SMARTEnvi PROJECT

SMART DECISION TOOLS FOR REDUCING HAZARDS TO OUR ENVIRONMENT AND WATER RESOURCES BY REHABILITATING OPEN DUMPS

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Waste dumps rehabilitation decision support tool

The manual

Silesian University of Technology

GEBZE TECHNICAL UNIVERSITY

PAMUKKALE UNIVERSITY 1992 DENİZLİ

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Leading partner:

Silesian University of Technology, Gliwice, Poland

Contributing partners:

Gebze Technical University, Kocaeli, Turkey

Pamukkale University, Denizli, Turkey

Petroleum-Gas University of Ploieşti, Ploieşti, Romania

Training 2000 psc, Mondavio, Italy

Denizli Metropolitan Municipality, Denizli, Turkey

Municipality of Fano, Fano, Italy

Sofia University “St. Kliment Ohridski”, Bulgaria

R&D Center “Biointech” Ltd., Bulgaria

Biogas part and tool integration was developed by: Silesian University of Technology,
Stability part was developed by: Gebze Technical University,
Leachate part was developed by: Pamukkale University

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Introduction

The Smart Decision Tool is a tool that allows you to assess an open landfill in terms of its impact on the natural environment. The tool can help in evaluation of potential benefits coming with rehabilitation of waste open dumps. Evaluation includes the entire life cycle, from the beginning of the landfill's existence to the end. It allows to assess environmental consequences of carrying out or not carrying out the rehabilitation of the open dump. It is therefore a tool that can provide decision makers with valuable information and arguments for or against rehabilitation.

The tool is available online on desktop computers and mobile devices. The use of it is open to general public and is not limited to any location of group of users.

The tool is prepared in 6 different language versions: English, Turkish, Polish, Italian, Romanian and Bulgarian. The tool is available through the project website: https://smart-envi.gtu.edu.tr/.

English version

Turkish version

Polish version

Italian version

Romanian version

Bulgarian version

The tool is online and was designed to be user-friendly. Calculations are performed in real time as soon as each data is entered. The system performs complicated mathematical operations and a huge number of calculations. Therefore, there may be slight delays in the operation of the system.

The rehabilitation of open dumps is a critical task for protecting the environment and public health. Open dumps can lead to the release of harmful chemicals and pollutants into the soil and groundwater, contribute to air pollution and greenhouse gas emissions, and create unsanitary conditions that can increase the risk of disease transmission.

Therefore, it is essential to evaluate the rehabilitation efforts of open dumps to ensure that they are effective in mitigating these risks and that the resources allocated to the rehabilitation are being used efficiently.

Using an online system for evaluating the rehabilitation of open dumps can help promote transparency, accountability, and effectiveness in these critical environmental and public health efforts.

It's important to note that an **online tool for evaluating the rehabilitation of open dumps have been designed primarily for educational purposes**. The tool provides users with information about the importance of rehabilitating open dumps. It could also provide users with a better understanding of the environmental and public health risks associated with open dumps, as well as the potential benefits of properly rehabilitating them.

By using the tool stakeholders such as community members, policymakers, and environmental organizations could gain a deeper understanding of the rehabilitation process, which could help build support for rehabilitation efforts and encourage more sustainable waste management practices.

The tool can provide significant benefits in evaluating the rehabilitation of open dumps, however it includes some simplifications or assumptions that can produce less strict results. Therefore, it is important to approach the system's outputs with caution and use them as one of several inputs in the decision-making process. It should not be the sole basis for decision-making. A comprehensive and detailed analysis is necessary to ensure that the rehabilitation efforts are successful in protecting the environment.

Evaluation process

The tool assesses three periods of the life cycle of a landfill. The first is the period from the beginning of its existence (DS), i.e. the time when the first portion of waste was accepted, until the time when we consider making a decision about its rehabilitation (DR). The analysis of this period constitutes scenario 1.

The second is the period from the decision on rehabilitation to the end of the landfill activity (DE). During this time period, two alternative scenarios are analysed. Scenario 2 is a situation when rehabilitation has not been implemented, and scenario 3 is a situation when rehabilitation has been implemented.

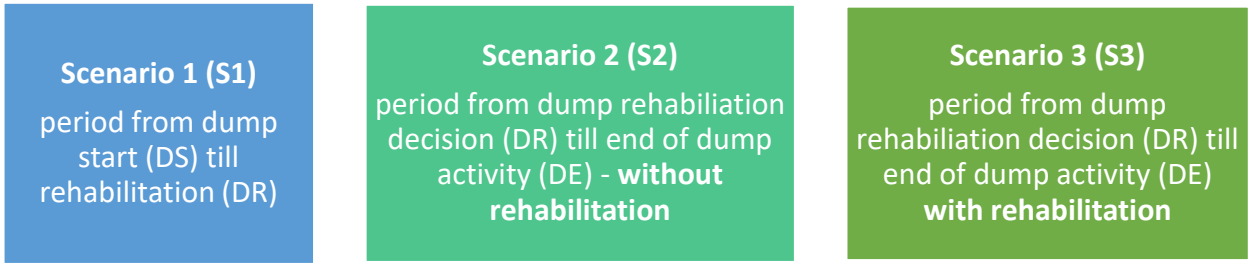


Fig. 1. Waste dump analysis scenarios.

The analysis process takes place in several steps (Fig. 2). At the beginning, the user defines the basic parameters of the landfill. Then, the elements that will be implemented as part of the rehabilitation are determined. After entering the relevant data, the system calculates indicators that will be useful for decision-makers and that highlight the most important aspects of the impact of the landfill on the natural environment.

