LIFE sedremed
ENHANCED BIOREMEDIATION OF CONTAMINATED MARINE SEDIMENTS

LIFE20 ENV/IT/000572

LIFE SEDREMED

Bioremediation of contaminated sediments in coastal areas of ex-industrial sites

LIFE20 ENV/IT/000572

START DATE OF THE PROJECT: 1 October 2021

DURATION OF THE PROJECT: 45 months

DELIVERABLE C1.4

Report on LCA/LCC analysis of implemented technologies

DUE DATE OF DELIVERABLE: **May, 2025**

ACTUAL SUBMISSION DATE: **June, 2025**

BENEFICIARY LEADING THIS DELIVERABLE: **ISO**

CONTRIBUTING BENEFICIARY: **UNIVPM, SZN, INV**

www.life-sedremed.eu | info@life-sedremed.eu

Index

www.life-sedremed.eu | info@life-sedremed.eu

1. Executive summary

The present report shows the results of the comprehensive LCA carried out to assess the environmental impact of the approaches considered inside the Life SEDREMED project. In addition to the environmental parameters, socio-economic indicators are also considered. Starting from the five scenarios identified from the literature analysis and assessed in the previous report, the Life SEDREMED solution is compared here against the disposal of contaminated sediments in a landfilling site for hazardous waste and against the remediation strategy currently under development by Invitalia (that is in charge for the remediation of the Bagnoli site). The report is structured as recommended in the ISO 14040:14044 standards.

The analysis quantified the potential benefit resulting from the implementation of SEDREMED technology (assuming its technical effectiveness).

The estimated environmental gain, compared to landfilling, exceeds 90% in key categories such as climate change and eutrophication marine. The advantages were proved also from social point of view, with a reduction of possible non-lethal accidents. The further elaboration of Blue Synergy data estimated also a cost saving higher than 90%, compared to the other two scenarios. Invitalia option sounds promising from environmental and social point of views (compared to landfilling), despite of the operative costs due to the thermal desorption.

2. List of acronyms and abbreviations

LCA, Life cycle assessment
EF, Environmental footprint
LPG, Liquefied Petroleum Gas
HSWT, health and safety working time
LCWE, life cycle working environment

www.life-sedremed.eu | info@life-sedremed.eu

3. Goal and scope of the analysis

This LCA analysis concerns the environmental effects of the remediation technology developed inside the Life SEDREMED project; in addition to the environmental parameters, socio-economic indicators are also considered. The disposal of contaminated sediments in a landfilling site and the remediation strategy based on soil washing and desorption are also considered as benchmark scenarios. All the specific details are described below.

A quantity of sediment subjected to remediation equal to 100,000 tons is chosen as the functional unit; this is considered as representative of the quantity of material with the highest level of contamination and hazard (i.e. falling in quality class E). The three scenarios under consideration are reported in **Figure 1.** Scenario 0 (landfilling) and Scenario Invitalia include first dredging operations to move the contaminated sediments to the treatment/disposal site. The dredging system will be located on land, it will have an engine power of 287KW, a load capacity of 250 cubic meters per hour and a consumption of 33 liters diesel per hour (Italdraghe-Dredging and pumping solution S.p.a.). After dredging, either the contaminated sediment is sent to a landfilling site located in Germany, suitable for hazardous waste (scenario 0), or it is subjected to a soil washing, followed by thermal desorption (scenario Invitalia). The innovative Life Sedremed approach includes an in-situ treatment based on the Ekogrid technology combined with the Idrabel one, and it will let to reduce the present contamination and downgrade the material from quality class E to quality class D. Such treatment will allow the disposal in confined disposal facility, after dredging. In this case, the benefit is due to the moving of a sediment with a lower content of contaminants.

