

Concepts for dealing with closed landfills in Germany and Europe

Dr. Ulrich Stock¹ (Landesamt für Umwelt)

Despite great progress in recycling waste, it will be inevitable in the future to dispose of waste by disposal on landfill. The existence of landfills with sufficient deposit volume is therefore an indispensable element of modern waste management. So for the foreseeable future we will have to deal with how we deal with disused landfills.

For the project order of the Interreg project COCOON (the author reported on this project in a lecture at the 13th landfill workshop in Zittau 2017), it is necessary to submit proposals for the handling of closed landfill sites as part of an Enhanced Landfill Management.

In order to be able to make such suggestions, an analysis of the current status is required. Indeed COCOON is not intended to carry out a scientifically accurate analysis of the waste management practices of the partner countries. However, the exchange of experience offers the opportunity to gain insight into the state of landfill of the project partners and to gain a certain overview without having to know the state of the art down to the last detail. In addition, the author has some experience in the field of landfills, not least from the transformation of the landfills in his own sphere of activity.

On the basis of this knowledge, the author tries to give an overview of strategies in dealing with closed landfills and, as required by COCOON's project mandate, to derive recommendations for further handling and to describe those already given by the COCOON partners.

Based on his experience, the author estimates that the landfill of each waste management takes a roughly same course of development, which can be described as follows.

First, it was about removing the waste from the cities. Waste management was originally a development in police and regulatory affairs or health policy, with the aim of preventing diseases by disposing of the waste. Accordingly, there was no other requirement for the early landfills than to be outside the cities. Technical security elements are not available, a landfill operation does not take place, the waste is dumped and possibly distributed in the area. Following the fashion of the time, naming everything possible with terms from the IT-technology, I refer to this stage of development as **Landfill1.0**. Many landfills in Third World countries are in this condition.

With the development of large-scale industry and the introduction of chemistry in the households, the character of the waste changed (who is interested in how the municipal waste still looked around 1900, climb into the underworld of the Leipzig Völkerschlachtdenkmal. This huge building was built on the urban waste of the city of Leipzig.). There were regulations for the installation of landfills necessary. Site selection, operation and remediating requirements have been met and approaches to a licensing system are developing. The erection of sealing systems was not yet common, characteristic is a large number of operated landfills, almost every city and every village has its own landfill.

The EU Commission estimates that there are approximately 500,000 waste dumps in the EU Member States.

We can refer to this stage of development as **Landfill2.0**.

Brandenburg and the other new federal states were at the end of this stage of development at the time of the political change 1989/90.

In the 1970s, and especially in the 1980s, many countries developed strong environmental awareness and awareness of the environmental impact of landfill. The state-of-the-art landfill

technology has developed rapidly, with the standard of equipping landfill and surface landfills with sealing systems and designing operations to minimize landfill emissions. The deposit of waste is thereby expensive, an economically landfill operation was only possible for a few large landfills. This phase was therefore also characterized by the closing of many no longer needed landfills.

At the same time, the countries' waste economies are developing into recycling economies, the focus of legislation and in the waste hierarchy the waste's prevention and recovery goes moved to the top, and waste disposal, e.g. by landfill, moved to the end of the hierarchy.

In people's minds, such developments can often only be realized through the payment of money, which, in turn, has the consequence for landfills that cheap landfill volume must be systematically taken out of the market by closing and remediating landfills that are no longer needed. This is a mandatory requirement for the establishment of a modern circular economy. In states at the end point of this development, landfills that are no longer needed are therefore remediated or plans and programs for carrying out the remediation exist.

At the end of this development we reached the level of **Landfill3.0**.

It is fair to say that, for example, Germany has reached this stage. The construction of landfills under existing legislation ensures a very high level of environmental protection over several generations.

However, some countries, including COCOON partners, are debating whether this stage is the endpoint of landfill development. It is to be noted that landfill sealing systems, like all human structures, have a definite lifetime and thus limited-life protection systems (the German Landfill Ordinance from 2009 requires sealing systems to demonstrate operability over 100 years), envelop dump bodies with conserved pollutant potential, and that it must be assumed that in the case of failure of the seals this potential can be brought to life again. Based on this insight, new landfill concepts are being developed. These concepts are summarized as "enhanced landfill management".