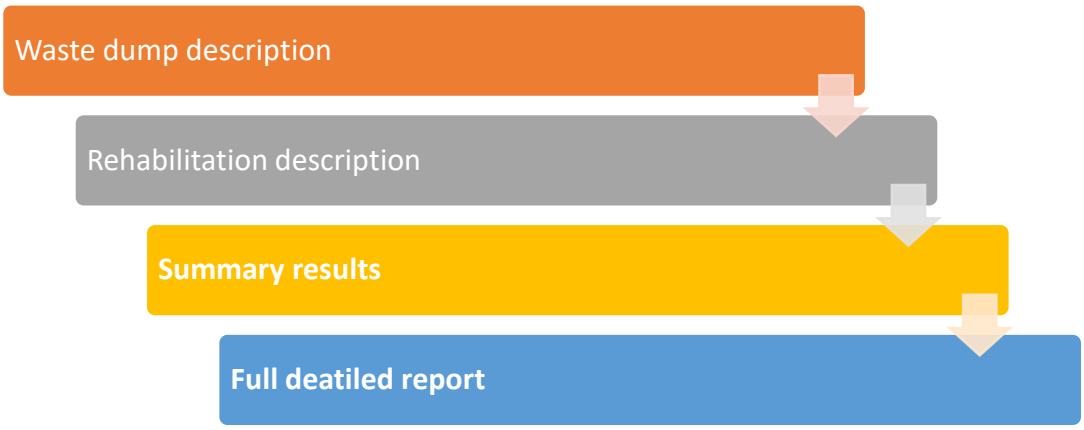


Fig. 2. Steps of the analysis.

3 major types of impacts are considered. They are related to:

- Landfill gas emission,
- Leachate emission,
- Stability.

The three major types of impacts are considered the most important because they have significant environmental implications.

Landfill Gas Emissions: Landfill gas emissions are one of the most significant environmental impacts of open dumps. Landfills generate gases such as methane, carbon dioxide, and volatile organic compounds, which can contribute to air pollution and greenhouse gas emissions. Methane, in particular, is a potent greenhouse gas that has a significant impact on climate change. Properly designed and maintained landfill gas management systems can help mitigate these emissions and reduce their impact on the environment and public health.

Leachate Emissions: Leachate is a liquid that forms when water percolates through waste in a landfill, picking up contaminants and pollutants along the way. Leachate can contaminate groundwater and surface water, leading to environmental degradation and public health risks. Properly designed and maintained leachate management systems can help reduce the impact of leachate emissions on the environment and public health.

Stability: The stability of an open dump refers to its ability to remain structurally sound and not collapse or experience significant settling. Stability is important because collapses and settling can lead to soil erosion, damage to nearby infrastructure, and potential harm to workers and the public. Properly designed and maintained landfill engineering measures can help ensure the stability of the dump and reduce these risks.

The motivation to include these three factors in the tool was the fact that by mitigating these impacts through proper rehabilitation, the risks to the environment and public health can be minimized, and sustainable waste management practices can be promoted.

Landfill gas emission

Biogas is a naturally occurring gas that is produced by the breakdown of organic materials by microorganisms in anaerobic conditions. Landfills are one of the major sources of biogas generation, as they contain large amounts of organic waste that decomposes over time.

The process of biogas generation in landfills begins with the deposition of organic waste materials in the landfill. As the waste decomposes, it produces a mixture of gases, including methane (CH4), carbon dioxide (CO2), and other trace gases. This gas mixture is known as landfill gas (LFG).

Waste dump rehabilitation refers to the process of restoring an old or abandoned landfill site to a functional and safe condition. In the context of landfill gas utilization, this process involves the extraction and utilization of landfill gas (LFG) as a renewable energy source, while simultaneously addressing the environmental concerns associated with landfill sites.

The rehabilitation of a landfill site typically involves several steps, including the removal of any remaining waste materials, the installation of a gas collection system, and the implementation of measures to prevent further environmental contamination. The gas collection system is a critical component of landfill gas utilization, as it allows for the capture and processing of LFG, which can then be used to generate electricity or heat.

The LFG can be extracted from the landfill using a system of pipes and pumps. The extracted gas can then be treated and used as a source of energy. Methane is the most valuable component of LFG as it can be used as a fuel for electricity generation, heating, or as a transportation fuel.

Once the gas has been extracted, it can be processed to remove impurities such as moisture, hydrogen sulphide, and other contaminants. The purified gas can then be used to generate electricity or as a fuel for other applications.

The major component of the landfill gas is CH4 (methane) is a potent greenhouse gas. CH4 is more effective at trapping heat in the atmosphere than CO2, with a global warming potential that is estimated to be 28 times higher than CO2 over a 100-year time horizon.

CO2 (carbon dioxide) is a component of landfill gas (LFG) that is produced as a result of the decomposition of organic waste in a landfill. While CO2 is a greenhouse gas that contributes to climate change, the CO2 produced from the decomposition of organic waste is considered to be "climate neutral" for a number of reasons.

First, the carbon contained in the organic waste that is decomposing in the landfill originally came from the atmosphere through the process of photosynthesis. As such, the CO2 produced during decomposition is simply returning carbon that was already present in the carbon cycle. This is in contrast to the use of fossil fuels, where carbon that has been stored underground for millions of years is being released into the atmosphere, contributing to a net increase in atmospheric CO2 levels.

Second, when LFG is captured and utilized as a source of energy, the CO2 produced during combustion is offset by the reduction in CO2 emissions that would have resulted from the use of fossil fuels. In other words, the CO2 emissions from LFG utilization are offset by the reduction in emissions from other sources of energy.

Finally, when LFG is not captured and utilized, the methane (CH4) contained in the gas can escape into the atmosphere, where it is a much more potent greenhouse gas than CO2. By capturing and utilizing LFG, the emissions of methane from landfills can be significantly reduced, providing a net benefit in terms of greenhouse gas emissions.

Overall, while CO2 produced from the decomposition of organic waste in landfills does contribute to climate change, it is considered to be "climate neutral" when LFG is captured and utilized as a source of renewable energy. This is due to the fact that the carbon in the waste is already part of the carbon cycle, the offset of emissions from fossil fuels, and the reduction of methane emissions from landfills.

