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Sustainable Remediation of a Closed Solid Waste Landfill Site: Development and Application of a Holistic Approach

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Although in the last decades site remediation activities have received more attention and funds, the high cost required for the remediation projects and the limited resources available have resulted in a limited implementation of site remediation practices. Considering the recent economic crisis which has taken several countries worldwide, most contaminated sites could remain so. For instance, a large number of closed landfill sites are present in the territory and they could require a lot of money for remediation. It is obvious that the redevelopment of the site can play a major role in the sustainability of the remediation project. In this study a guideline was developed to evaluate the sustainability of site remediation and reuse projects. This guideline is based on a holistic approach which takes into account all the factors related to the site remedial actions, including political-decisional factors, social-economical factors, environmental factors, and technical factors. The developed guideline was applied to evaluate the sustainability of the remediation of a closed municipal solid wastes landfill site. In particular, it was proposed the reuse of the landfill restored site as a solar park. Obtained results have demonstrated that the restoration and land reuse projects is sustainable only when government subsidies are provided.

1. Sustainability of site remediation

The interest in "Sustainable Remediation" and in "Green and Sustainable Remediation" has grown in the recent years (U.S. EPA, 2008). For example, in the United States "The Interstate Technology & Regulatory Council-Green and Sustainable Remediation Team" has recently produced a very interesting document on "Green and Sustainable Remediation" (ITRC, 2011). This document shows that there is a global consensus on the concepts of green and/or sustainable remediation but that there is not a general guideline to apply these concepts. Several methods are investigated and used for evaluating the sustainability of actions. Among these, the Life Cycle Analysis (LCA) and the Net Environmental Benefit Analysis (NEBA) are the most used. Recently, an increasing interest on the use of LCA (Schnoor, 2009) has been observed. However, this tool has limitations due to the rigidity of the inventory and its incapability to specific cases (Morais and Delewrue-Matos, 2010). For example, the absence of evaluation of water consumption (Cooney, 2009) and the lack of spatial and temporal information represent significant limitations that some researchers are trying to overcome developing "dynamic" LCA (Levasseur et al., 2010) or using ad hoc models; a method was developed for assessing the environmental impacts of freshwater consumption (Pfister et al., 2009) and a model was proposed to evaluate impacts from water unavailability in LCA analysis (Boulay et al., 2011). In particular, in the context of the assessment of the sustainability of remedial actions and site redevelopment, it appears necessary to integrate the LCA procedure with specific site information and with the public perception. The NEBA is another methodology that can be used as an alternative to LCA and whose objective is to evaluate the changes in the values of natural resources associated with different soil management alternatives (Efroymson, et al. 2004). The NEBA has the advantage of being more flexible and adaptable than the LCA (Colombo et al., 2012). However, limited information for applying these methodologies to the remediation of contaminated sites is available. Therefore, the goal of this study is to develop and apply a holistic approach for the evaluation of the sustainability of site remediation projects.

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2. Development of a guideline for the evaluation of the sustainability of site remediation projects

On the basis of the concepts of Sustainable Remediation and NEBA (Ellis and Hadley, 2009) and on the holistic approach developed for the assessment of the sustainability of wastewater reuse (Roccaro and Vagliasindi, 2007), a guideline has been developed for evaluating the sustainability of site remediation. This guideline has been developed by integrating the Italian administrative procedure set by the current regulation (D.L. 152/2006) with all factors related to remediation and reuse of contaminated sites. These factors can be grouped into the following categories: technical factors; social and economical factors; environmental factors; political decision-making factors. With regard to technical factors, a remedial action is characterized by: a cognitive phase (site inspection), a risk analysis for the determination of contaminant maximum limit, and, if needed, the implementation of remedial actions (US EPA, 1994) and environmental restoration. Social and economical factors play a key role; the social aspect, perhaps too often overlooked, also contributes to the success of a reclamation and reuse project. For example, the public perception is critical. Economical factors are the basis for every decision and implementation of activities. However, it is difficult to quantify social indicators which are often qualitative. Environmental factors are those that determine the need for intervention. All environmental impacts should be identified and, if possible, quantified. Political decision-making factors focus on the relationships and interactions of the action with the territory and the citizens. Political decision-making factors include regulatory aspects, land planning, availability or funds research and any Government incentives.