More in detail, scenario 0, after dredging, includes transportation using trucks with a capacity of 27.4 t, at a distance of 2,000 km, to reach the hazardous waste landfilling site, placed in Germany, identified as the most suited to receive that huge quantity of sediment with high contaminant concentrations. Invitalia scenario, resulting from the discussion with Invitalia experts, envisages a soil washing technology, resulting in two fractions: the finest (25% of the whole sediment) to send to the landfilling site for hazardous waste identified for scenario 0 and the coarsest one to send to the thermal desorption, to produce a clean sand. The treatment of wastewater produced during the soil washing is also considered.

www.life-sedremed.eu | info@life-sedremed.eu

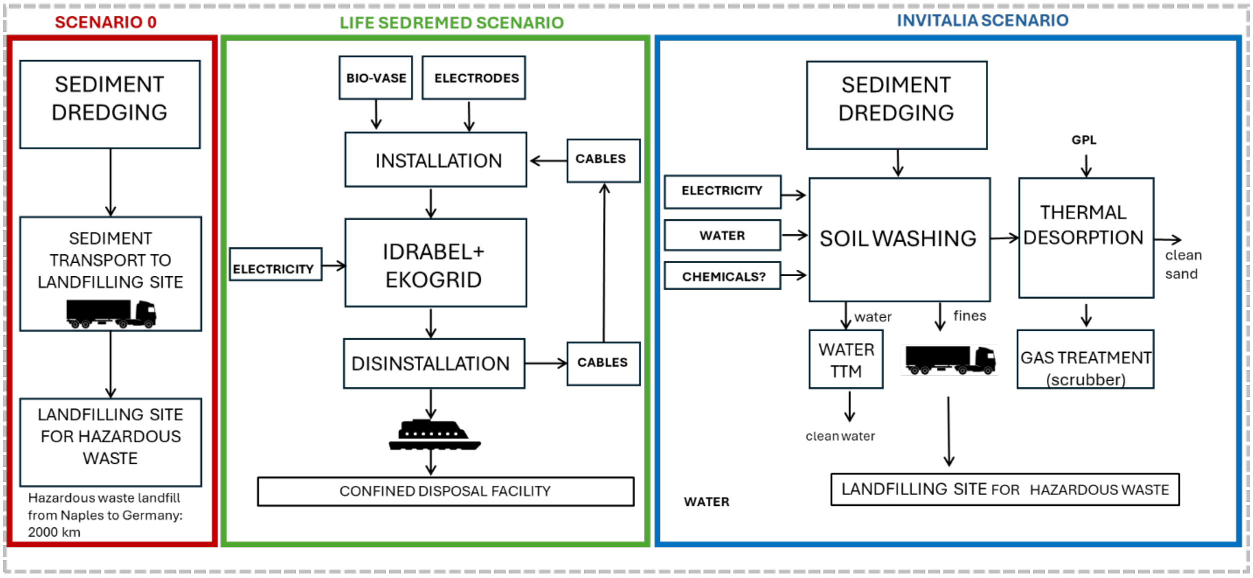

Figure 1. System boundaries in LCA.

4. Life cycle inventory

Table 1 summarizes the mass and energy balances built to perform the LCA. The dredging operations were included in all scenarios, before treatment for scenarios 0 and Invitalia, after treatment for Sedremed one. The operations connected to the confined disposal (building and transportation) are a part of Sedremed options.

Table 1. Mass and energy balance (100.000 tons sediment) for the different scenarios.

INPUT	OUTPUT
DREDGING	
-Diesel 33,000 L	-Sediment plus water: 250,000 m^3
Scenario 0	
- sediment 100,000 tons - 16,000,000 Km (considering return trips), truck capacity 27.4 ton	

www.life-sedremed.eu | info@life-sedremed.eu

Scenario SEDREMED	
In-situ treatment	
- electricity 500 MWh - electrode and cables 4,500 units (considered re-usable) - zeolite 0.36 tons - socks 4,500 units - calcium carbonate 1.4 tons - anode (titanium) 25,368 kg - cathode (steel) 17,663 kg	- sediment to confined disposal facility 100.000 tons
Confined disposal facility	
- concrete 34,000 t - steel 230 t - diesel for excavation: 5,511 L	
Scenario Invitalia	
Soil washing	
- sediment 100,000 tons - hydrogen peroxide 3,129 tons - water 24,650 tons - electricity 503 MWh	- finest fraction to send to hazardous landfilling site 25,000 tons - coarse fraction to thermal desorption - wastewater to treat 24,650 tons
Coarse fraction transport	
- sediment 25,000 tons - 40,000,000 Km (considering return trips), truck capacity 27.4 ton	
Thermal desorption for coarse fraction	
Sediment 75,000 tons Electricity 1,464 MWh LPG 1,400,130 m^3	Clean sand 75,000 tons Gas emissions to treatment 11,250,000 m^3
Gas emission treatment	
Gas emissions to scrubber 11,250,000 m^3 Natural gas 2,754 kg Compressed air 563 Nm^3 Zeolite 4,185 kg Electricity 3,600 kWh	CO_2 emissions 2,351 kg Water (gas phase) 956 kg Emissions to air 11,246,693 m^3
Confined disposal facility	
- concrete 34.000 t - steel 230 t - diesel for escavation: 5511 L	
Treated sediment transportation	
18.000 km Vessel Capacity 124 t	

www.life-sedremed.eu | info@life-sedremed.eu

5. Assumptions

Some assumptions were made during the system boundaries definitions. These aspects were described below to ensure the reproducibility and the repeatability of the analysis.