In the tool, all CO2 emissions - i.e. free landfill gas emissions as well as emissions from the landfill gas treatment plant - are treated as climatically neutral. Emissions of CH4 are treated as a thread for climate change. For practical reasons CH4 is recalculated to CO2 equivalent in order to facilitate the real impact on the environment of different emissions.

Biogas generation in landfills can have significant environmental and economic benefits. By extracting and utilizing LFG, landfills can reduce their greenhouse gas emissions and contribute to renewable energy production. Additionally, using biogas as a fuel source can reduce dependence on fossil fuels and provide a sustainable source of energy.

Figure 3 shows illustrations of landfill emissions that are considered in the tool.

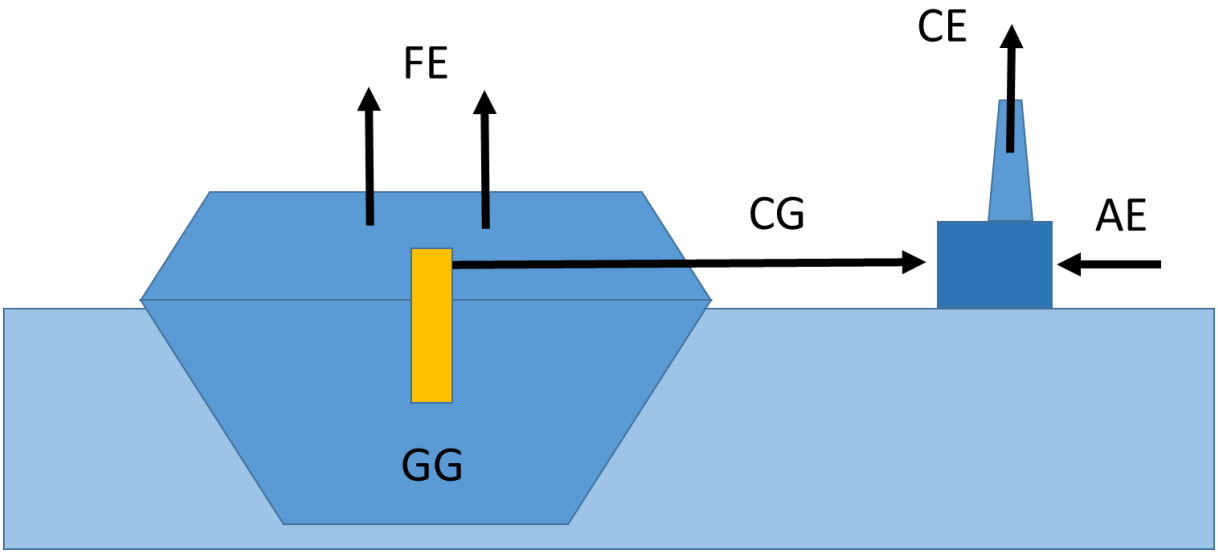


Fig. 3. Emissions evaluated in the tool.

In tool the following gases parameters are evaluated:

- **Landfill gas generation** (GG) – calculation made on the basis of the mass, fraction composition and environment (wet, dry, medium).
- **Free emission** (FE) – emission of landfill gas which is not collected by gas collection system (efficiency lower than 100%)
- **Collected landfill gas** (CG)– part of the generated landfill gas which is collected by landfill gas collection system and directed to utilization installation.
- **Avoided emission** (AE) – emission that will not take place due to replacement of energy sources (this parameter is affected by location of the installation and local energy grid parameters);
- **Combustion emission** (CE) – emission of landfill gas utilization installation (flare or energy recovery). In the installation combustion process takes place and the CH4 is transformed into CO2. This CO2 is climate neutral which means that CE is always 0.
- **Effective emission (EE) –** final emission of all GHG gases produced in CO2 equivalent including FE, CE, AE and efficiency of gas collection and energy generation. **This can be treated a s a measure of real environmental impact of the landfill in climate change impact category.**

If 1 kWh of energy from the grid, which emits X kg of CO2, is replaced by energy from another source, which emits Y kg of CO 2, then we can say that this action has caused a change in the environmental impact. By replacing one energy source with another, we avoided part of the emissions. This avoided emissions is the difference between the CO2 emissions associated with the use of both energy sources: AE=X-Y.

Avoided emissions refer to the reduction of greenhouse gas emissions that would have occurred if a particular activity had not been undertaken. In the case of landfill gas (LFG) utilization for energy generation, there are several ways in which avoided emissions can be achieved.

Taking into account **avoided emissions**, **the effective greenhouse gas emissions** (EE) can therefore be negative and cause environmental relief according to the equation:

Utilization of LFG can be treated as a source of renewable energy, it can displace the use of fossil fuels such as coal, oil, and natural gas, which emit large amounts of CO2 and other greenhouse gases when they are burned. By using LFG instead of fossil fuels, emissions of CO2 and other greenhouse gases are avoided, leading to a reduction in the overall carbon footprint of energy generation.

The prediction and evaluation of landfill gas emission is made on the basis of United States Environmental Protection Agency model LandGEM.

Leachate emission

Landfill leachate is defined a high strength wastewater which has high pollutant and toxic content. Leachate is extremely harmful to the environment. The one of the most important effects of landfill leachate are that it mixes with aquatic ecosystems such as lakes and streams, causing an increase in algae and plankton. The amount of oxygen in the water body decreases and the life of the aquatic ecosystem is endangered over time. Due to its high toxicity, garbage leachate is a major threat to ground and surface waters. The content of landfill leachate depends on the composition of the waste, climatic conditions and the age and degradation rate of the solid waste.

The qualitative and quantitative characteristics of landfill leachate depend on multiple factors, some of which are difficult to control such as weather conditions, hydrological features, waste composition and age, etc.). All these elements imply critical management issues which led to different systemic approach, both at European and national level.

From the quantitative point of view, the production of leachate is largely attributed to external inputs (rainwater infiltration, both superficial and underground) and internal inputs such as the level of moisture content waste and the water balances related to the biochemical reactions of waste disposal.

