_2$ eq, whereas the total savings of greenhouse gases amount to about 62,900 Mg CO$_2$ eq. Hence, the project saves$^{25}$ in total 11,200 Mg CO$_2$ eq. Hence, it has a negative climate impact (savings are larger than burdens). The specific net climate impact SNCI amounts to -0.112 Mg CO$_2$ eq per ton waste excavated.

From a climate perspective, the presented landfill mining project should be conducted, as it reduces the overall emissions of greenhouse gases.

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$^{24}$ Combustion of plastics present in the combustibles

$^{25}$ Savings are indicated by negative values
The results of the climate impact assessment are summarized in a subsequent graph and table.
3-Results on the economy of LFM project

The results on the economy impact of the project are summarized in table form under 3-Results on the economy of LFM project.

In particular, initial costs (occurring at the beginning or prior the start of the mining project), annual costs during the mining project, annual costs after the mining project, one-time costs at the end of the project as well as annual revenues during the project and revenues at the end of the project are distinguished.

Initial costs include

- initial costs for intermediate use (e.g., installation costs for solar panels) – in case there is an intermediate use of the landfill prior its mining
- costs for planning and permits of the landfill mining project
- costs for the purchase of the site and installations (other than those required for intermediate use)
- investment costs for excavation, sorting and upgrading (e.g. investment costs for machinery, sorting plants)

Annual costs during the project include:

- annual costs for the intermediate use (e.g., costs for rents, costs for maintenance of solar panels) - during the time of intermediate use
- annual costs for landfill management - during the time of landfill mining (e.g., costs for the collection and treatment of leachate at the landfill site which is mined)
- annual operational costs for excavation, sorting, upgrading - during the time of landfill mining (e.g., costs for maintenance of machinery, fuel costs, electricity costs, labour costs)
- annual costs for thermal treatment of combustibles recovered - during the time of landfill mining (e.g., gate fees for the treatment of combustibles)
- annual costs for the processing of solid residues generated during thermal treatment (in case that the waste to energy plant is considered as “external” plant (with gates fees), the costs for solid residues processes are accounted for by the annual costs for thermal treatment)
- annual disposal costs or landfilling costs, which include all costs related to the final disposal of residues/fines, hazardous waste and residues derived from thermal treatment.
- annual transport costs, which include the costs of all transports necessary within the project
Annual costs after the end of the project:

If waste/residues are re-deposited at the landfill site, which has been mined, annual aftercare costs for this re-deposition (such as costs for leachate treatment or gas collection) are summarized. In the present version of OnToL however, no re-deposition of the waste at the same site can be considered. Hence, annual costs after the end of the project are 0.

One-time costs at the end of the project include:

- Costs for the installation of a final cover (if waste has been re-deposited at the landfill site, which has been mined). In the present version of OnToL however, no re-deposition of the waste at the same site can be considered. Hence, one-time costs after the end of the project are 0.
- Costs for Landscaping, environmental supervision and overhead arising after the end of the landfill mining project.
- End-of-life Costs for intermediate use at the end of the intermediate use (e.g., de-installation costs, waste management costs for solar panels) – in case there is an intermediate use of the landfill prior its mining.

Annual revenues during the project include:

- annual revenues by und during intermediate use (e.g. valorisation of electricity generated by solar panels) – in case there is an intermediate use of the landfill prior its mining.
- annual revenues by the landfill itself during intermediate use (e.g., vaporization of electricity generated by the collected landfill gas).
- annual revenues by the valorisation of electricity and heat generated by the collected landfill gas at the landfill site during the time of mining.
- annual revenues by the valorisation of electricity and heat generated by the thermal utilization of combustibles (in case that the waste to energy plant was chosen as “external”, revenues by the valorisation of electricity and heat are already accounted for by the gate fee of the plant. Hence, if the waste to energy plant is considered “external”, annual revenues by thermal utilization are 0).
- annual revenues by the valorisation of materials (e.g., revenues for scrap metals, aggregates, recyclable plastics)

Revenues at the end of the project include:

- revenues by the valorisation of land recovered by the mining project (the cleaned up land of the mined landfill is valorised)

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26 which is to be mined
- revenues by the valorisation of landfill space recovered by the mining project (the recovered landfill space can be used for the disposal of “new” waste and hence gate fees for the landfill can be collected).
- revenues by the valorisation of used machinery of the mining project (the used machineries for excavation, sorting, upgrading are valorised).

In the results section on the economics of the project, also the calculation of the annual cash flows is summarized in table form. Costs, revenues, avoided revenues (e.g., electricity generation from landfill gas is not possible anymore, if the site has been mined) and avoided costs (e.g., aftercare costs are not necessary anymore, in case of landfill mining) are shown for each year of the project (including the time of intermediate use and necessary aftercare period, in case that the landfill would not be mined).

For the herein presented case study no intermediate use was defined and also no aftercare of the unmined landfill is necessary. Hence, the present cash flows are shown only for the proposed period of the mining project (4 years).
The net present values NPV of the annual cash flows are presented in the subsequent table and graphs. For the calculation of the NPV the discount rate (see D-General data) is applied to the annual cash flows.

The net present value of costs, avoided revenues, revenues and avoided costs are further divided into different subcategories (see subsequent figure).

Based on the net present value of all costs and revenues, the total net present value TNPV of the project is calculated. Furthermore, the specific net present value SNPV (TNPV divided by the mass of waste excavated/mined) is given. The SNPV gives the overall costs (negative value of SNPV) or overall revenues (positive value of SNPV) of the project per ton of waste mined.