If the goal of the development of the landfill site is the landfill, which is not a threat to the environment even in the distant future, a further development step towards the **Landfill4.0** is needed.

This level can - theoretically - be achieved in the following ways:

- complete inertisation of landfill bodies
- development of sealing systems which are durable over geological periods and which safely exclude elution of pollutants
- Disposal of landfill by dumping, e.g. through landfill mining projects
- organizational and financial security of an eternal repair operation.

Is it conceivable that one of these levels can be skipped? Is it possible, for example, to get to landfill4.0 from landfill2.0?

This would be possible if technologies for the complete inertisation of landfill bodies or everlasting sealing systems were available.

However, this is not the case. Although important steps have been taken in the direction of inertization by removal of the biodegradable parts of waste, complete inerting of the landfill bodies can not be effected thereby. For incineration or mechanical-biological treatment, as well as subsequent in-situ stabilization, leave the inorganic pollutants untouched. For landfills for mineral waste, this form of pollutant removal is ineffective.

The author is aware of neither sealing systems of infinite durability nor of researches which seek to develop such sealing systems. The same applies to methods for inerting the landfill body.

The currently more realistic option for permanently sure landfill is the legal and financial implementation of a permanent repair operation. However, it remains interesting to observe how alternative landfill concepts, which not only see a danger potential in the landfill but also a raw material and land potential, develop and complement the well-known concept of encapsulation of landfill bodies.

In addition, the question will be investigated on which level the landfill is located.

Europe

The requirements for the construction and operation of landfills are set out in Council Directive 1999/31 / EC of 26 April 1999 on the landfill of waste (European Landfill Directive) [01].

The European Directive requires the presence of a geological barrier for the protection of soil and groundwater and (in the case of landfills for non-hazardous and hazardous waste) the establishment of a basic sealing system (see Annex 3, point 3) as a rule variant. The absence is permitted if, on the basis of a risk assessment, the competent authority has established that there is no risk to soil and groundwater.

- Deponie für gefährliche Abfälle: $K \leq 1,0 \times 10^{-9}$ m/s; Mächtigkeit ≥ 5 m;
- Deponie für nicht gefährliche Abfälle: $K \leq 1,0 \times 10^{-9}$ m/s; Mächtigkeit ≥ 1 m;
- Deponie für Inertabfälle: $K \leq 1,0 \times 10^{-7}$ m/s; Mächtigkeit ≥ 1 m;

Sickerwassersammlung und Basisdichtung

Deponieklasse	Nicht gefährlich	Gefährlich
Künstliche Abdichtungsschicht	Erforderlich	Erforderlich
Drainageschicht $\geq 0,5$ m	Erforderlich	Erforderlich

Figure 1: Requirements of the EU Landfill Directive for geological barriers and basic sealing system

The European landfill directive is less consistent in the requirements for surface sealing. The application of a surface seal to the landfills covered by the Directive is formulated as an optional provision, even if a "hazard to the environment" is identified.

Annex 1, point 3.3, last paragraph:

'If the competent authority, after weighing up the risk to the environment, considers that the formation of leachate must be prevented, a surface seal may be required.'

In this case, the guideline recommends the following structure:

Deponieklasse	Nicht gefährlich	Gefährlich
Deponiedrainageschicht	Erforderlich	Nicht erforderlich
Künstliche Abdichtungsschicht	Nicht erforderlich	Erforderlich
Undurchlässige mineralische Abdichtungsschicht	Erforderlich	Erforderlich
Drainageschicht $> 0,5$ m	Erforderlich	Erforderlich
Oberbodenabdeckung > 1 m	Erforderlich	Erforderlich

Figure 2: Recommendation of the European landfill directive for the construction of surface sealing systems

In view of the fact that a basic sealing system is required for 2 landfill classes, this formulation seems a bit strange. Because one should assume that a landfill, which was equipped with a base seal, also receives a surface seal. If the pot has no lid and is in the rain, it will overflow at some point.