In particular, external inputs relate to:

- Meteorological and hydro geological characteristics on the site, particularly related to rainfalls, temperatures, solar or wind exposition, water body infiltration, both superficial and underground.
- The landfill management model: presence of drainage, primary or secondary liner system, daily extension and coverage of the waste tank, possible leachate recirculation.
- Waste characteristics: composition of waste, level of moisture content, possible pre-treatments, size, level of compactness.

Leachate composition and strength varies widely from landfill to landfill, even within a given landfill. It should be noted that, even in absence of external inputs (e.g. a landfill capping system), the anaerobic decomposition of the waste and its leachate production continues even after the end of the landfill life cycle. This means that landfill managers need to keep the drainage and treatment plants operating while ensuring that the surrounding environment is safe from contamination, in conformity with the national laws.

From the qualitative point of view, it’s impossible to describe a typical landfill leachate composition, being it influenced by different factors that specifically affect the biodegradation process of waste, thus contributing to the seepage of different pollutants.

The main factors affecting the biodegradation progress are:

- Level of moisture content of disposed wastes
- Quantity and nature of organic components (especially if sewage sludge, off-spec compost)
- Levels of metals and/or toxic substances from batteries, drugs, solvents, etc.
- Levels of separate waste collection surrounding the landfill plant which can vary the type of waste disposal.

Waste pre-treatments and placement in the landfill are another two important factors which affect the water absorption capacity of the waste mass leading to the migration of pollutants in leachate.

Consolidated studies show that the concentration of pollutant inside the leachate is higher within the first operating year of the landfill, progressively decreasing through years. This trend affects organic parameters chemical oxygen demand (COD) and biochemical oxygen demand (BOD) and the main inorganic salts (heavy metals, sulphates, etc.)

The removal of organic material based on COD, BOD and ammonium from leachate is the usual prerequisite before discharging the leachates into natural waters.

From the microbiological aspect, the proliferation of fungi and bacteria is inhibited by common environmental conditions (high temperatures and pH) during the biodegradation process.

In tool the following leachate parameters are evaluated:

- **Leachate generation** is total waste water originated from precipitation and water content of solid waste.
- **Leachate quantity after compaction** waste water quantity in case of compacter using at open dump area.
- **Solid waste water content** is moisture of the solid waste according to composition.
- **Leachate quantity originated from precipitation** is raining and snowing on the surface area.
- **Ron (Total)** shows infiltration of precipitation on the surface area.
- **Roff (Total)** shows flow of precipitation on the surface area.
- **Chemical oxygen demand (COD)** is calculated according to waste composition.
- **COD Load** is calculated according to COD concentration and leachate volume.

Threats related to stability

Instability on the slope of a landfill can result in injuries to people, contamination of the surrounding environment, and damage to property. In addition, when a slope failure occurs in a landfill, the gas in the waste (if any) can be released into the environment, which adversely affects the environment. As a result, maintaining the safe functioning of landfills and the stability of landfills is an essential duty for governments and environmental professionals (Toprak et al., 2021). It is also important for people who live within a short distance to landfills.

Stability of a slope is often measured in terms of a safety factor (FS). The safety factor of a slope is the ratio of shear strength of soil to shear stress of a potential sliding surface of the slope. Typically, the definition of the safety factor is

$$FS = \frac{\tau_f}{\tau_d}$$

In this equation, τ_f is average shear strength of the soil and τ_d is average shear stress on a potential sliding surface.

When landfills are built in earthquake prone areas, it is necessary to pay attention to the earthquake effect while designing and managing the landfill. For earthquake condition, the pseudo-static method is one of the most used methods. This method is also one of the simplest ways to idealize the slope subjected to earthquake. Although the force of an earthquake is dynamic, the main cause of instability may be considered to be the inertial force. The acceleration caused by an earthquake's shaking is viewed as producing inertial forces in the pseudostatic approach. Earthquake forces operate in both the horizontal and vertical directions. The definition of the forces is

$$f_h = \frac{a_h W}{g} = k_h W$$

$$f_v = \frac{a_v W}{g} = k_v W$$

where k_v and k_h are dimensionless vertical and horizontal pseudo-static coefficients and W is the failure mass weight. The forces acting on a slope for circular failure surface and linear failure surface can be seen in Figure 4 and Figure 5.

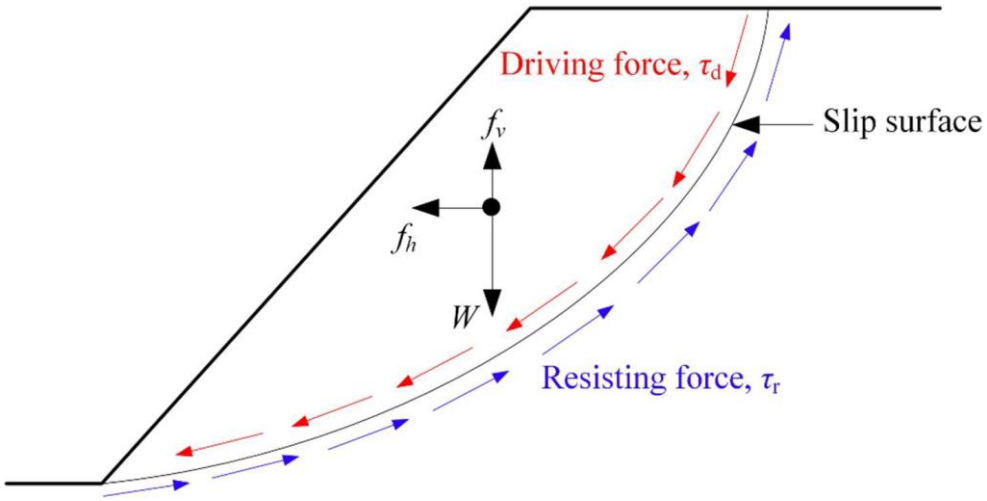


Fig. 4. Forces acting on a slope in pseudostatic slope stability analysis for circular failure surface.