The presented study yields a negative TNPV of almost 4 Mio. Euro, which means that the project developer would need to pay 4 Mio Euro (net sum) in order to conduct the landfill mining project.
The net present value NPV of the project is also shown in the subsequent figure. The net present value of costs is indicated by negative values, the NPV of revenues by positive values.

If the total net present value $\text{TNPV}^{27}$ is positive (the sum of all discounted revenues is higher than the sum of all costs), the project can be considered to be feasible from an economic point of view. If the total net present value is negative, costs are higher than the revenues generated.

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$^{27}$ Indicated by a black triangle
4-Results on resource classification of LFM project

Based on the results of the **economic evaluation** (specific net present value SNPV), the **climate evaluation** (specific net climate impact SNCI), the **project status** (defined under A-Landfill) and the **geological knowledge** (knowledge about the waste composition – defined under A-Landfill), the classification of the project according to the United Nations Framework for Resource Classification UNFC is done.

For the **socioeconomic viability** E, 3 classes are distinguished:

- **E1** Extraction & sale has been confirmed to be economically viable\(^b\)
- **E2** Extraction & sale is expected to become economically viable\(^a\) in the foreseeable future
- **E3** Extraction & sale is not expected to become economically viable\(^b\) in the foreseeable future\(^a\) or evaluation is at too early stage to determine economic viability

\(^a\)The length of “foreseeable future” can vary, depending on the commodity, but amounts typically to 20 years.  
\(^b\) “Economically viable” includes the “consideration of prices, costs, legal /fiscal framework, environment, social and all other non-technical factors that could directly impact the viability” (UNECE 2013).

Note: A positive Net Present Value (NPV) results automatically in E1. In case of a negative NPV, cut-off values for key parameters will decide, whether there are reasonable prospects for future economic extraction (E2) or not (E3).

For the **project feasibility** F, 4 classes are distinguished:

- **F1** approved (project could start immediately)
- **F2** approval phase (project documents have been submitted to the authority)
- **F3** approval not started/exploration phase (project documents have not prepared or submitted to the authority yet, the landfill is explored\(^28\), test excavations and test sorting are conducted)
- **F4** pre-exploration phase (no investigations into the landfill have been conducted yet)

For the **geological knowledge** G, 4 classes are distinguished:

- **G1** very good (detailed information about the waste composition and the applied technology is available, systematic test excavations and sorting analysis have been conducted)
- **G2** medium (information about the waste composition and the applied technology is available, a significant number of waste samples has been analysed)

\(^28\) e.g., investigations into the landfill composition
G3  poor (limited information about the waste composition and the applied technology is available, only few waste samples has been analysed)

G4  unqualified estimate (based on the waste type landfilled at the site, the waste composition has been roughly estimated)

The best score for the classification represents E1F1G1. For details regarding the applied resource classification system, the user of OnToL is referred to the guidelines for classifying anthropogenic resources (UNECE, 2018) [http://www.unec.org/fileadmin/DAM/energy/se/pdfs/UNFC/Anthropogenic_Resources/UNFC_Antropogenic_Resource Specifications.pdf](http://www.unec.org/fileadmin/DAM/energy/se/pdfs/UNFC/Anthropogenic_Resources/UNFC_Antropogenic_Resource Specifications.pdf) or (Winterstetter et al., 2018, Winterstetter et al., 2015)

The presented case study received the following classification E2F4G3.

Calculation of cut-off values

Cut-off values describe how economic key parameters (prices and / or costs) have to change to make a mining project economically viable (TNPV>=0).

If the “original” Total Net Present Value TNPV of the project is negative, the necessary increase in the land price and metal price, as well as the necessary decrease in disposal costs of residues is calculated and displayed in the subsequent table and figure (if).
If the “original” TNPV is positive, then the possible decrease in the land price and metal price, as well as the possible increase in disposal costs of residues is calculated, in order to reach a TNPV of 0 (break-even point)

For the calculation of the different cut-off values, it is assumed that only one of the parameter (land price, metal price and disposal costs) is varied.

For the present case study, the land price would need to increase from 50 Euro/m² to 452 Euro/m² to reach a TNPV of 0. For metals, the price would need to increase from 388 Euro/ton to 1800 Euro/ton, whereas the disposal costs would need to decrease from 50 Euro/ton to -328 Euro/ton.

A negative value means that the waste owner does not have to pay money but rather receives money for the disposal of his waste.
Literature


Acknowledgements

The funding of the software OnToL by the following organizations is greatly acknowledged:

- Public Waste Agency of Flanders (OVAM) - https://www.ovam.be/
- Austrian Federal Ministry for Sustainability and Tourism (BMNT) - https://www.bmnt.gv.at/

Furthermore, OnToL also includes substantial works conducted during a large-scale research initiative on anthropogenic resources (Christian Doppler Laboratory for Anthropogenic Resources). The financial support of this research initiative by the Federal Ministry of Digital, Business and Enterprise and the National Foundation for Research, Technology and Development is gratefully acknowledged. Industry partners co-financing the research centre on anthropogenic resources are Altstoff Recycling Austria AG (ARA), Borealis group, voestalpine AG, Wien Energie GmbH, Wiener Kommunal-Umweltschutzprojektgesellschaft GmbH (WKU), and Wiener Linien GmbH & Co KG.