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Sustainability Index: Green and Sustainable Evaluation of Active and Passive Remediation Techniques

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Abstract

Green and sustainable remediation (GSR) is major goal for the United States Department of Energy's Office of Environmental Management (DOE-EM). Pacific Northwest National Laboratory (PNNL) recently published an exit strategy for pump and treat remediation technologies as part of an effort to move away from active remediation in favor of passive techniques. In the summer of 2016, a team of interns developed a high level sustainability analysis comparing active and passive remediation technologies at Hanford 100 and 200 area sites and the Mound, Ohio site. The sustainability index attempts to quantify the relative sustainability of active and passive remediation strategies by examining a variety of metrics and perspectives from those involved in the decision-making process. The analysis compares 10 metrics encompassing environmental, social, and economic aspects of sustainability for the two types of remediation techniques. It also incorporates the perspectives and values of the investors, regulators, scientists, and community members involved in the decision-making process. Data collected through surveys for active and passive remediation technologies at Hanford 100 and 200 area sites and the Mound, Ohio site was inputted into a spreadsheet. Based on this data, overall, passive remediation technologies performed better in terms of sustainability performance than active technologies. The analysis showed that switching from active remediation to passive remediation techniques has the following impacts: aids in the conservation of local ecosystems, reduces community impacts and improves the community perception of the cleanup, lowers the life-cycle cost of the project, and contributes positively to global sustainability by using less energy and raw materials. By applying the analysis to future feasibility studies, EM takes the next steps as being one of the leaders towards global sustainability.

Keywords: Sustainability, Remediation, Index

1. Introduction

The U.S. Environmental Protection Agency (EPA) defines green remediation as that which not only takes into account all of the environmental effects of the remedy implementation, but also utilizes available options to reduce or remove the environmental footprint of cleanup actions. Essentially, it is the integration of best management practices that may be employed during a project, especially considering sustainability aspects including emerging techniques that offer significant environmental and social benefits while still being economical. As environmental remediation is the main purpose of the Department of Energy's Office of Environmental Management (DOE EM), it aligns with the goals of the DOE Sustainability Performance Office (SPO) to consider this method before defaulting to using the cheapest or fastest remedies- 2.

Before a remediation process begins, DOE evaluates all potential remediation technologies in terms of Comprehensive Environmental Response, Compensation, and Liability Act (CERLCA) criteria. CERCLA holds the responsible parties accountable, if possible, for any release into the environment and ensures their participation in the cleanup. CERCLA has nine criteria for the selection of the type of remediation: overall protection of human health and the environment; compliance with ARARS (applicable or relevant and appropriate standards); long-term effectiveness and permanence; reduction of toxicity; mobility or volume; short-term effectiveness; implementability; cost; state acceptance; and community acceptance-8.

Established in 1989, EM has been responsible for completing the cleanup of this legacy of over a hundred sites across the country, managing the remaining nuclear materials, and overseeing the world's largest soil and groundwater remediation program. The Office of Subsurface Closure (EM-4.12) works with legacy sites around the country to find solutions to specific technical issues, while also funding national labs around the country to perform research and demonstration projects to test new technologies and remediation approaches. EM-4.12 is focused on delivering approaches and technologies from highly leveraged and strategic investments that maximize the impact to reduce risk and life-cycle cleanup costs.

1.1. Pump-and-Treat Groundwater Remediation

Pump-and-treat (P&T) remediation is an established technology which is currently in use at numerous DOE sites across the country. The technology has three main characteristics: groundwater extraction, aboveground treatment, and groundwater monitoring. It is an active treatment method, which means it is human-run and quite energy and water intensive. Recent research has identified factors that impact the overall performance of the P&T remedies. Such information is important for assessing performance optimization or comparing P&T to other remediation alternatives. Some benefits of using this treatment system include effective plume and source contaminant reduction, strong aboveground operational performance, and ease of integration and co-performance with other technology elements of a remedy. However, there are also several negative aspects that include difficult secondary waste handling and disposal, high energy and operational costs, poor sustainability performance, hydraulic gradients that induce accelerated downgradient contaminant migration, and injection well fouling. Primarily because of the many cons of using P&T remediation, it is important to explore other options when examining the best type of remediation for a site-6.