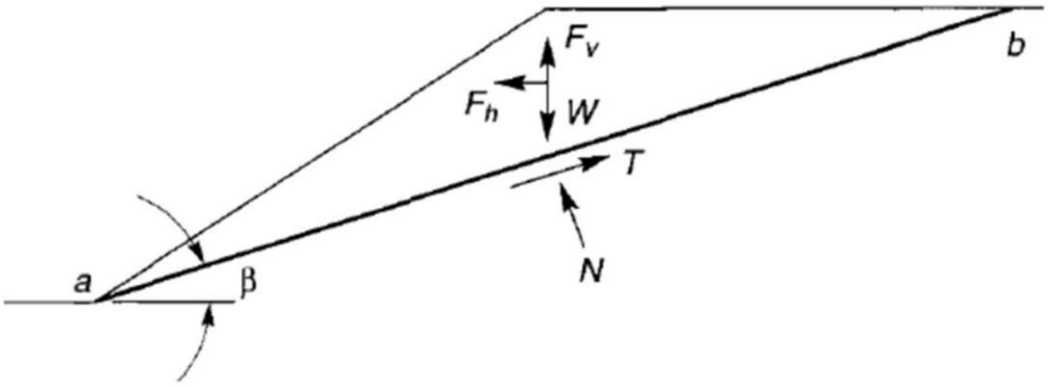


Fig. 5. Forces acting on a slope in pseudostatic slope stability analysis for linear failure surface.

FS of the slope in Fig. 5 can be calculated with the following equation:

$$FS = \frac{resisting\ force}{driving\ force} = \frac{c\ l_{ab} + [(W - F_v)\cos\beta - F_h\ sin\beta]\ tan\varphi}{(W - F_v)\sin\beta + F_h\ cos\beta}$$

As shown in the equation, cohesion (c), internal friction angle (ϕ), unit weight of waste which effects the sliding weight, k_h and k_v seismic coefficients can affect the results of the formula in the calculation of FS of the slope. Leachate level effects the unit weight of waste and water pressure in the landfill, so it is also an important parameter.

Description of input and output data

In order to use the tool the user should supply the necessary data.

Waste dump description section

In this section user should define the waste dump by supplying the following information:

- **Start operation year (DS)** – year when the first waste was stored on the dump.
- **End operation year** – this will define the time since the initial time of dump operation to the time when dump stopped to accept waste.
- **Waste stored** – total mass of the waste stored on the dup (tonnes) at the moment of its closure (DE).
- **Environment** – simplified description of the environment where dump is located. User can choose *wet, dry* or *medium*. This would affect the volume and composition of the landfill gas;
- **Country** – the location of the dup which is needed to calculate the potential savings of the GHG emission due to substitution of grid electricity with one generated from landfill gas (if rehabilitation include this). On the right side the emission factor of CO2 related to MWh of grid electricity in specified location is shown. It is calculated automatically.
- **Precipitation** (mm/year)– Precipitation refers to any form of water that falls from the atmosphere and reaches the Earth's surface. This can include rain, snow, sleet, hail, and other forms of precipitation. Precipitation occurs when water droplets or ice crystals in clouds grow large enough to fall to the ground under the influence of gravity. Precipitation will affect the leachate generation.
- **Total storage area** (m2)– The total storage area have a significant impact on leachate generation. Leachate is the liquid that results from the percolation of water through waste materials, typically in a landfill or other waste disposal site. The amount of leachate generated can depend on several factors, including the amount of waste present, the type of waste, the moisture content, and the storage area. A larger storage area can lead to greater amounts of waste being stored, which can result in higher levels of leachate generation. Additionally, a larger storage area may allow for more moisture to accumulate in the waste, leading to increased leachate production.
- **Compaction in the area** – user can choose yes is compaction is used and No is not. Landfill compaction is an important aspect of landfill design and operation.
- **Compaction rate** (%). Compaction refers to the process of compressing waste materials in a landfill to reduce their volume and create more space for additional waste. Effective compaction can also help to minimize the production of leachate by reducing the amount of air and water that can penetrate the waste. This can help to prevent the contamination of groundwater and reduce the risk of environmental damage.
- **Are there closed area in open dump** –Dump sites may consist of several parts (lot). The area filled with garbage are closed and covered with soil. Garbage dumping continues to other sections at open dump.
- **Closed area percentage** (%) – the percentage of area (lot) where the garbage dump is completed and covered with soil at the open dump.
- **Waste fraction composition** – user should supply data on the share of paper, textiles, food, garden waste, sewage sludge, disposable diapers, wood and straw in the total mass of stored waste. Input data should be produced in %. The internet fraction is calculated automatically.

The total of all fraction should be 100%. If the value of inert fraction is lower than 0 it means that the entered data was not correct and must be checked. Waste fraction composition refers to the different types and amounts of waste materials. The composition of the waste can influence the characteristics of the leachate, including its pH, chemical composition, and potential to cause environmental harm. Organic waste, for example, can produce high levels of leachate due to its high moisture content and biodegradability. Similarly, landfill gas is produced as a byproduct of the decomposition of waste materials in a landfill. The composition of the waste can influence the types and amounts of gases that are produced. For example, organic waste can produce significant amounts of methane gas, which is a potent greenhouse gas that contributes to climate change.

- **Landfill height** – this represents the current height of the open dump/landfill from the ground level. The user can select an integer value between 10 m and 60 m (Fig. 6).
- **Slope angle** – this is the angle of the slope of the open dump/landfill. 1V/1H (1 vertical: 3 horizontal, 18.43˚), 1V/2H (1 vertical: 2 horizontal, 26.57˚) and 1V/3H (1 vertical: 1 horizontal, 45˚) can be chosen (Fig. 6).