The extent to which the level of landfill3.0 is achieved by applying the European Landfill Directive depends very much on the actual implementation of the recommendation in the individual Member States.

As far as the author is aware, within the framework of the regulations of the new waste management package, an adaptation of the landfill directive was only necessary, as was necessary to implement the requirements of the circular economy, the requirements for the de-pollution have not changed (Dr Biedermann will tell us more about this at this conference).

The author is not aware of any directives or recommendations for action at European level for handling landfills whose deposition phase ended before the entry into force of the European Landfill Directive.

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Following a question from the Member of the European Parliament Hilde Vautmans (Parliamentary Question E-007864/2015), the European Commission replied as follows (Official answer of the EC 28-7-2015):

- The European Commission has no strategy in dealing with the 150,000 to 500,000 Landfills on the territory of the European Union.
- The European Commission has no idea about the costs of rehabilitation these landfills.
- There is no promotion of landfill mining projects in the EU.

These findings prompted MEPs during a workshop on landfills to invite representatives of public authorities, waste management companies and scientific institutions present to provide the EU Commission with guidance on how to develop such a strategy [02].

This not only in terms of the fact that the landfills can not only cause an environmental impact, but also in terms of the fact that the landfills represent a considerable raw material and land potential.

The mentioned number of up to 500,000 in the territory of the EU sounds gigantic, but is not unlikely. In Brandenburg (2.5 million inhabitants), more than 5,000 waste deposits were

counted after the political changes, of which about 3,000 can be regarded as landfills in terms of waste legislation. The vast majority of these landfills, however, is small and harmless.

Germany

The German landfill philosophy follows the multibarrier concept developed by STIEF. According to this, several barriers that act independently of each other should prevent that emissions caused by landfills are polluting the environment.

In the years following its creation, the multibarrier concept has undergone a small but significant change. In its fundamental article 1986 [03], STIEF mentioned the following barriers:

- the landfill site
- the landfill base sealing system
- the landfill body
- the surface sealing system
- the use
- the aftercare and the controllability and reparability of the barriers

In a textbook [04] the multibarrier concept is described 8 years later as follows:

- 1st barrier: Waste treatment
- 2nd barrier: geology and hydrology of the site
- 3rd barrier: landfill body with predictable behavior
- 4th barrier: the basic sealing system
- 5th barrier: the surface sealing system
- 6th barrier: the aftercare and the controllability and reparability of the barriers.

By treating the waste to be deposited with the aim of eliminating the biologic degradable components, a largely inert landfill body is to be produced. The disposal of waste with biodegradable components is prohibited in Germany since 01.06.2005.

The multi-barrier concept is therefore implemented for all landfill bodies arising after this date. However, according to the Landfill Ordinance [05], which has been in force since 2009, the principle that the immediate application of the surface sealing system takes precedence over subsequent inerting of the landfill body still applies to the old bodies. Suggestions to anchor technologies for inerting the landfill body more strongly into the landfill-specific regulations [06] and to allow at least a equivalent alternative to the surface sealing could not prevail in the new version of the 2009 Landfill Ordinance.

The disadvantage of this procedure, that the pollutant potential inherent in the landfill body is preserved with a quick and complete encapsulation, was accepted.

The construction of waterproofing systems was almost perfected in Germany. High demands are placed on the materials, components and systems used in landfill construction, compliance with which must be proven in approval procedures (see Annex 1, No. 2.1 of the Landfill Ordinance). 8 directives and 34 approvals of the Federal Institute for Materials Research and Testing for artificial sealing layers and geo-synthetics as well as 24 federal uniform quality standards and 9 federal uniform approval assessments of the LAGA-ad-AG landfill technology for landfill construction materials for other landfill construction materials guarantee the high standard of landfill construction in Germany.

In the approvals and suitability assessments the proof of functionality is provided over a period of 100 years. The consistent implementation of the multibarrier concept means that the environment is reliably protected for several generations from the danger caused by landfills.

