CL:AIRE

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Concawe bulletin

CL:AIRE's Concawe bulletins describe the deployment of sustainable remediation techniques and technologies on sites in Europe. Each bulletin includes a description of the project context and conceptual site model along with a sustainability assessment. This bulletin describes how a sustainability assessment was used to help decide the remedial approach on a former petrol station site.

Natural Source Zone Depletion in a Dismantled Petrol Station

1. INTRODUCTION

In April 2009, a petrol station operated by bp was decommissioned. In 2010, bp hired AECOM to help manage the soil and groundwater hydrocarbon impact that was present at the site. Environmental works are currently underway.

These environmental works have been focused on improving the knowledge of the Conceptual Site Model (CSM) and the remediation options for the removal of the Light Non-Aqueous Phase Liquid (LNAPL) present at the site. The LNAPL is below the residual LNAPL saturation[1] in some areas of the site.

A human health quantitative risk assessment was undertaken in 2010 by AECOM which concluded that there were no unacceptable risks to receptors, and that groundwater was not used. Site characterisation efforts also determined that the LNAPL transmissivity is low and it is not feasible to hydraulically remove said LNAPL. However, the legal framework currently enforced mandates that LNAPL must be removed. Therefore, the primary remediation goal for the site is to remove the LNAPL, to the maximum extent possible. As a secondary objective, the dissolved hydrocarbon concentrations in groundwater should be reduced.

With the vast amount of information gathered, a decision had to be made on which remedial technique would be optimal to achieve the goals. This decision was made with the support of the results obtained from a sustainability assessment based on the SuRF-UK framework (CL:AIRE, 2010) and the ISO 18504:2017 standard (ISO, 2017). Following the tiered approach to the sustainability assessment (from Tier 1, qualitative, to Tier 3, quantitative), the remedial option was selected based on a Tier 2 assessment, which is detailed further herein.

In the following sections, the CSM, investigations undertaken at the site and the sustainable remediation assessment process are presented. Finally, the main conclusions can be found.

2. SITE DESCRIPTION

This site was occupied by a petrol station built in 1966 and decommissioned in 2009. The above-ground equipment and buildings were removed and the underground infrastructure was left in place but filled with solid foam (piping) and grout (tanks). The petrol station stored fuel in nine 20,000 L capacity underground tanks. The entire surface of the site is covered by asphalt hardstanding, which is currently in poor condition with many holes and cracks. A former abstraction well, used to supply a car washing tunnel, is located adjacent to the eastern border of the site. The well was decommissioned and sealed and is now paved over (Concawe, 2020).

The site is in an urban area and surrounded by a hotel to the west, an industrial area further west, commercial and industrial areas to the east and the south, agricultural land further to the south and a residential area to the north.

3. CONCEPTUAL SITE MODEL

3.1 Local geology

The geology is composed of anthropogenic fill material of gravels in a sandy matrix to a depth of 2 m below ground level (bgl). The fill material is underlain by natural soil of gravels and pebbles in a silty matrix to a depth of 12 m bgl. This material is underlain by compact loamy clays mainly in the western area, gravels in silty clay matrix mainly in the eastern area and sandstone from 15 m bgl (see Figure 1).

[1] Residual LNAPL saturation is defined as the saturation under which the LNAPL is "immobile under the applied gradient". LNAPL below residual saturation is neither mobile nor hydraulically recoverable; although a technology that changes the LNAPL physically or chemically may be capable of increasing contaminant mass recovery (EnvGuide, 2022).

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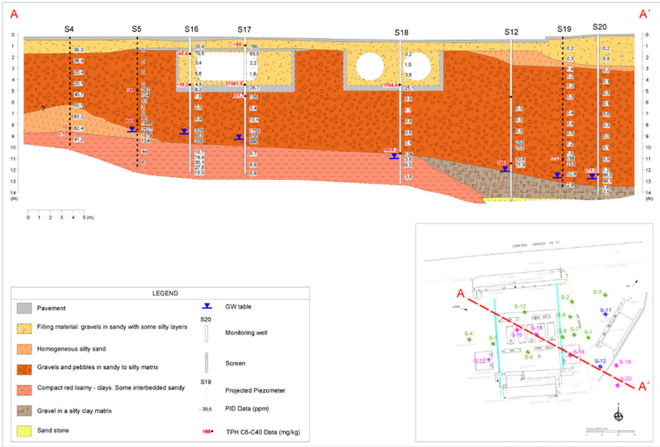

Figure 1: Site cross section.