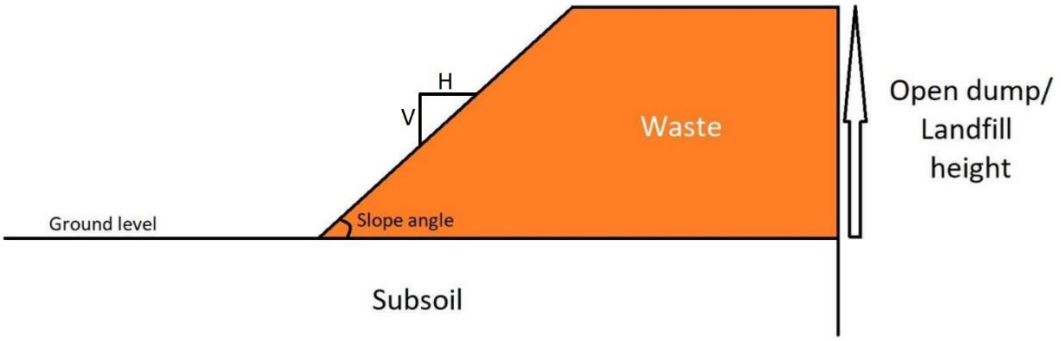


Fig. 6. Landfill height and slope angle

- **Water (leachate) level above ground/landfill height** – this quantifies the ratio of the leachate height to open dump/landfill height. The options are 0 (no leachate level in the waste), 0.25 and 0.75 (Fig. 7).

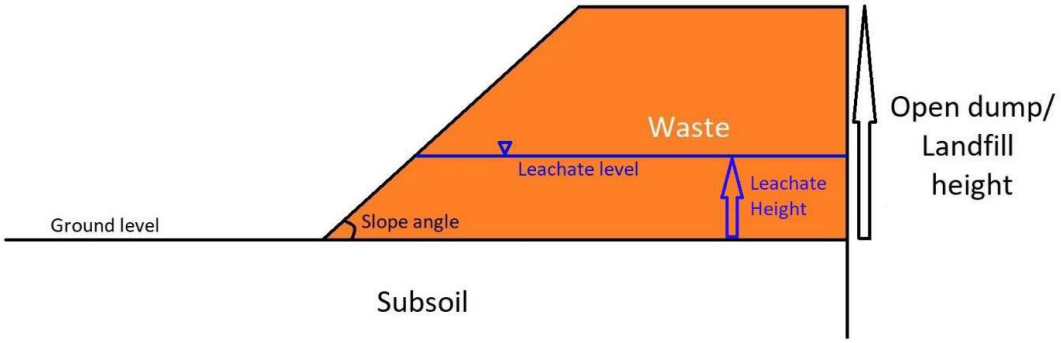


Fig. 7. Leachate level and leachate height

- **Unit Weight of waste (γ)** – this quantifies the weight per unit volume of the waste. The user can select an integer value between 6 and 14 kN/m^3.
- **Cohesion of waste (c) (0 - 80 kPa)** – this represents the tendency for particles of waste to stick together. It is one of the shear strength parameter. Shear strength is defined as the maximum

shear stress that the waste may sustain without experiencing failure. The user can enter an integer value between 0 and 80 kPa.

- **Internal Friction Angle of waste (ϕ) (0-50 deg.)** – it is another shear strength parameter. The user can enter an integer value between 0˚ and 50˚.
- **kh (horizontal pseudostatic coefficient) and kv (vertical pseudostatic coefficient)** – they are used to compute the horizontal and vertical forces caused by a potential earthquake. They are dimensionless. The options are 0 – 0, 0.05 – 0, 0.05 - kh/2, 0.05 – kh, 0.1 – 0, 0.1 - kh/2, 0.1 – kh, 0.2 – 0, 0.2 - kh/2, 0.2 – kh, 0.3 – 0, 0.3 - kh/2, 0.3 – kh, 0.4 – 0, 0.4 - kh/2, 0.4 – kh. Theoretically, the values of the seismic coefficients ought to be based on some indicator of the magnitude of the inertial force that an earthquake's dynamic forces cause in the slope. Because soil slopes aren't stiff and an earthquake's peak acceleration only lasts for a short time, the acceleration values used in practice are usually much lower than the estimated peak accelerations. The choice of coefficients utilized in the slope stability study generally relies on the design code used in the country. It certainly depends on the location of the dump/landfill with respect to seismic map. Some generalized suggestions are also available in the literature such as Marcuson and Franklin (1983), Hynes-Griffin and Franklin (1984) and Melo and Sharma (2004).

Rehabilitation description

In this section user can describe what measures will be taken in rehabilitation process. The following information should be supported:

- **Dump rehabilitation year** (DR)– year when rehabilitation is done.
- **Gas utilization** – user should define what type of landfill gas will be implemented. Energy recovery or Flare could be selected. Landfill gas, which is produced as a by-product of the decomposition of waste materials in a landfill, can be utilized as a source of renewable energy. Landfill gas typically contains high levels of methane, which can be captured and used to generate electricity, heat buildings, or fuel vehicles. There are several benefits to utilizing landfill gas as a source of energy. Firstly, it can help to reduce greenhouse gas emissions by capturing methane that would otherwise be released into the atmosphere. Methane is a potent greenhouse gas that is estimated to be over 20 times more effective at trapping heat than carbon dioxide, making its capture and utilization an effective way to mitigate climate change. Secondly, landfill gas utilization can provide a source of renewable energy that can help to reduce reliance on fossil fuels. This can contribute to energy security and help to promote a more sustainable energy system.
- **Gas collection efficiency** (%) – user can define the ration of landfill gas that will be collected. 100% means that all landfill gas will be collected and utilized. Landfill gas can be collected through a variety of methods, including wells, collection pipes etc. Unfortunately, no gas collection system is 100% efficient. Gas collection efficiencies ranged between 13 and 86% with an average of 50%. these values vary from country to country (for instance in for Sweden -58%, UK -64% and US -63%) and depend on a number of factors such shallow gas collection pipes, leakage from installations (e.g. leachate wells, gas engines), low gas recovery due to minimal gas production or a lack of gas collection in active waste cells. User should determine the average efficiency on the basis of the technical analysis of the proposed solution (Duan Z. et al. 2022).
- **Energy generation efficiency** (%) – user can define what share of gas energy potential will be utilized. In other words, it is measure of efficiency of energy generation from landfill gas. This

ration will affect the result in case if energy recovery is selected. Once collected, the gas can be cleaned and processed to remove impurities before being used as a source of energy. Landfill gas utilization projects can range in scale from small on-site projects to large-scale commercial operations. The energy generation efficiency is different for different options. For instance gas turbines have net efficiencies around 30-40%, gas engines show values of up to 46%. By applying heat recycle solutions, the gas turbines net efficiencies increase up to almost 60% and for engines around 50%. The user should determine the average efficiency based on the technical analysis of the proposed solution.