- The dredging system is connected to the shore since the highest contamination sediments are located near the coastline, where the shallow depth makes dredging unfeasible by vessels. The dredger has an engine power of 247 kW and it can collect up to 2000 m3 per day of sediment. The considered dredged material is composed of 80% of water and 20% of solid.
- Before the ex-situ treatments (scenarios 0 and Invitalia), the sediment is separated from water that is discharged into the sea (within Bagnoli site)
- The clean sand from Invitalia scenario was considered with 0 impact since it is ready to be reused as filling material (or discharged into the sea).
- The gas emissions from thermal desorption were filtered and adsorbed on activated carbons (1). Mass and energy balances were built in agreement with Abromaitis (2011) (2).
- Socks (sxcluding bacteria) and cables were considered re-usable at the end of the treatment (with a consequent 0 impact).
- For the electrodes was considered a re-usability of 50%. It was considered a titanium anode and a Fe/Zn cathode (assimilated to steel), with a thickness of 1 cm and surfaces of 1,125 m2 and 450 m2, respectively, in agreement with the starting project (3).
- For the social analysis, titanium was considered as steel, due to the data lack in the database.

6. Software and methods

The LCAs were performed in agreement with the ISO standards 14040 and 14044:20021. The software used for data collection was LCA for Experts, and it was integrated with Professional Database version 2024.1. The method selected for the analyses, which included the classification and characterization, normalization and weighting steps, was Environmental Footprint (EF) 3.0, and it included all environmental categories and recommended models at midpoint, together with their indicators, units, and sources.

www.life-sedremed.eu | info@life-sedremed.eu

7. Life cycle impact assessment (Environmental results)

The results of classification and characterization **(Figure 2)** confirm the disposal to landfilling site (without pre-treatment) as the worst option in all categories, excluding eutrophication freshwater, ozone depletion and resource use, minerals and metals and human toxicity-cancer (where the steel demand for the confined site building and the titanium for anode make the Sedremed scenario the most impacting). It is evident that the identification of the landfilling site in a German area, significantly affects the whole result, compared to the preliminary scenario, described in the previous deliverable, where the site was in Naples, close to Bagnoli area. In this regard, the transport contribution exceeds 60% of the scenario 0 impact in the categories of acidification (B), eutrophication (C-E), ecotoxicity freshwater (F), photochemical ozone formation (K), particulate matter (L), resource use minerals and metals (M), resource use, fossils (O), land use (P).
The Life Sedremed scenario is the greenest option, showing an impact saving up to 95% (compared to the other scenarios), in categories such as eutrophication marine (E).
The Invitalia option decreases the environmental burden, more than half, compared to scenario 0. However, the necessity of hazardous waste exportation affects the whole result, making it significantly worse than the Life Sedremed technology, though the quantity is one-fourth than that disposed in scenario 0. Furthermore, the LPG consumption for thermal desorption affects the categories of ecotoxicity freshwater (F), human toxicity (H-I) and resource use, fossils (O). The contribution of hydrogen peroxide is visible in the categories of ionizing radiation (J, 29%) and resource use fossils (O, 16%).