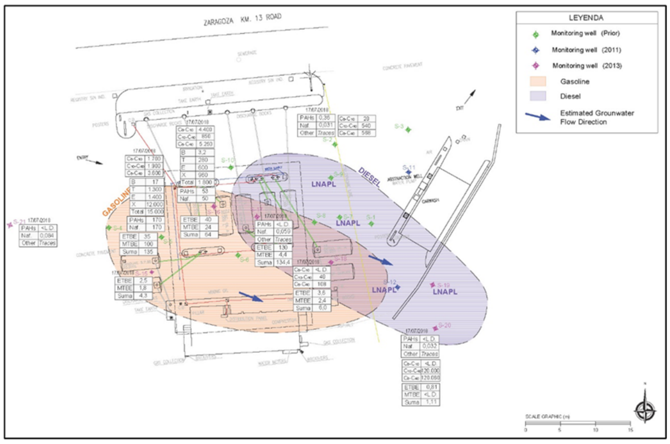

Figure 2: Groundwater contaminant concentrations (July 2018) and estimation of areas of gasoline and diesel impacts.

3.2 Hydrology

The main watercourse is a river located 400 m to the east. It flows towards the northeast. Also, several irrigation channels were identified, collecting surface water from a reservoir located 3.5 km to the west.

3.3 Hydrogeology

No groundwater bodies of regional interest were found in the literature, although there may be aquifers of local interest. Locally, the aquifer is in the gravel layer (quaternary terraces of the adjacent river). The permeability of the free alluvial aquifer is medium to high. However, the transmissivity is low due to the limited thickness of the saturated zone as was observed during the drilling of boreholes to install monitoring wells. The base of the aquifer is made up of clay and sandstone. The main hydrogeological features are:

- Groundwater table depth from 8 to 11 m bgl.
- Groundwater flow direction to the east-southeast.
- Hydraulic gradient from 1%, in the west and east of the site, to 5% in the central area.
- Low thickness of the saturated zone, between 1 and 2 m.

4. AREAS OF CONCERN

4.1 Hydrocarbon distribution

Figure 2 shows the baseline concentrations of Total Petroleum Hydrocarbons (TPH) measured in July 2018.

Two impacts were identified:

- A diesel-related impact in the eastern area, where LNAPL was identified. This area is shown in Figure 2 as a purple shaded area.
- A gasoline-related impact in the western and central area, where the concentrations of hydrocarbons are mainly due to the presence of lighter fractions of TPH, benzene, toluene, ethylbenzene and xylenes and the additives methyl tert-butyl ether / ethyl tert-butyl ether - orange shaded area in Figure 2.

The impacted areas of diesel and gasoline are estimated at 190 and 125 m^2, respectively.

In 2014, the LNAPL thickness distribution profile was estimated by taking well measurements (Figure 3).

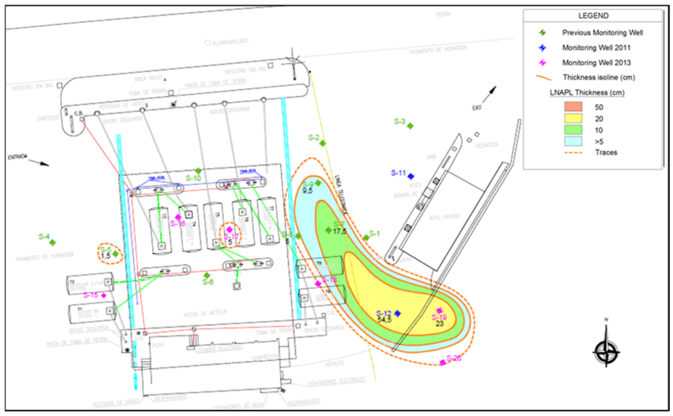

Figure 3: Thickness of the LNAPL plume, May 2014.