1.2. Enhanced Attenuation and Natural Monitored Attenuation

Enhanced attenuation (EA) and natural monitored attenuation (NMA) are both passive remediation methods, meaning they utilize the natural water flow and require little human input after their initial setup. Structured geochemical zones are an example of EA, created by the injection of vegetable oil (an electron donor) into the groundwater to deplete volatile organic compounds (VOCs). Under NMA, the area is remediated to a certain standard and then allowed to exist in its natural state with periodic monitoring for contaminant levels. These passive remediation methods are beneficial for minimizing the rebound of groundwater concentrations above regulatory targets and avoiding plume expansion while the P&T system is turned off, as well as transitioning completely away from P&T-6.

1.3 Investing in Sustainability

A 2016 study published by MIT Sloan in collaboration with the Boston Consulting Group (BGC) shows that sustainability matters to investors. The article states that three-quarters of executives in investment firms consider good sustainability performance as materially important when making investment decisions. It goes on to elaborate on the growing importance of environmental sustainability for staying competitive in the current market. As investors and stakeholders play a key role in the decision-making process for DOE national labs, this study is significant in many ways. The index highlights more sustainable options that illustrate how DOE and its investors care about environmental sustainability in the remediation industry. The article also points out that integrating sustainability indicators into investment models has been difficult in the past because, as Banco Bilbao Vizcaya Argentaria's head of responsible business Antoni Ballabriga puts it, "Sustainability types speak in PowerPoint, and investors speak in Excel." The index described in this report aims to speak in both qualitative and quantitative terms to provide the data needed to show how to make more responsible, sustainable choices when it comes to cleanup. Applying the index in future feasibility studies, DOE-EM can be an international leader promoting global sustainability in remediation.

2. Research Description

In order to generate a quantitative value for the relative sustainability of two remediation methods, a five step process was used: (1) choose and define the metrics, (2) create bins to normalize the data, (3) establish a weighting system, (4) design an algorithm to apply the weights, and finally (4) put it all together in an editable spreadsheet.

2.1. Defining the Metrics

There are countless parameters that could be used to describe sustainability, and there is no consensus on which ones should be used universally. This project narrowed the parameters to 10 metrics that focus on three categories which are often referred to as the three pillars of sustainability or the triple bottom line: economic, environmental, and social factors. The 10 parameters were chosen because of their relevance to EM's sustainability goals, to the remediation process and to social and economic responsibility. Once the metrics were chosen, they were defined as related to the remediation process and their environmental significance was noted Table 1.

Table 1 Definitions and environmental significance of metrics used for sustainability index

Metric	Definition	Environmental Significance
1. Life Cycle Cost	Life cycle cost (LCC) - total cost of the remediation process	Feasibility of project
2. Time	Start of remediation to NMA	Feasibility of project
3. Materials	Percent of land and materials reused and recycled	Promotes conservation of resources
4. GHG emissions	Greenhouse gas emissions in **metric tons** of CO_2, CH_4, and NO_x	Climate change/ atmospheric warming
5. Clean energy	Percent of renewable and sustainable energy being utilized (amount of energy from renewable and sustainable sources divided by the total amount of energy used)	Minimal environmental impact; mitigating climate change
6. Freshwater consumption	**Volume** of freshwater used for remediation in gallons	Local watershed, aquifers, water conservation and availability
7. Source removal	Time to endpoint of remediation, measured by year until ARARS compliance	Likelihood of implementation; overall impact
8. Ecological services	<u>Disposal</u> acts as an absorptive sink for residuals (i.e. carbon sequestration); Change in pH as a result of remediation <u>Economic</u> functions such as lumber and pharmaceuticals (biodiversity and ecosystem health are important factors); property value <u>Recreational</u> services for human beings such as public parks and natural areas	Conservation of local ecosystems, biodiversity, air and water quality, prevention of overexploitation, etc.; monetary value of ecosystems
9. Community impact	If/ how the community is affected by the cleanup & how people see the remediation as impacting them (i.e. turning the river green)	Likelihood of implementation; social responsibility
10. Worker safety/ Risk	Risk of fatality - number of deaths	Likelihood of implementation