www.life-sedremed.eu | info@life-sedremed.eu

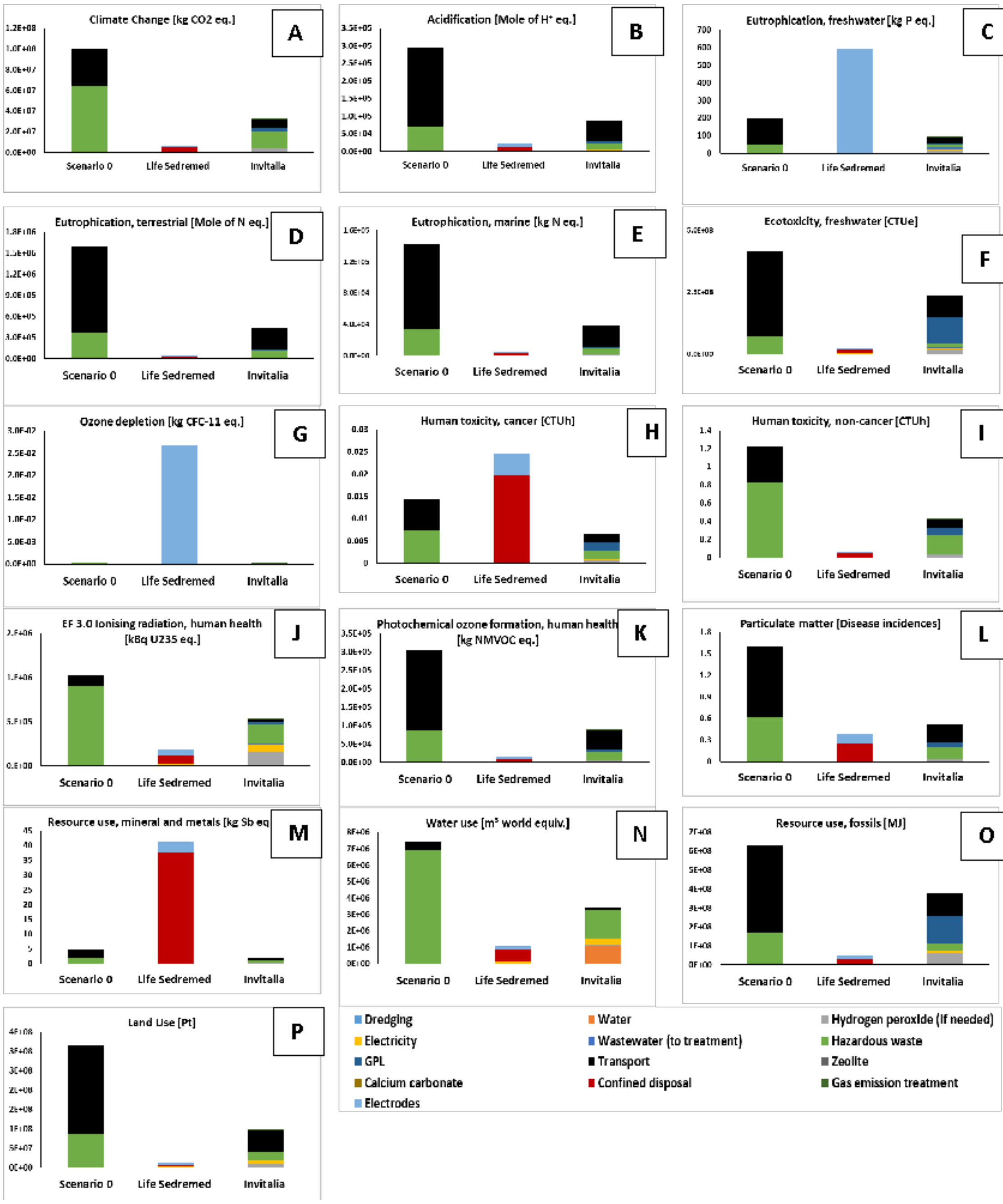

Figure 2: Results of classification and characterization steps (Functional unit: 100,000 tons of sediment).

www.life-sedremed.eu | info@life-sedremed.eu

The normalization and weighting were performed for a more complete view of the results, also considering the relevance of the different impact categories. Figure 3A confirms the advantage of Life Sedremed scenario with a whole impact saving above 90%, compared to scenario 0, and 85% compared to soil washing. Its impact is almost completely due to confined site building. Concerning Invitalia scenario, the normalized and weighted results show the greatest contribution of the finest fraction management (32% for the transport and 28% for to dispose it of), followed by the LPG consumption, which explains the environmental footprint of 16%. It is evident that identifying a closer landfill site (currently unavailable in Italian territory, based on discussions with Invitalia) could reduce the overall impact of both Scenario 0 and the Invitalia scenario, without altering the general conclusions of this study.
As reported in Figure 3B, climate change represents the most affected category, mainly in scenario 0 and Invitalia, due to the hazardous waste issue.