This study showed the plume was not expanding. Using the API Interactive LNAPL Guide[2] to estimate saturation, it was observed that LNAPL saturation at the edge of the plume was below the literature residual saturation values (between 5% and 10%, given the soil and LNAPL type and concentration (Brost and DeVaull, 2000)). Residual saturation can be defined as the value below which LNAPL is neither mobile nor hydraulically recoverable (EnvGuide, 2022), thus no further LNAPL migration processes were expected.

The total mass of LNAPL in the saturated zone was approximately 1200 kg (estimated from a volume of 1400 L of diesel, assuming a density of 0.86 g/cm^3).

5. NATURAL SOURCE ZONE DEPLETION STUDY

A detailed Natural Source Zone Depletion (NSZD) study was launched in 2016, including testing of several monitoring methods of NSZD to evaluate the most appropriate for a paved site. Naturally occurring processes of biodegradation were quantified with the estimation of a

[2] https://www.api.org/oil-and-natural-gas/environment/clean-water/ground-water/lnapl/interactive-guide

biodegradation rate. The following monitoring methods were included (Concawe, 2020):

- Gradient method based on measurement of O_2 and CO_2 concentration profiles.
- Thermal approach that quantifies NSZD rates based on heat generation in the source zone related to biodegradation of TPH.
- Passive CO_2 flux traps that capture CO_2 generated by microbial degradation of TPH as the CO_2 is discharged from the subsurface to the atmosphere.

All three methods provided strong qualitative evidence that biodegradation is taking place at significant rates at the site. While the quantitative estimations of biodegradation rates varied between methods, the results generally reflected the complexity of the processes responsible for NSZD, and the interferences that each method is subject to under the unique conditions at the site.

6. SUSTAINABILITY ASSESSMENT

Following the site assessment phase, work was undertaken to select the preferred remedial option. To support the decision, a sustainable remediation assessment was conducted to identify the optimal sustainable approach. The selected solution would address the impacted areas, minimise risks to receptors, and be accepted by stakeholders (regulators, land owner, bp, neighbourhood). As a first step, a Tier 1 SuRF-UK sustainable remediation assessment was undertaken. As a support document, the ISO 18504:2017 of Soil Quality – Sustainable Remediation was considered.

The following constraints (CL:AIRE, 2020a) were identified and considered in the process:

- The need to remove LNAPL (regulatory requirements).
- Although the permeability is medium to high, the transmissivity is low (low thickness of the saturated zone) and thus, hydraulic removal of LNAPL can be difficult in some areas of the site.
- The site is currently dismantled and has no infrastructures (water, energy, effluent discharge, etc.).
- The site is currently being used for parking and it is preferable that the remedial option chosen allows it to continue to be used as such.

The remediation goals for the site are to: 1) remove LNAPL and 2) reduce the dissolved hydrocarbons concentrations. To achieve these goals, the following options were evaluated, ranging from more passive to more active:

- **Option 1: Site wide NSZD**. Long-term low energy passive option (ITRC, 2011), including a long-term monitoring programme of dissolved TPH, temperature, oxygen, carbon dioxide and electron acceptors (such as nitrate, sulfate, methane, etc.) concentrations. The efficiency of naturally occurring biodegradative processes to ensure that both the LNAPL plume and the dissolved concentrations are reducing was assessed. This approach would require biannual visits.
- **Option 2: Site wide NSZD and passive skimmers in eastern area for LNAPL removal.** Long-term passive option, but timeframe could be reduced with passive skimming to remove LNAPL that accumulates in the monitoring wells of the eastern area. This approach would require a first stage of LNAPL removal with quarterly visits, which in a second stage could be biannual.
- **Option 3: Site wide enhanced natural attenuation by oxygen injection and active and passive skimmers in the eastern area for LNAPL removal.** Oxygen injection (through emitters, ceramic diffusers, etc.) would help to maintain an aerobic environment to facilitate contaminant biodegradation. Aerobic microorganisms utilise oxygen and contaminants as part of their metabolism and convert the contaminants into carbon dioxide, water, and microbial biomass. This technique would be applied site wide.

  In the eastern area, before the oxygen injection, active skimmers would be used to remove the hydraulically removable LNAPL and where LNAPL saturation is below residual saturation, passive skimmers would be installed. The system needs an air compressor for the active skimmers and a LNAPL storage tank.