2.2. Creating the bins

The second step was creating bins, or ranges of values, for which each metric could be assigned values on a scale of one to five, one being the worst or least sustainable, and five being the best or most sustainable. Putting all of the metrics on the same grading scale normalized the data and generated realistic quantitative scores.

Another advantage to using the bins was that exact data was not needed, which made it easier to gather information and input information for the spreadsheet to see the overall strengths and weaknesses of each specific remediation process.

Table 2 Bins and units assigned to each metric

Metric	Units	Bins
1. Life Cycle Cost (LCC)	Dollars ($)	1. 1 billion+ 2. 100 mil – 1 billion 3. 10 mil – 100 million 4. 1 mil – 10 million 5. 0 – 1 million
2. Time	Years	1. 100 + 2. 51-100 3. 26-50 4. 6-25 5. 0-5
3. Materials	Percent recycled (%)	1. 0-20% 2. 20-40% 3. 40-60% 4. 60-80% 5. 80-100%
4. GHG emissions (normalized to equivalents of CO_2 using GWP factors)	Metric tons	1. 8,000+ 2. 6,000-8,000 3. 4,000-6,000 4. 2,000-4,000 5. 0-2,000
5. Percent of **clean energy** used	Percent (%)	1. 0-20% 2. 20-40% 3. 40-60% 4. 60-80% 5. 80-100%
6. Volume of freshwater used	Gallons	1. 100,000 + 2. 75,000-100,000 3. 50,000-75,000 4. 25,000-50,000 5. 0-25,000
7. Source removal - time to ARARS compliance	Years	1. 100+ 2. 60-100 3. 30-60 4. 10-30 5. 0-10
8. Environmental services	+ or -	1. Net negative 2. Medium-negative 3. Neutral 4. Medium-positive 5. Net positive
9. Community impact	+ or -	
10. Risk - fatality	Number of fatalities	1. 4 + 2. 3 3. 2

Metric	Units	Bins
		4. 1 5. 0

2.3. The Weighting System

A survey was designed in order to collect information about which metrics different groups of people involved in the remediation process value as most and least important. When deciding which type of remediation to implement, four categories of contributors in the decision-making process were identified. The four categories looked at were:

1. Investors or stakeholders
2. Regulators
3. DOE scientists and engineers
4. Community members

Surveys were filled out by members of each category, ranking the metrics from 1 to 10, with 1 being the most important metric and 10 being the least important based on their professional and personal values. At the bottom of the survey was an either/or section that specifically looked at some opposing factors to gain further understanding of what people value. The survey responses were solicited by sending out emails, making phone calls, having face-to-face meetings, and interviewing local community members at the National Mall in Washington, DC.

2.4. The Algorithm

On one side of the scale is the 1 to 10 ranking system used in the weighting survey Table 3. Recall that 1 is ranked the most important and 10 is the least important. On the other side is the weighting value each rank was assigned.

In the weighted score, the bin score is multiplied by a percentage based on its rank to either increase or decrease its relative value based on its importance to each group of people.

For example, the bin score of the highest ranked metric gets multiplied by 0.19 or 19% weight since it is the most important compared to the metric with the lowest rank which gets multiplied by just 0.01 or 1% since it is the least important.