- **Cover material** – user can define the cover layer of the waste dump installed during the rehabilitation process. Sandy soil – Slope 0-7%, Sandy soil – Slope >7%, Clay – Slope 0-7%, Clay – Slope >7% can be selected. The surface flow coefficient is shown after selection of cover material. It is calculated automatically. Cover material used in a landfill plays an important role in controlling the generation and migration of leachate. Preventing water from entering the landfill, the cover material can also affect the quality of the leachate that is generated. If the cover material is not effective in preventing water infiltration, the resulting leachate can become contaminated with pollutants from the waste materials.
- **New slope angle** – the slope angle can be decreased. The options are 1V/1H (1 vertical: 3 horizontal, 18.43˚), 1V/2H (1 vertical: 2 horizontal, 26.57˚) and 1V/3H (1 vertical: 1 horizontal, 45˚).
- **New landfill height** – the landfill height can be decreased. The user can enter an integer value between 10 m and 60 m.
- **New water (leachate) level above ground/landfill height** – user can decrease the ratio of water (leachate) level above ground to landfill height. The options are 0 (no leachate level in the waste), 0.25 and 0.75.
- **Future Landfill Height without rehabilitation** – this represents the future height of the open dump/landfill from the ground level without rehabilitation. The user can select an integer value between 10 m and 60 m.
- **Future water (leachate) level above ground/landfill height without rehabilitation** – this quantifies the ratio of the future leachate height to open dump/landfill height without rehabilitation. The options are 0 (no leachate level in the waste), 0.25 and 0.75.

Results – Summary

In this section general, the most important results of the calculations is presented. In clear table user can compare values for all 3 scenarios.

The results for Scenario 1 give an overview of the impact of the landfill on the environment from the beginning of its existence to the date of the decision whether to rehabilitate. These are results relating to the past period. Comparison of scenarios 2 and 3 gives an idea of the possible impact on the environment in the future - that is, from the time of the decision on rehabilitation to the end of the period of the landfill's activity. The difference between the results for both scenarios can be considered the value of the decision itself and should be a motivation to undertake rehabilitation.

In this section tool shows the following results of calculation:

- **Effective emission** (total emission of greenhouse gases given in Mg of CO2eq) – it includes own emissions from dump, biogas utilization installation and emission avoided due to energy generated from biogas;

- **Green energy generation due to utilization of biogas** – energy generated in biogas utilization installation;
- **Leachate emission** (total emission form waste dump) - Total waste water originated from precipitation and water content of solid waste.
- **Chemical oxygen demand** - Chemical oxygen demand of leachate according to waste composition.
- **Factor of safety for slope stability** - the ratio of shear strength of waste to shear stress of a potential sliding surface of the slope.
- **Safety condition** - according to the "Factor of safety" output, it shows the landfill safety against slope failure and how the landfill managers/employees should react to the problem if necessary.

Results – Landfill gas

Results are grouped into sections related to scenarios. In each scenario the following results are calculated:

Scenario 1

- **Landfill gas generation (GG)** – this is total od landfill gas that was generated for the very beginning of the erection of waste dump (DS) to the time when the rehabilitation decision are to be taken (DR). The overwhelming majority of this gas was emitted to the atmosphere. It could have been used for generation of green clean energy – but was not due to late decisions of rehabilitation or building a good landfill at once. In other words, it is the measure of lost and wasted chances.
- **Collected landfill gas (CG)** – represents the quantity of landfill gas collected in the waste dump. As scenario 1 refers to the open dump before rehabilitation it is assumed that the gas collection system is not installed. In this scenario CG is always 0.
- **Free emission (FE)** – In scenario 1 this represents of total landfill gas emitted since the beginning of waste dump operation (DS) till the date of rehabilitation (DR). This is emission that already took place. The emitted landfill gas consists of several gases. The majority of them are CH4 and CO2. The emission is calculated and expressed in CO2 equivalent which represents the total impact that emitted gas is making on the climate change. It is assumed that the stream of waste directed to the landfill is constant throughout the entire period of operation. This means that the same amount of waste was deposited there every year. This assumption affects the estimation of biogas and leachate emissions.
- **Avoided emission (AE)** – as in scenario 1 landfill gas utilization devices are not installed there is no chance for generating energy which could replace some energy form the grid. In this scenario AE is always 0.
- **Effective emission (EE)** – in scenario 1 EE is the same as FE due to fact that no gas collection system was installed.
- **Green energy generation** – represents the amount of energy that will be generated in time period form DR to DE. As no gas utilization devices are installed in this scenario the amount of energy is always 0.

Scenario 2

- **Landfill gas generation (GG)** – this is total of landfill gas that was generated in the landfill in time period form decision of rehabilitation (DR) to the end of its activity (DE). As in scenario 1,

due to fact that the gas collection system is not installed the landfill gas is emitted to the atmosphere freely. It could be treated a s a measure of potential source of green energy if the decision of rehabilitation would be taken. In other words it is the measure of potentially lost benefits in the future.