  The removal of LNAPL would require monthly visits during the first year, which would be reviewed according to the volume of LNAPL recovered and the remaining concentrations in groundwater.

  The oxygen injection and active skimmers are expected to reduce the timeframe of the remediation when compared to the previous options.
- **Option 4: Soil vapour extraction (SVE) with pump and treat (P&T)**. This strategy combines two active techniques (SVE + P&T) which could help further reduce the timeframe required to achieve the remediation goals.

  The SVE consists of applying a vacuum to the unsaturated zone to induce the controlled flow of air and remove volatile contaminants from the soil. The gas leaving the soil is collected and treated.

  For its operation, a blower, an electrical connection or a generator, additional wells to achieve radius of influence and a granular activated carbon (GAC) filter to treat the extracted air before release to the atmosphere would be required.

  The P&T solution consists of installing submersible pumps to remove impacted groundwater site-wide and free-phase product in the eastern area. The mixture would be pumped to the surface and pre-treated on site. A hydrocarbon separator and effluent transport to an authorised treatment plant or connection to the municipal sewer network would be required. Also, external sources of water, energy, compressed air, etc. would be required. Finally, six additional wells would need to be installed, four in the eastern area and two in the central and western area. The implementation of this technology would require initially biweekly visits for maintenance and monitoring, and review of results in six months.

Following the Tier 1 SuRF-UK-based sustainable remediation assessment and the ISO 18504:2017 standard, the categories chosen as relevant from the sustainability indicators are provided in Table 1.

Table 1: Headline categories for sustainability indicators.

Environmental	Economic	Social
Emissions to air	Direct economic costs and benefits	Human health and Safety
Soil and ground Conditions	Indirect economic costs and benefits	Ethics and equity
Groundwater and surface water	Employment and employment capital	Neighbourhoods and Locality
Ecology	Induced economic costs and benefits	Communities and community involvement
Natural resources and waste	Project lifespan and flexibility	Uncertainty and Evidence

The categories in grey (Table 1) were excluded as they were not substantially different between remedial options for the following reasons:

- Soil and ground conditions: none of the options would change soil or geotechnical functionality.
- Ecology: no sensitive receptors were identified in the proximity of the site that would be affected.
- Employment and employment capital: the options will not have differentiating outcomes in the local opportunities for job creation in the community.
- Induced economic costs and benefits: this category is already covered in the indirect economic costs and benefits.

The criteria were all considered to contribute equally to the final classification (i.e. at this stage no weighting was used to prioritise any category over another category). Individual indicators were aggregated from each category and a ranking from 1 (best option) to 4 (worst option) was established for comparison. For example, the environmental category "Emissions to air" includes various indicators such as climate change-greenhouse gases (GHG), acid rain - emissions of NO_x and SO_x and ground air quality - particulates, volatile contaminants, etc. These were aggregated to give an overall comparison by the headline category.

Table 2 (on next page) presents the classifications obtained for the categories in each option. The lines of evidence (CL:AIRE, 2020b) are also included for a better understanding of the criteria used.

As can be observed, the best classified (lowest scoring) was option 1, followed closely by option 2. The worst classified is option 4 (Figure 4).

From Figure 4, it can be concluded that option 1 is strongest for the following reasons:

- Environmental indicator: emissions to air and natural resources. This option does not include emissions except the ones associated with light road traffic for monitoring; the only material used is for sampling.
- Social indicator: health and safety, neighbourhoods and locality and communities and community involvement. No civil works are required, no noise, vibrations or air emissions, and no machine/equipment installation and operation, minimising risk to workers and others. Regarding neighbourhood, there is little nuisance and the current use of the site as parking is not hindered.
- Economic indicator: direct economic costs and benefits and project lifespan and flexibility. This option is the least expensive and therefore could better resist eventual economic changes.

Option 1, however, has low scores in the following individual categories which must be discussed as to their influence on the final decision:

- Indirect costs reflect the local community's perception of the works undertaken, i.e., the more active the technical approach, the better the perception.
- Uncertainty and evidence: approach may not be acceptable to the regulators for not actively removing LNAPL.
- Ethics and equity: the LNAPL will be in the subsurface for a long period of time which may raise intergenerational equity issues.