Table 3 Weighting factors used for each rank

Rank	Weight
1	19%
2	18%
3	17%
4	16%
5	15%
6	5%
7	4%
8	3%
9	2%
10	1%

2.5 The Index

All of the steps were combined into a table in an Excel spreadsheet to generate a template for the actual index Figure 1. On the spreadsheet, the 10 metrics were listed down the middle so that two remediation techniques could be compared side by side. The inner columns are for the raw bin values or estimations obtained from the site being examined for each process. The outer columns then calculate the weighted values depending on the ranking given to each metric by the group being examined.

At the bottom of the table (rows 14, 15, and 16), the bin scores are added to create a raw score in the inner columns, which is divided by the total possible score of 50. In the outer columns, the weighted scores are added and then divided by the total possible of five to obtain a decimal, which is subsequently multiplied by 100 to create a percentage. Similar to a report card, the percentage from the raw score determines how sustainable the remediation strategy is (with 100% being the most sustainable scenario possible). The value of the weighted score shows whether the sustainability score correlates favorably or unfavorably with the weighted values of the particular group being examined.

A1	B	C	D	E	F
2	=C*%	(Bin 1-5)		(Bin 1-5)	=E*%
3	**Weighted P&T**	**P&T**	**Metric**	**Oil Injection**	**Weighted Oil Injection**
4			**Life Cycle Cost**		
5			**Time**		
6			**Recycling/ Reuse**		
7			**GHG Emissions**		
8			**Renewable Energy**		
9			**Freshwater Consumption**		
10			**Contaminant Removal**		
11			**Ecological Conservation**		
12			**Community Impact**		
13			**Safety/ Risk**		
14	=sum(B4:B13)	=sum(C4:C13)	**TOTAL**	=sum(E4:E13)	=sum(F4:F13)
15	=B14/5	=C14/50		=E14/50	=F14/5
	=B15%	=C15%		=E15%	**=F15%**

Figure 1: The sustainability index template

In order to generate examples of how the sustainability index could be practically put to use, data was obtained for two different sites. The first site was Mound, Ohio, which was originally treated using P&T and then transitioned to the oil injection/ funnel and gate passive remediation method. It has since been cleared to normal standards and is in the process of being re-integrated into the community.

The second set of data used in this analysis was a hypothetical example provided by DOE scientist Mike Truex at the Hanford Site. This data compared an appetite barrier, passive remediation method, with P&T at the 200 W area of the site. There were some key differences between these two sites that made a large impact on their overall sustainability scores, notability the use of clean energy by the Hanford Site because of its abundant availability in Washington, as well as the high scores of the Hanford Site in the community section because of some local pushback regarding the Ohio Mound site. The same data from the ranking surveys was used for both of the examples, as it was assumed that the perceptions of the various groups would not vary significantly over the different areas.

3. Results and Analysis

3.1. Surveys

The results from the ranking surveys distributed to the various groups highlighted the values of those involved in the decision-making hierarchy when choosing a remediation method. It was found that the values of the regulators and investors were typically in alignment, although this system is fairly objective and could vary depending on the regulator and the investor asked. The community members involved in this data had no experience with the cleanup process, and the ranking obtained was, again, very objective and somewhat varied. The most typical responses were used for the purposes of the weighting.