The proposed approach tries to assign a cost to each factor, in order to have a guideline useful for the evaluation of the appropriate remedial actions and site redevelopment. Furthermore, to take into account the depreciation over the life period of the reused site, all factors related to the remedial actions and redevelopment site activities, whenever possible, are expressed in Euros per year of the redeveloped site life time. The proposed guideline includes the following stages:

- Identification of the sustainability factors;
- Analysis of the screening factors;
- Site inspection and risk analysis;
- Evaluation of the context factors;
- Evaluation of alternative site redevelopment/reuse;
- Evaluation of process factors;
- Identification of the site remedial actions;
- Evaluation of the cost factors;
- Evaluation of the sustainability remediation index (SRI).

The first phase of the methodology involves the identification of sustainability factors which have a part in the evaluation procedure. Tables 1, 2 and 3 list a set of sustainability factors, which can be integrated with other factors if necessary. Furthermore, Tables 1, 2 and 3 show the category of the factors (political decisional factors, environmental factors, social and economical factors and technical factors) and the description of each factor together with its unit. The second step involves evaluation of screening factors (listed in Table 1) that are needed for the site characterization and risk analysis. The third step involves the assessment of the context factors (also listed in Table 1) and the identification of one or more site reuse alternatives, while the next phase includes the evaluation of the process factors (listed in Table 2) which determine the type of remedial actions and related technology to be employed in order to fulfill the target quality standard, while minimizing the impacts generated by the same remedial action. The next phase is dedicated to the evaluation of the cost factors (listed in Table 3) which are expressed in Euro per year and contribute to the calculation of the SRI. Indeed, in order to calculate this index it is necessary to define the site useful life in years (from the beginning of the remedial action to the end of the site reuse) and to compute the cost factors in EUR per year of site life. The SRI is defined in Eq.(1).

$$SRI(€/year) = (PuF + PrF + GS + VRS - RCC - SRCC)\frac{i(1+i)^n}{(1+i)^n - 1} + (ISR - ROM - SROM) \quad (1)$$

where:
i = interest rate;
n = serviceable life of the site;
the other factors are defined in Table 3.

Table 1: Screening and Context Factors

Factor	Phase	Category	Description and unit
Normative	Screening	Political-decisional	It can also be considered in other phases
Health	Screening	Technical	Considered in the risk analysis
Contaminant properties	Screening	Technical	Type, concentration, bioavailability, etc.
Fate of the contaminant	Screening	Technical	Based on the contaminant properties (e.g. Kow)
Mining and transportation	Screening	Technical	Material for mining, transportation and disposal (kg)
Contaminated matrix	Screening	Technical	Impact on site remediation method and technology
Water protected or reclaimed	Screening	Environ.	Amount of water protected or reclaimed (m^3)
Soil protected or remediated	Screening	Environ.	Amount of soil protected or remediated (m^3 or m^2)
Biodiversity	Screening	Environ.	Number of protected species
Habitat	Screening and Context	Environ.	Characterization of the site habitat (useful for the risk analysis and for the alternative post-restoration site use)
Social economical context	Context	Social-economical	Non-monetary evaluation useful to set constrains for the post-restoration site use
Site characteristics	Context	Environ.	Based on geography, topography, etc. (useful for the selection alternative post-restoration site use)
Existing constrains	Context	Environ.	Constrains to be considered during the site remediation and/or post-restoration site use
Planning	Context	Political-decisional	The site remediation and restoration project must be integrated with the existing plans
Public perception	Context	Political-decisional	Public must participate in the decision concerning the site remediation and/or post-restoration site use

Table 2: Process factors

Factor	Category	Description and unit
Remedial process and technologies	Technical	Possible process and technology to be applied
Impact of process on water	Technical	Water consumption (m^3) and wastewater production (m^3)
Impact of process on air	Technical	Green gas emission (CO_2 equivalent)
Impact of process on habitat	Technical	Impact on fauna and flora
Impact of process on noise and vibration	Technical	Produced dB
Impact of process on energy	Technical	Consumed kWh
Impact of process for odour emission	Technical	Odour analysis
Impact of process on worker's risk	Technical	Based on dangerous materials, technologies, number of working hours
Impact of process for light	Technical	Impact of artificial light
Impact of process on waste	Technical	Produced dangerous and not dangerous waste (kg)
Impact of process on material consumption	Technical	Used material from other sites (kg)