www.life-sedremed.eu | info@life-sedremed.eu

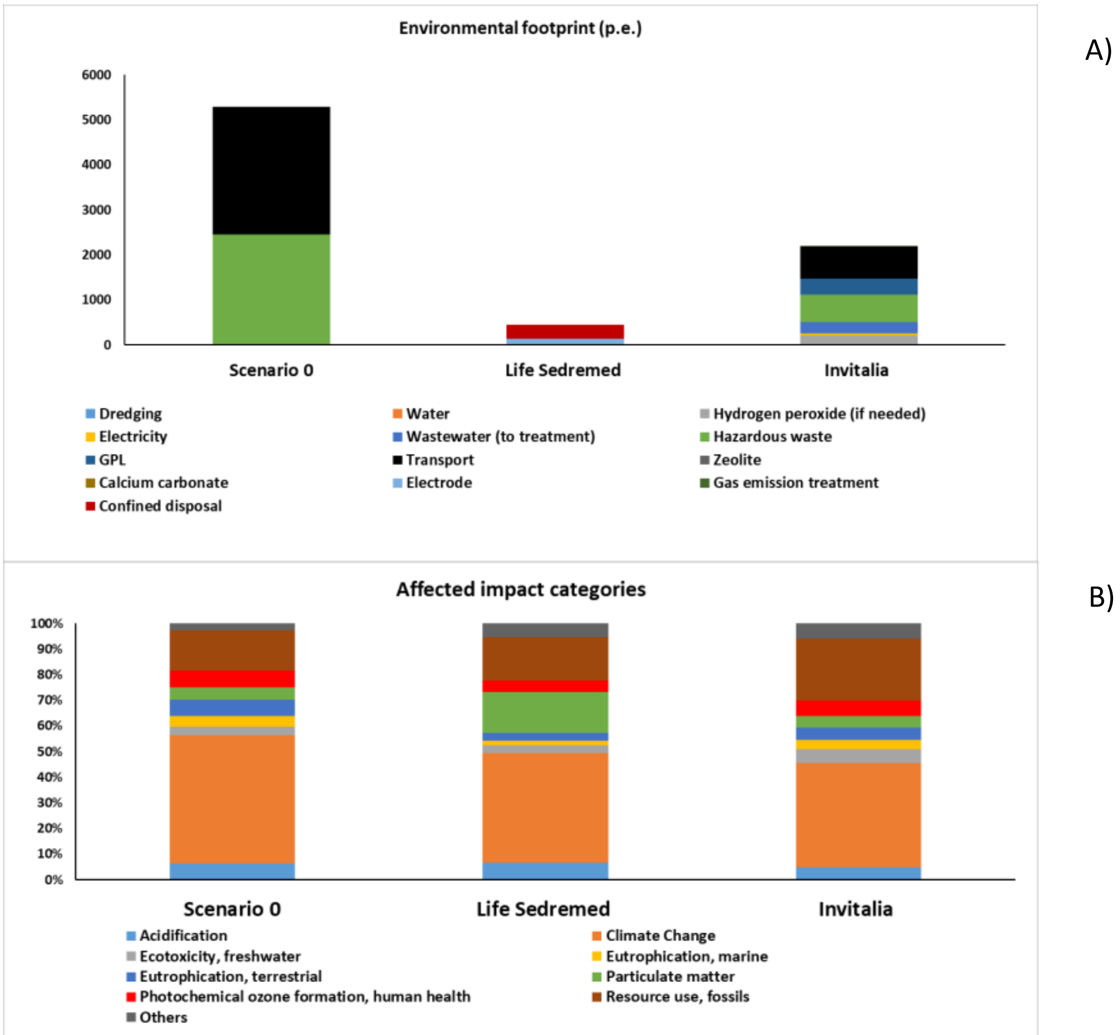

Figure 3. Results of normalization and weighting (Functional unit: 100,000 tons of sediment).