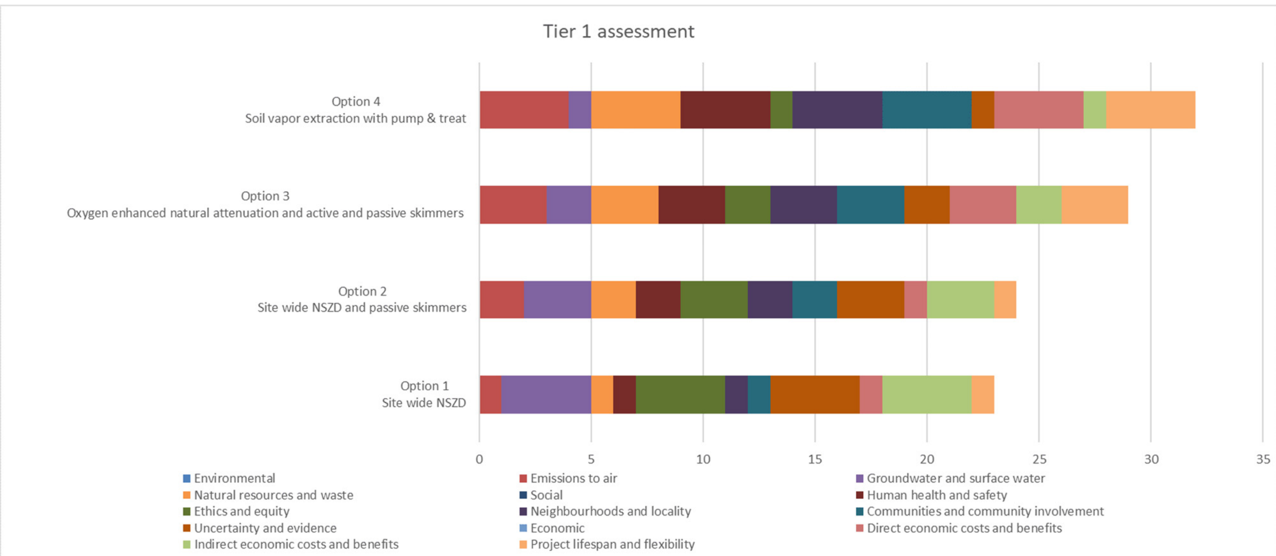

Figure 4: Tier 1 sustainable assessment cumulative scores.

Table 2: Final classifications of Tier 1 (Note: 1 – best option; 4 – worst option).

Categories	Lines of Evidence	Option 1: Site wide NSZD	Option 2: Site wide NSZD and passive skimmers	Option 3: Oxygen enhanced natural attenuation and active & passive skimmers	Option 4: SVE and P&T
Environmental Indicator					
Emissions to air	• Combustion from generators or other equipment / machinery • Emissions: ◊ volatile compounds (effluent and LNAPL storage, SVE system) ◊ transport of equipment / machinery ◊ particles, dust and GHG • Medium to long term occasional emissions of gases by vehicles	1	2	3	4
Groundwater and surface water	• Timeframe for achieving goals	4	3	2	1
Natural resources and waste	• Energy resources (compressor, pumps) • Waste generation and legacy impacts (LNAPL, GAC, contaminated personal protective equipment (US EPA, 2008), sampling disposable material, purge water) • Fossil fuels consumption	1	2	3	4
Social Indicator					
Human health and safety	• Machinery / equipment hazardous to workers (compressor, generator, etc.) • Road transport of machinery /equipment • Civil works • Transport of hazardous waste off-site	1	2	3	4
Ethics and equity	• Timeframe for achieving goals associated with probability of transferring contamination to future generations	4	3	2	1
Neighbourhoods and locality	• Noise from equipment / machinery • Heavy load traffic • Dust (civil works)	1	2	3	4
Communities and community involvement	• Restrictions of use of parking (civil works or equipment installation)	1	2	3	4
Uncertainty and evidence	• Likelihood of regulatory acceptance	4	3	2	1
Economic Indicator					
Direct economic costs and benefits	• Costs of installation, operation and maintenance (drilling, monitoring, permitting, etc.)	1	1	3	4
Indirect economic costs and benefits	• Corporate reputation: neighbourhood perception of the remediation is likely to be more favourable in the presence of permanent equipment and machinery, as the approach is perceived as more intense and faster	4	3	2	1
Project lifespan and flexibility	• Flexibility and resilience to cope with changing economic conditions and circumstances (if the pollutant - petrol station operator - has changes in its economic conditions)	1	1	3	4
Overall		23	24	29	32
		Best option	Better / average option	Worse / average option	Worst option

Table 3: Weighted categories for Tier 2 sustainability assessment.