But also 100 years are over once.

Currently, the German regulation system is based on the assumption that the application of sealing systems guarantees the long-term safety of landfills. Consequently, after a sufficiently long after care phase (the Circular Economy Act requires the financial security of the aftercare for at least 30 years), it is possible to set up the observation of landfills and to release the landfills from the waste authorities supervision. Financial provision for the period thereafter does not have to be made according to legal requirements.

This view is increasingly being discussed in Germany's landfill community and, according to the author, will not be able to endure in the light of the above.

A working group set up by the Waste Working Group of the German states has found that there are circumstances that prevent an ending of the after care phase [7]. In particular, securing the permanent stability of the landfills and the sealing systems is considered critical. Furthermore, it is stated that the soil protection authorities responsible after the end of the after care phase do not have sufficient legal instruments to act in the event of problems with closed landfills.

From the point of view of the author of this article, it is therefore necessary to change the legal regulations towards ensuring a "permanent repair operation". The regulatory and supervisory powers and the financial provisions must be regulated so that long-term repairs are guaranteed.

This will not be achieved by tightening the criteria for ending of the aftercare phase alone. This will only lead that the current regulations on the ending of the after-care phase are going to nowhere. It is advisable to say goodbye to the idealized idea of a permanently safe landfill.

Other states of the EU

Many EU Member States are on their way from landfill 2.0 to landfill3.0. How far they have advanced in this way, the representatives of these states can best judge for themselves.

Although this connection is not mandatory, it is reasonable to assume that there is a connection between the state of landfill and the transformation of waste management into a genuine circular economy. The latter is reflected in the amount of municipal waste landfilled at landfills.

The following table shows the amount of municipal solid waste landfilled at COCOON partner landfills (for sub-regional partners, data from Member States were used as a basis).

	Einwohner	Deponierte feste Siedlungsabfälle (kg/Ew.)	Anteil am Gesamtaufkommen fester Siedlungsabfälle (%)	Gesamtmenge deponierter fester Siedlungsabfälle
Andalusien	8.380.000	239	55	2003
Brandenburg (einschl. Berlin)	6.070.000	6	1	36
Zypern	855.000	443	76	379
Flandern	6.516.000	4	1	26
Malta	440.000	564	80	248
Niederlande	16.901.000	5	1	85

Figure 3: Data on landfill of municipal solid waste in COCOON partners' territory according to [08]

To supplement: In the reporting period, the amount of solid municipal waste landfilled in landfills in the Czech Republic was 282 kg / eh and a) and in Slovakia 207 kg / eh and a), which was 56% (Czech Republic) and 66, respectively % of total municipal solid waste.

The following chart shows the total amount of waste dumped in the COCOON partner regions.