Table 3: Cost factors

Factor	Category	Description and unit
Capital cost for the remediation (RCC)	Social-economical	Cost of the site remediation activity (€)
O&M cost of the remediation (ROM)	Social-economical	Operation and management costs associated to the monitoring activities pre and post remediation (€)
Capital cost for the site reuse (SRCC)	Social-economical	Cost for the realization of the post-restoration site use (€)
O&M cost for the site reuse (SROM)	Social-economical	Operation and management costs associated to the post-restoration site use (€)
Income for the site reuse (ISR)	Social-economical	Economical development through (work position, industry, tourism, energy production, etc.) (€)
Value of the restored site (VRS)	Social-economical	Valued of the site after the remediation and restoration (€)
Government subsidy (GS)	Social-economical	Funds from the Government for specific activity (€)
Private funds (PrF)	Social-economical	Non public funds (€)
Public funds (PuF)	Political-decisional	Funds available from the local governments(€)

3. Application of the proposed guideline to a case study

The developed methodology was applied to a closed municipal solid waste (MSW) landfill site. It is located in the southern part of Sicily, with an extension of 157,200 m^2 and a volume of waste of about 700,000 m^3. As a result of the site characterization and risk analysis, the remedial activities conducted were:

- Slopes stabilization of the landfill;
- Containment by landfill cover (capping);
- Realization of a system for collection and management of biogas;
- Realization of a leachate collection and management system;
- System for the collection and disposal of surface water.

These remedial actions were financed by the Commissioner for Emergency Waste and Remediation of Contaminated Sites for a total amount of € 6,577,000. Thanks to the availability of such public funds the operation was feasible. However, in the absence of public funds it would have been difficult to realize this remedial activity. In addition, it is necessary to point out that in the present case, as in many other similar cases, post-remediation management is paid by the local authorities (for example the municipality).

In order to assess the sustainability of remediation and reuse of the site, even in the absence of the above funding, the proposed guideline was applied under different scenarios. Based on the analysis of the context factors (Table 1), the redevelopment and reuse of the site involves the construction of a solar park to cover all the available area. One of the context factors that had a substantial weight in the choice of the functional use of the site is the "geography of the site". In fact, the site is exposed to South, ensuring the optimal exposure to sunlight, while it is far enough from the town making quite inappropriate any recreational use. The objective was therefore the reuse of the area as a solar park, receiving the government subsidy through the incentive tariff which was recognized for 20 y from the date of commissioning of the photovoltaic (PV) system. However, it should be pointed out that the incentive rate (€/kWh) decreased over the years. In particular, from the 2012 was no longer available for that king of PV application. Table 4 reports the cost of the PV plant, calculated considering a net area of 50,000 m^2, an installed capacity of 3.0 MW and a cost per kWp variable over time due to the reduction in the market price of the PV panels. Considering a specific energy production of 1,400 kWh/kWp (for irradiation value adopted in Sicily) and the incentive rates provided by the laws under different time scenarios, the values of the incentives and the SRI have been calculated, as shown in Table 4. Table 5 shows the main cost factors calculated for the purposes of the proposed guideline. The values of the SRI demonstrate that the sustainability of the intervention is achieved only when the subsidy is available (years 2008-2011). In these cases, the remedial activities could have been realized, even without the public funding provided from the Commissioner. From the 2012 the PV installations on the ground was not allowed, but in any case the subsidy had been not sufficient to result in a positive value of the SRI. It is clear that the presence of the subsidy for the solar plant is of fundamental importance for the sustainability of the restoration of abandoned landfills and therefore this subsidy should be provided by the government for specific cases like this.

Table 4: Investment cost of photovoltaic (PV) plant, incentives provided by the regulations at different time scenarios and relative values of SRI (assuming i = 5 %, and n = 20, available area 50,000 m^2, installed power 3,000 kWp, specific energy production 1,400 kWh/kWp)

Scenario	Specific cost of PV plant. (€/kWh)	Capital cost of PV plant - SRCC (€)	Subsidy for PV (€/kWh)	Subsidy for PV - ISR2 (€/y)	SRI (€/y)
2008	4,000	12,000,000	0.400	1,800,000	615,832
2009	3,500	10,500,000	0.392	1,764,000	579,832
2010	3,000	9,000,000	0.384	1,728,000	543,832
Jan-Apr 2011	2,000	6,000,000	0.313	1,408,500	224,332
May-Aug 2011	2,000	6,000,000	0.289	1,300,500	116,332
Sept-Dec 2011	2,000	6,000,000	0.264	1,188,000	3,832
Jan-June 2012	2,000	6,000,000	0.203	912,600	-271,568
July-Dec 2012	2,000	6,000,000	0.182	819,000	-365,168
No subsidy	2,000	6,000,000	0	0	-1,184,168