Environmental		Economic		Social	
Category	Weight	Category	Weight	Category	Weight
Emissions to air	3	Direct economic costs and benefits	3	Human health and Safety	1
Soil and ground conditions	-	Indirect economic costs and benefits	1	Ethics and equity	0
Groundwater and surface water	0	Employment and employment capital	-	Neighbourhoods and Locality	1
Ecology	-	Induced economic costs and benefits	-	Communities and community involvement	1
Natural resources and waste	3	Project lifespan and flexibility	0	Uncertainty and Evidence	3

Option 4 (SVE and P&T), which is the most active and shortest-term, is the most penalised in the assessment, mainly due to the following individual categories / indicators:

- Greatest use of natural resources and waste generation.
- Greatest health and safety risks, due to the installation of machinery, increasing road traffic for equipment transport and monitoring, noise emitted by the machinery, need for civil works, etc.
- Greatest impact on the neighbourhood and locality, due to the higher nuisance caused (civil works, volatile compounds emissions, noise, loss of parking space, etc.).
- Greatest direct economic costs, given that this is the most expensive one, considering installation, operation and maintenance.
- Project lifespan and flexibility: this option is the most expensive one to implement and maintain and in case of economic changes, it is less resilient.

For the reasons mentioned above, options 3 and 4 were discarded as they are deemed to be less sustainable.

Overall, option 1 was the best classified, with a slight score difference from option 2. However, careful consideration was given to the timeframe associated with this technique and in ensuring the approach would be in line with regulatory requirements. Given these considerations and the closeness of scores between options 1 and 2, a Tier 2 evaluation was undertaken.

In the Tier 2 process, options 1 and 2 were further evaluated following a weighted multi-criteria comparison (Brinkhoff, 2011; United Kingdom Department for Communities and Local Government, 2009). The categories were weighted according to their relative importance in the final decision. Table 3 presents the weights for each category as 0, 1 and 3, with 0 being the lowest weight and 3 the highest.

The highest weight was given to the categories emissions to air; natural resources and waste; direct economic costs; and uncertainty and evidence, as these are considered to be most relevant to the stakeholders. Also, a numerical score from 1 to 5 was given to each category in both options. Preferred options (i.e. those options considered more sustainable) scored higher.

To compare the two options more accurately, the timeframe to achieve the remediation goals was estimated as 48 years in option 1 and 42 years in option 2. The same hydrocarbon mass removal was assumed for both options. The calculations were made considering the biodegradation rates that were estimated in the 2016-2020 NSZD field study. The timeframe was based on the hydrocarbon mass removal rate and the LNAPL volume removal considering the technical specifications of the skimmers.

The following parameters were chosen to be assessed for both options (Table 4) because of the lack of bias associated with their estimation:

- Carbon footprint;
- Waste volumes; and
- Direct costs.

Table 4: Quantitative estimations of carbon footprint and waste volume.

Remedial option	Carbon footprint (tonne CO_2)	Waste volume (kg)
Option 1	0.79	537
Option 2	0.96	779
Rationale For the carbon footprint, the following assumptions were made: • 3144 L of gasoline in option 1 • 3767 L of gasoline in option 2 • Waste in option 1 includes sampling waste (tube, gloves, absorbent paper, plastic bottles) • Waste in option 2 includes sampling waste and LNAPL associated waste (skimmers, absorbents)		

The carbon footprint calculation spreadsheet was developed by AECOM to calculate both direct and indirect GHG emissions of remediation works. The methodology is based on the ISO 14064:2019 and ISO 14069:2013. GHG emissions are calculated according to:

GHG emissions = Activity data factor * Emission factors

The activity data factor represents the operation generating GHG emissions (fuel consumption, distance travelled, etc.). Emission factors derive from the information published by the Spanish Ministry of Ecological Transition and Demographic Challenge (2021) and United Kingdom Department for Environment, Food & Rural Affairs (2021).