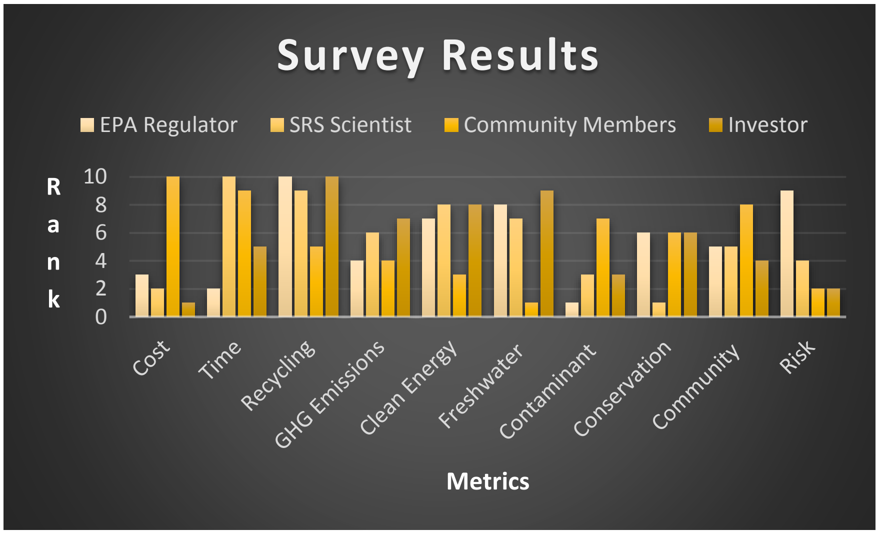

Figure 2: Bar graph exhibiting survey results

3.2 Hanford Site

The Hanford Site data compares a pump-and-treat (active) remediation method with an appetite barrier (passive) remediation system. The raw data collected in the bins for each of the metrics showed that several of the parameters were exactly the same in terms of sustainability Figure 2 while there was only a slight difference in the other parameters. This was unexpected as the research done prior to creating this index indicated that the oil injection method would have a significantly higher bin score than the P&T method. Nevertheless, the oil injection did have consistently higher bin scores than P&T. It should be noted that some of the bins could still be optimized to properly highlight the relative sustainability within each metric.

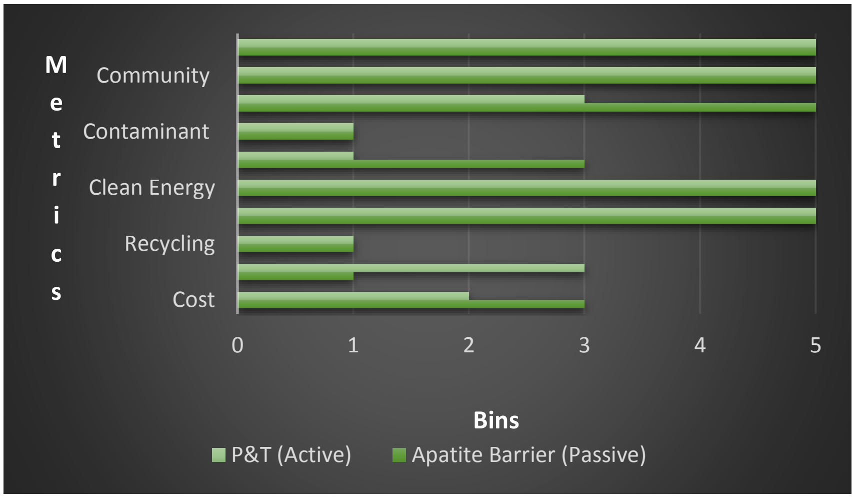

Figure 3: Raw bin data from the Hanford Site

The results from the weighted data using the rankings given by the regulator who took the survey minimize the values of recycling, clean energy, and risk, while maximizing the values for freshwater consumption, greenhouse gas emissions, and community impact. In the sustainability index table, the numbers come together for a total weighted score of 61.6% for the appetite barrier and 62.2% for the P&T method, showing a slight favorability for the appetite barrier from the regulator's perspective. The differences in the sustainability scores become clearer in the scenario using the rankings obtained from community members. In this scenario, the weighted appetite barrier scored almost 10 percent higher than the weighted P&T method. This is because of the correlation between the values of the community members with high scoring metrics for the appetite barrier method. Interestingly, the difference between the scores for the passive and active remediation methods from the investor's point of view was negligible (less than 1%), while, from the scientist's values, the passive method scored 12% higher than the active method.