- **Collected landfill gas (CG)** – represents the quantity of landfill gas collected in the waste dump in time form DR to DE. As scenario 2 refers to situation when rehabilitation is not implemented it is assumed that the gas collection system is not installed. In this scenario CG is always 0.
- **Free emission (FE)** – this represents the emission that will take place if the decision on rehabilitation is not taken. The emission is calculated for time since decision of rehabilitation (DR) to the end of life of dump (DE), the time when dump will no longer produce landfill gas. The emission is calculated and expressed in CO2 equivalent. Similarly to scenario 1 all landfill gas is emitted freely to the atmosphere. This is the measure of the total of greenhouse gases that will occur in the future.
- **Avoided emission (AE)** – as in scenario 2 no gas utilization devices are installed no avoided emission could be expected. and AE is always 0.
- **Effective emission (EE)** – in scenario 2 EE is the same as FE due to fact that no gas collection system was installed.

Scenario 3

- **Landfill gas generation (GG)** – this is total of landfill gas that was generated in the landfill in time period form decision of rehabilitation (DR) to the end of its activity (DE). The volume of gas generated in scenario 3 is the same as in scenario 2. However, due to installation of gas collection system it can be utilized in flare or in energy recovery installation.
- **Collected landfill gas (CG)** – represents the quantity of landfill gas collected in the waste dump in time form DR to DE. In scenario 3 the gas collection system is installed. However, it is not 100% efficient. As a result, only some part of the gas generated in the landfilled is collected and transported to gas utilization installation.
- **Free emission (FE)** – As the gas collection system is not 100% efficient some part of gas is emitted freely to the atmosphere without utilization. FE represents this part of landfill gas. FE represents the emission that will take place if the decision on rehabilitation is not taken. The emission is calculated for time for the time since decision to the end of life of dump (time when dump will no longer produce landfill gas). The emission is calculated and expressed in CO2 equivalent. Similarly, to scenario 1 all landfill gas is emitted freely to the atmosphere. This is the measure of the total of greenhouse gases that will occur in the future.
- **Avoided emission (AE)** – in scenario 3 the gas utilization devices are installed. If this is energy recovery system, the energy form it could replace some energy form the grid. As a result, some avoided emission will occur. The higher efficient of gas collection system and the higher energy generation system efficiency the higher amount of avoided emission occurs.
- **Effective emission (EE)** - this represents the emission that will take place if the decision on rehabilitation is taken. The emission is calculated for time for the time since decision to the end of life of dump (time when dump will no longer produce landfill gas). If the emission is lower than emission indicated in case if rehabilitation is not taken this is due to better management and use of landfill gas. The emission could be even negative (indicated as the vale in in brackets – for instance (100) Mg CO2eq means minus 100 MgCO2eq). Negative emission could appear because of substitution of grid electricity in defined location by the electricity generated from collected landfill gas. Is environmental impact from the latter is

lower (in relation to unit of energy) that impact from grid electricity the negative emission could appear. In this situation we can talk about environmental relief.

- **Green energy generation** – this represents the total energy which will be generated because of rehabilitation and implementation of energy recovery from collected landfill gas.
- **Graph - Emission projection (with and without rehabilitation)** – this graph visualizes the comparison of environmental impact related to climate change in case if the decision on rehabilitation is taken or not. In other words, it is visualization of the value of the decision to make rehabilitation of open waste dump.

Results – Leachate

- **Leachate generation** This represents the total waste water originated from precipitation and water content of solid waste. The water generated during the anaerobic digestion of waste is neglected.
- **Leachate quantity after compaction** This represents waste water quantity in case of compacter using at open dump area
- **Solid waste water content** This represents moisture of the solid waste according to composition.
- **Leachate quantity originated from precipitation** This represents raining and snowing on the surface area.
- **Ron (Total)** This represents infiltration of precipitation on the surface area.
- **Roff (Total)** This represents flow of precipitation on the surface area.
- **Chemical oxygen demand (COD)** This represents chemical oxygen demand of leachate. This value is calculated according to waste composition.
- **COD Load** This term is calculated according to COD concentration and leachate volume.
- **Leachate quantity up to the time of rehabilitation** This represents evaluation of time from the beginning to the decision time on the rehabilitation.
- **COD loading up to the time of rehabilitation** This represents evaluation of time from the beginning to the decision time on the rehabilitation.
- **Future leachate quantity without rehabilitation** This represent evaluation of time from decision time on the rehabilitation to the end of active life of the dump without rehabilitation.
- **Future COD loading without rehabilitation** This represent evaluation of time from decision time on the rehabilitation to the end of active life of the dump without rehabilitation.
- **Future leachate quantity with rehabilitation** This represent evaluation of time from decision time on the rehabilitation to the end of active life of the dump with rehabilitation. This value will be “0”. After rehabilitation, leachate generation doesn’t increase because of covering top surface.
- **Future COD loading with rehabilitation** This represent evaluation of time from decision time on the rehabilitation to the end of active life of the dump with rehabilitation. This value will be “0”. After rehabilitation, COD load doesn’t increase because of covering top surface.

Results – Stability

The results are determined according to FS. The following results are calculated:

- **Factor of Safety for slope stability** – the ratio of shear strength of waste to shear stress of a potential sliding surface of the slope. The possible outputs for "Factor of Safety against stability" can be seen in Table 1.
- **Safety Condition** – According to the "Factor of Safety" output, it shows the landfill safety against slope failure and how the landfill managers/employees should react to the problem if necessary. The possible outputs for "Safety Condition" can be seen in Table 1.

These outputs are also calculated for each rehabilitation process and all the rehabilitation processes together to see each rehabilitation effect on the stability of the landfill. Therefore, as a preliminary assessment, the authorized person for an open dump/landfill can easily see the impact of these rehabilitation options on the landfill. The FS against stability determines for static and dynamic conditions and the possible outputs for the results can be seen in Table 1.

Table 1: Possible outputs in the Calculation Results section.

Condition	FS against stability	Safety Condition
Static (kh=0, kv=0)	>1.5 1.1-1.5 <1.1	SAFE NOT SAFE - Detailed reassessment is required NOT SAFE -Immediate action is required
Dynamic (kh≠0)	>1.2 <1.2	SAFE NOT SAFE

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