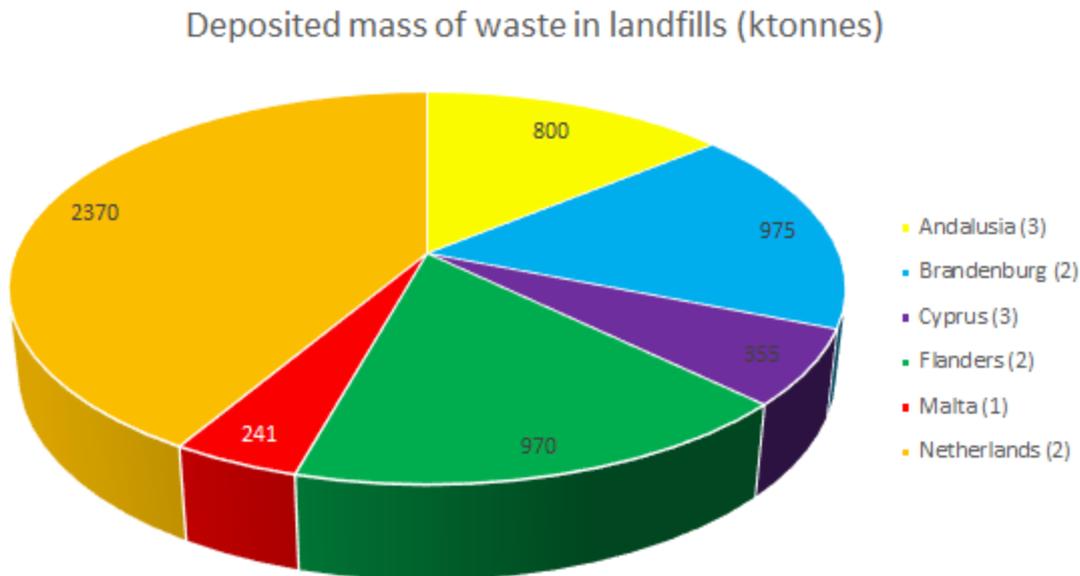


Figure 4: Total amount of landfilled waste on the territory of the COCOON partners (from [08])

What conclusions can be drawn from these figures?

The state of development of waste management towards circular economies differs strong between the COCOON partners.

In Flanders, the Netherlands and Brandenburg are the predominant ones amount of waste landfilled with waste other than municipal solid waste (mineral waste from construction and industry). In the small island states Malta and Cyprus, on the other hand, will have little or no other than permanent settlements deposited on landfills.
(The numbers provided by Andalusia are contradictory.)

From the number of landfills still in operation and those already secured, certain conclusions can also be drawn.

Number of operational landfills

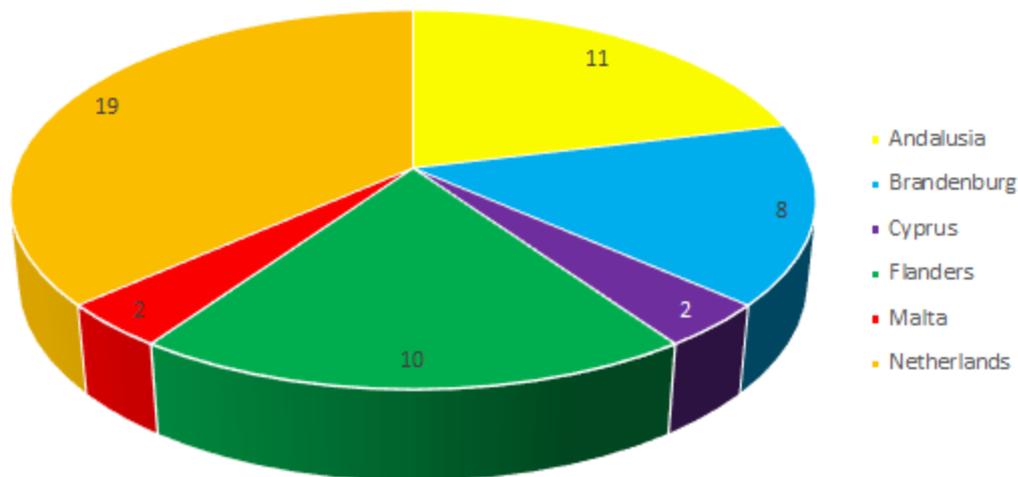


Figure 5: Number of landfills operated on the territory of the COCOON partners (from [08])

The number of landfills still in operation is small in all partner regions. This can be interpreted as meaning that all partners are on their way to landfill3.0.

More differentiated is the assessment of the closed landfills.