Table 5: Values of the main cost factors under different scenarios

Activity	Factor	Cost
Capital cost for remedial activities (€)	RCC	6,577,000
PV plant (solar park) (€)	SRCC	(see Table 4)
Income from produced energy sold at 0.095 €/kWh (€/y)	ISR1	540,000
Subsidy for PV (€/y)	ISR2	(see Table 4)
O&M cost for the remedial activities (€/y)	ROM	85,000
O&M cost for the PV plant (solar park) (€/y)	SROM	36,000

4. Conclusions

The remediation of contaminated sites supports the goal of sustainable development but may also have social, environmental and economical impacts at a local, regional and global scale. In particular, the high cost required for the remediation projects is a relevant issue. For instance, a large number of closed landfill need to be restored and the post-restoration land uses could play a major role in the sustainability of the remediation project. Therefore, in this study a holistic approach was developed to assess the sustainability of site remediation activity. This approach resulting in a guideline was applied to a case study which is a closed solid waste landfill site. Among the redevelopment site alternative, the solar park was found the most sustainable. However, considering the government subsidies for PV plant which decreased up to zero in the last years, the sustainability of the site remediation and reuse site as solar plant changed with the time of intervention. The developed guideline could be useful for local authorities and decision makers in order to compare the sustainability of different site remediation projects and, therefore, to identify priorities.

References

Boulay A.-M., Bulle C., Bayart J.-B., Deschenes L., Margni M., 2011, Regional Characterization of Freshwater Use in LCA: Modeling Direct Impacts on Human Health, Environ. Sci. Technol., 45, 8948–8957.

Colombo F., Nicolette J., Wenning R., Travers M., 2012, Incorporating Ecosystem Service Valuation in the Assessment of Risk and Remedy Implementation, Chemical Engineering Transactions, 28, 55-60, DOI: 10.3303/CET1228010.

Cooney C., 2009, LCA finally takes water into account, Environ. Sci. Technol., 43 (11), 3986–3986.

Efroymson R., Nicolette J., Suter G., 2004, A framework for net environmental benefit analysis for remediation or restoration of contaminated sites, Environmental Management, 34 (3), 315-331.

Ellis D.E., Hadley P.W., 2009, Sustainable Remediation White Paper—Integrating Sustainable Principles, Practices, and Metrics Into Remediation Projects, Wiley Interscience (www.interscience.wiley.com), DOI: 10.1002/rem.20210.

ITRC (Interstate Technology & Regulatory Council), 2011, Green and Sustainable Remediation: State of the Science and Practice, GSR-1, Washington, D.C.: Interstate Technology & Regulatory Council, Green and Sustainable Remediation Team, www.itrcweb.org, accessed 24.03.2013.

Levasseur A., Lesage P., Margni M., Deschênes L., Samson R., 2010, Considering Time in LCA: Dynamic LCA and Its Application to Global Warming Impact Assessments, Environ. Sci. Technol., 44, 3169–3174.

Morais S.A., Delewrue-Matos C., 2010, A perspective on LCA application in site remediation services: critical review of challenges, J. Hazard. Mater., 175 (1-3), 12-22.

Pfister S., Koehler A., Hellweg S., 2009, Assessing the Environmental Impacts of Freshwater Consumption in LCA, Environ. Sci. Technol., 43 (11), 4098–4104.

Roccaro P., Vagliasindi F. G. A., 2007, Sustainable wastewater reuse: development and application of a holistic approach, Proceedings of 6th IWA Specialist Conference On Wastewater Reclamation And Reuse For Sustainability: Guiding the growth of water reuse, Antwerp, Belgium, October 9-12, 2007.

Schnoor J.L., 2009, LCA and Environmental Intelligence? Environ. Sci. Technol., 43 (9), 2997–2997.

U.S. EPA (Environmental Protection Agency), 1994, Remediation Technology Screening Matrix and Reference Guide. Second Edition. EPA/542/B-94/013.

U.S. EPA (Environmental Protection Agency), Office of Solid Waste and Emergency Response, 2008, Green Remediation: Incorporating Sustainable Environmental Practices into Remediation of Contaminated Sites, EPA 542-R-08-002, April 2008.