Table 5: Weighted scores and results of Tier 2 sustainability assessment (Note: the higher the score, the better the option, i.e. more sustainable).

Category	Weight	Option 1 Site wide NSZD		Option 2 Site wide NSZD and passive skimmers	
		Score	[Weight x Score]	Score	[Weight x Score]
Environment					
Emissions to air	3	5	15	4	12
Groundwater and surface water	0	-	0	-	0
Natural resources and waste	3	5	15	2	6
Social					
Human health and safety	1	4	4	4	4
Ethics and equity	0	-	0	-	0
Neighbourhoods and locality	1	5	5	5	5
Communities and community involvement	1	5	5	5	5
Uncertainty and evidence	3	1	3	3	9
Economic					
Direct economic costs and benefits	3	5	15	5	15
Indirect economic costs and benefits	1	1	1	2	2
Project lifespan and flexibility	0	-	0	-	0
Final result [Weight x Score]		63		58	

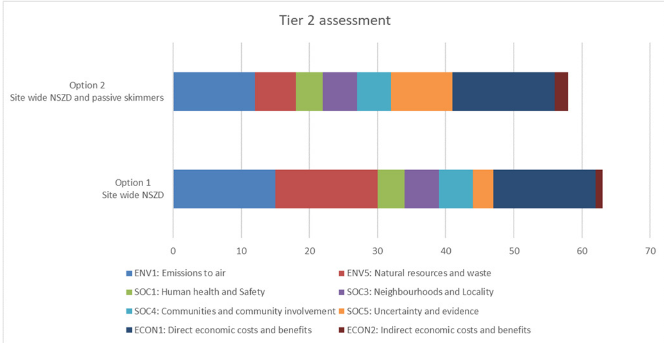

Figure 5: Tier 2 sustainability assessment cumulative scores.

The matrix and graphic results obtained are presented in Table 5 and Figure 5.

Tier 2 reinforces the results obtained in Tier 1, of option 1 as the most sustainable (highest global result and highest score in the categories with the highest weights) although the gap between both options is still slight.

There is however one high weighted category in which option 1 obtained the lowest score, which is Uncertainty and Evidence, related to the likelihood of acceptance by the regulator. This is a key factor in the final decision and for this reason, this option should be the least preferred.

In this case, the Tier 2 results, although not decisive, were useful to reflect and highlight the importance of the categories expected to be more relevant to the stakeholders.

7. CONCLUSIONS

A Tier 1 and Tier 2 sustainability assessment methodology was applied to identify the most sustainable remedial solution to address the impacts associated with the historical operation of a decommissioned petrol station.

The objective of the assessment was to identify the optimal sustainable remediation approach for managing risks to people and the environment and achieving regulatory closure. The assessment was used to compare four options that would all achieve the remediation goals. Each option had different resource requirements, timeframes and costs. Eleven individual categories were chosen from the fifteen proposed in the SuRF-UK framework and the ISO 18504:2017 standard for their relevance in this specific case.

After the Tier 1 evaluation, two options were discarded for being the least sustainable. Option 1 scored highest. However, the score obtained for options 1 and 2 was close. Therefore, a Tier 2 assessment was undertaken to obtain a higher level of confidence in the final choice.

In the Tier 2 assessment, the two options were further evaluated and compared against each other. The carbon footprint, waste volumes generated, and direct costs were quantified for each option. These were selected due to their lack of bias. A relative weight was given to each category that would represent the hierarchy of the criteria from the stakeholders' point of view. The assessment identified option 1 as the most sustainable, which reinforced the Tier 1 assessment results, although the scores were again close to each other. The weighted approach given by Tier 2 assessment was useful to highlight the categories that were expected to be more important to the stakeholders.

Although option 1 was identified as the preferred option by the sustainability assessment, the selected approach needed to align with the request from the regulators for active removal of LNAPL. Therefore, option 2 was selected as the preferred remedial option for the site.

The results from the sustainability assessment can be a useful tool when discussing the advantages and disadvantages of each option from a sustainability view with the regulators and other stakeholders. The results from the sustainability assessment can help justify the selected remedial approach.

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