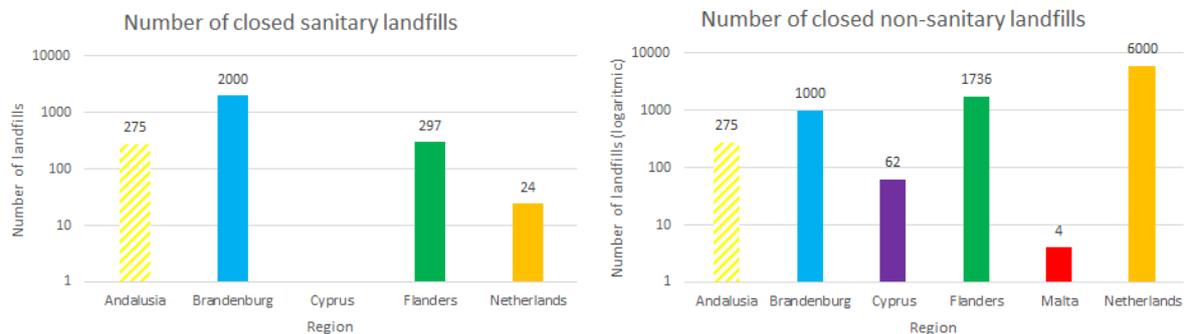


Figure 6: Number of closed rehabilitated and non-rehabilitated landfills in the territory of the COCOON partner (from [08])

The indication of rounded or unclear numbers (Netherlands, Brandenburg, Andalusia) suggests that there is no exact information. Other sources show, that Flanders and Brandenburg have exact numbers. In Cyprus, no landfill site has yet been remediated, surprising the number mentioned by the Netherlands.

(To the indication "Brandenburg": The waste management program Brandenburg 1997 gives a very exact number with 5193 determined deposition sites. The distinction between landfills covered by the waste legislation and old landfills falling within the scope of the soil protection law, which differs from the end of the waste deposition, becomes difficult - after or before 01.07.1990 - this finding is difficult on a case-by-case basis, which is why the author gave an estimate.)

During the COCOON meetings, the author was able to convince himself of the efforts of the project partners to adapt the landfills operated to the standard of the European landfill directive (including the construction of treatment facilities) and to rehabilitate abandoned landfills. In the most cases the visited landfills and facilities do not need to shy away from comparisons with the state of the art [09] [10] [11]).



Image: closed and remediated landfill Puente Genil in Andalusia (from [08])

The COCOON project members made the following conclusions and stated in [08] the following recommendations:

1. The requirements of the EU Landfill Directive are implemented by the competent authorities in each COCOON partner. Different timeframes for implementation have been identified.
2. The information on closed landfills is not at the same level as for the landfills operated. There is no consistent monitoring system for these closed landfills. Each of the partners pointed out that there are specific rules, but they do not always correspond with each other or with the Landfill or Waste Management Acts.
3. It is important to note that landfills closed before the implementation of the EU fall outside the scope of the Directive. For closed landfills the directive has only an advisory function.
4. The current knowledge about closed landfills is unsatisfactory. The experience shows that the introduction of a modern waste management is not possible if the continued use of officially closed landfills is not prevented consistently and these landfills are not rehabilitated. The EU should encourage measures to collect data on closed landfills and their rehabilitation in all Member States.

The landfill regulation in the **Netherlands** differs from the German regulations in 2 notable cases.

The legal basis for aftercare can be found in the Environmental Management Act. The requirements for carrying out aftercare are laid down in Chapter 8 and the financial regulations in Chapter 15.
(A full list of legal standards applicable to landfills in the Netherlands and Belgium can find in [08].)

Every landfill operator in the Netherlands must become a member of a fund company that takes over the after care of the landfills. The carriers of the fund companies are the provinces. Landfill operators must pay funds to the fund at a level set by the provinces, so that the after care of the total number of landfills in the province, including any repair work, can be covered indefinitely. All landfill owners, including those under public law, are affected by this rule because, according to the Dutch colleagues, public landfill owners may become insolvent under Dutch law [12].

In the opinion of the author, this provision offers a number of advantages over German practice.

- The implementation of aftercare is no longer dependent on the financial capacity and the financial performance of the individual landowner. Insolvencies of individual landfill operators are cushioned and do not burden the public sector.
- The burden of aftercare is borne by the community of landfill operators in each province. This may be burdensome for individual landfill operators and relieving for others. Overall, the financial burden on the individual landfill operator is likely to be lower than if each individual landfill operator were to face the financial risk. In that regard, the fund model is similar to an insurance model.
- The implementation of aftercare is raised to the rank of a state task, is thus clearly regulated and secured for a long time.

Of course, the implementation of the regulations goes not without problems on the stage. Thus, the amount of funds to be paid is a constant point of discussion between the province and the landfill operator (the Dutch colleagues did not mention absolute figures in their presentation). Also, the provinces operate not uniform.