3.2. Ohio Mound Site

The data from the Mound, Ohio site compared the P&T (active) method with an oil injection (passive) system, both of which were used at the site while it was considered active. As such, the data used in this example was from actual estimated results and not hypothetical like the Hanford Site data. The raw data obtained for the bins, like the Hanford Site, had some surprising similarities, notably the low scores in contaminant removal and clean energy use, as well as the high bin scores for freshwater consumption and risk for both methods.

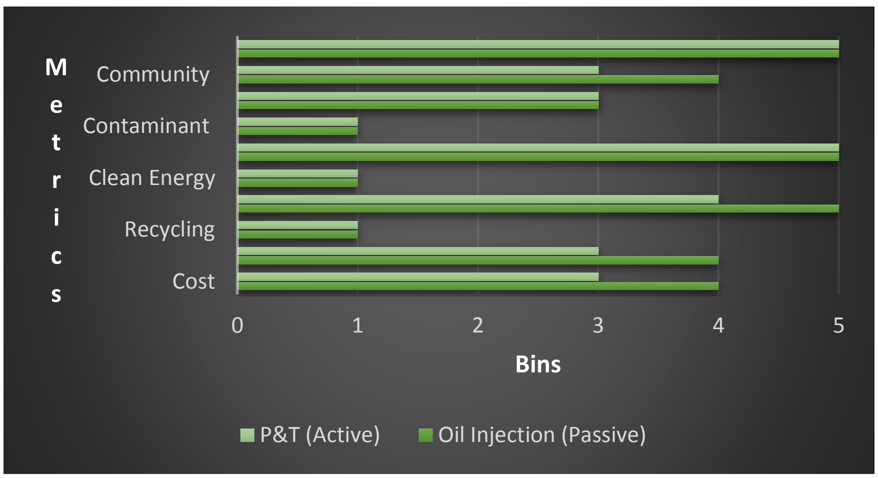

Figure 4: Raw bin data from the Ohio Mound site

It can be noted that the oil injection consistently scored significantly higher in terms of sustainability performance when weighted with the values of all four groups. With further analysis of the charts, one can compare the bin scores with the values and determine why certain scores are low while others come out much higher. For example, for the regulator at the Hanford Site, contaminant removal and life cycle cost are both ranked highly, but the bin scores are low, while conservation is ranked highly for community members and scientists. This is important to address moving forward in order to reach a compromise and satisfy all groups involved.

4. Conclusion

Overall, passive remediation techniques scored better than active techniques in terms of sustainability performance. Therefore, it can be concluded that switching to passive remediation techniques from active ones will increase the economic, environmental, and social sustainability of the system. Positive impacts of a more sustainable system include reduction of impact on communities by the cleanup, conservation of local ecosystems and preservation of ecological services, lower life cycle costs, and lower emissions and freshwater use. Switching from P&T to more passive remediation methods also aligns with EM's goals of reducing its carbon footprint by lowering its energy intensity as well as decreasing water use intensity.

The sustainability index spreadsheet created in Excel could be edited to be applied to any two systems to compare their relative sustainability and generate a numerical score. Estimations of the bin data for each metric are all that would be needed to calculate this number. Additionally, the survey could be given to any person involved in the decision-making process to help understand his or her values and weight the raw data in the index accordingly.

Moving forward, the index could be improved by optimizing the bin ranges for each metric based on actual data and statistical averages obtained from other sites which have previously switched from active to passive remediation methods. If the maximum, minimum, and median data points could be obtained for each metric, the bin values could be defined using this data, rather than approximations which are currently in use. This would greatly improve the validity of the data generated using the bins, and improved bin values would increase the accuracy of the final value obtained for the sustainability score. It is not representative of the values of DOE or of any group in general. By interviewing local community members at the specified sites would give a better perspective of illustrating the values of the community members. In order to obtain the appropriate weights for another comparison, the survey in appendix A should be distributed to those involved.

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