On the basis of a regulation known as Greendeal "sustainable landfill management" (2015), the aim is to render the landfill body inaccessible by treating the landfill body (aeration, infiltration of water) in such a way that the landfills can be secured without requiring a surface seal (or at least should the requirements be simplified) can be performed. The deal is therefore in "landfill treatment against waiver of surface sealing". In addition there are 3 pilot projects, the results of which are expected to be available in 2026 [13].

The technical approach is very similar to the one proposed in [06] and funded under the National Climate Initiative on in-situ stabilization of landfill sites in Germany.

It seems worthwhile to the author to follow the work of the Dutch colleagues. The clarification of such questions should be interesting, as far as the biodegradation is to be driven forward, in order to obtain what "reward" in the form of reducing the Oberflächenab-seal. The success of the pilot projects is also of interest.

In **Belgium**, based on some of the legal foundations of the Flemish regional government (Soil Remediation Decree), the focus is on the dismantling of landfills.

The motives for carrying out landfill redevelopment projects can be the following:

- Elimination of a danger emanating from the landfill
- Landfill removal as an alternative to conventional security
- extraction of raw materials and materials (landfill mining)
- Extraction of land

The fact is that the disappearance of a landfill also their potential danger disappears. In particular, if this is accompanied by the destruction of the pollutant potential of the waste, landfill decommissioning represents a superior alternative to securing by surface sealing and thus a conceivable way to landfill4.0. But also the shift of the pollutant potential to a better one securing or less sensitive location can be an improvement of the situation.

The dismantling of a landfill is indeed the more sustainable, but also much more expensive variant of landfill remediation.

The Belgian colleagues in cooperation with the scientific institutions of other Member States of the EU see a significant resource potential in the landfills ("Landfill mining"). Also, the extraction of land in a densely populated country like Belgium has a higher priority than for example in Brandenburg. However, they also agree with their German colleagues that landfill mining as a method of extracting raw materials is not currently economically viable. In Germany, the dealing with landfill mining was essentially ended with this statement.

In Belgium, however, extensive research projects are initiated, mainly funded by the European Union, with the aim of improving the efficiency of landfill mining ("enhanced landfill mining"). This will be done through improved processing technology and waste composition analysis methods. As a basis of a successful landfill mining concept, the thorough exploration of the landfill is seen [14].

In addition, Belgium regards landfill dismantling as part of "enhanced landfill management" strategy. In addition to the possibility of using the raw material potential, landfill mining is to be established as a remediation variant. Decision support will be developed to take account not only of the landfill site but also of the landfill environment and to allow landfill owners and competent authorities to determine the appropriate remediation procedure [15].

It remains exciting to see how this alternative variant of landfill remediation will develop in addition to the classic remediation variant of encapsulation that is perfected in Germany.

The Belgian colleagues are working together with members of the European Parliament and have also tried to implement landfill mining under the European Waste Package in the European Landfill Directive. However, this failed in the so-called trilogue procedure. From the author's point of view, the Commission's position on this issue is understandable. The fear of frightening states that have made troublesome their way from Landfill2.0 to Landfill3.0 with elements of Landfill4.0 and thus failing the entire regulatory package seems realistic.

The different levels of development of waste management in EU member states in general and landfill specificity in particular must be taken into account in EU legislation.

From the author's point of view, the following approach by the EU Commission should be welcomed:

- The state of the art of landfills, in particular the remediating of landfills, should be in the European landfill directive and the requirements are made more concrete.
- Measures and programs for the collection of informations, mapping and rehabilitation of those landfills countries outside the scope of the EU Landfill Directive should be supported financially and through workshops, promotion of best practices examples and so on.
- Measures and programs under the Enhanced Landfill Management program which show the road to Landfill4.0 should also be financially supported by support programs and in the context of workshops, promotion of best practices examples and so on be made known.

The author's experience of participating in the COCOON project is that even looking at improving the landfill site in Germany, a look beyond one's own nose does not hurt.

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