8. Life cycle costs- Economic results

The system boundary reported in Figure 1 and the inventory reported in Table 2, were used to assess the economic sustainability of the three scenarios. Both CAPEX and OPEX in

Figure 4 a-b were estimated using the unitary costs supplied by Blue Synergy, adapted on the scenario 0, Life Sedremed and Invitalia described in the present report. Furthermore, the additional cost due to the implementation of the confined disposal was assessed starting from that reported in the report about the case study of Brindisi site *(4)*.
The results in Figure 4A show a higher investment cost of Life Sedremed scenario, mainly due to the confined disposal building in addition to the implementation of the EKOGID+IDRABEL technology. Overall, the most relevant cost is that related to the dredging operation, common to the three scenarios (the only difference is the dredging time, before the sediment treatment in Scenario 0 and Invitalia, after the in-situ remediation for Life Sedremed option). A completely different trend was observed in OPEX estimation (Figure 4B), where Invitalia is the worst option, due to the high LPG demand for the step of thermal desorption. On the other hand, the low operational costs make Sedremed scenario the best one, mainly considering the low contribution of the capital expenditure on the whole scenario costs (Figure 4C).

www.life-sedremed.eu | info@life-sedremed.eu

Figure 4. Estimation of A) CAPEX, B) OPEX, C) Total costs of the three scenarios (Functional unit: 100,000 tons of sediment.

www.life-sedremed.eu | info@life-sedremed.eu

9. Social LCA

The software LCA for Experts was also used for the estimation of the social LCA considering the aspects of qualified working time and the health and safety (HSWT) focusing on the indicators of qualified working time (assessed as hours) and accidents for workers (both lethal and nonlethal, expressed ad number of cases). The parameters are defined as one of the core goals of the life cycle working environment (LCWE) methods (implemented within the European Commission Project n° QLRT-1999-01298).

More in detail, the levels identified within the qualified working time are 5, where:

- Level A (Highest Level), represents the most advanced job positions. The worker that reaches Level A has in-depth knowledge and extensive experience in a specific field. In the workplace, it could correspond to management or expert roles, where the person has a high degree of autonomy and responsibility.
- Level B, is usually associated with professionals who have a good understanding and competence in their field, but not to the highest degree of specialization. People with Level B qualifications work independently with some experience but may still need supervision or support for complex tasks.
- Level C, at this level, the required skills are more basic than the higher levels. Level C might correspond to entry-level roles or positions that require some training but not highly specialized skills. People at this level may need ongoing education or supervision.
- Level D, and Level E (The lowest level), include the basic level, where the person has just entered the field or has limited experience (lower in Level E). They may correspond to apprenticeship positions, initial training, or roles that require little prior experience or skills.

The results, summarized in Table 2, are related to all the downstream and upstream operations of the three scenarios and should be added to the working period estimated by Blue Synergy for the remediation on Bagnoli site (reported in the last row of the Table). The analysis highlights the highest indexes related to the Sedremed scenario, mainly due to the production of huge quantities of concrete to build the confined disposal. The job positions involved at Bagnoli site (estimated by Blue Synergy) are 11 in the Invitalia scenario (9 only for dredging operations), necessary to perform all the process steps.

Table 2. Estimation of social indexes of the three scenarios. (Functional unit: 100,000 tons of sediment)

Index	Scenario 0	Life Sedremed scenario	Invitalia scenario
GQL A [hours worked]	3	137	1
GQL B [hours worked]	51	2552	24
GQL C [hours worked]	62	3050	29
GQL D [hours worked]	86	4228	40
GQL E [hours worked]	37	1817	17
Qualified working time (QWT) - internal [hours worked]	**238**	**11784**	**112**
Lethal accidents - internal [cases]	**0**	**1**	**0**
Serious non-lethal accidents - internal [cases]	**36**	**1781**	**17**
Job positions at Bagnoli site	**9**	**9**	**11**

10. Sensitivity analysis

The analysis, particularly the social sustainability assessment, identified a relevant issue due to the confined disposal construction, almost completely justified by the high concrete demand (i.e. 34,000 tons). The mining activity related to concrete production can justify many achievements, for example, the high number of serious non-lethal accidents (see Table 2). It was considered useful to include the confined disposal building in the analysis since the site will be dedicated to the disposal of sediment from Bagnoli site.

To be coherent with this choice, the building step should be included also in the hazardous waste disposal (considering the plant constructions). However, in agreement with the LCA practices, the infrastructures are excluded since their impact is considered amortized by the long lifetime. In this context, the sensitivity analysis aimed at assessing the effect of excluding the confined disposal construction from both environmental and social assessment, since this management is considered a permanent solution.

The impact variation was evaluated on the EF to include all the environmental issues. The results in Figure 5 show a burden halving, but without a change in the whole conclusion since the Sedremed scenario was already the best choice.

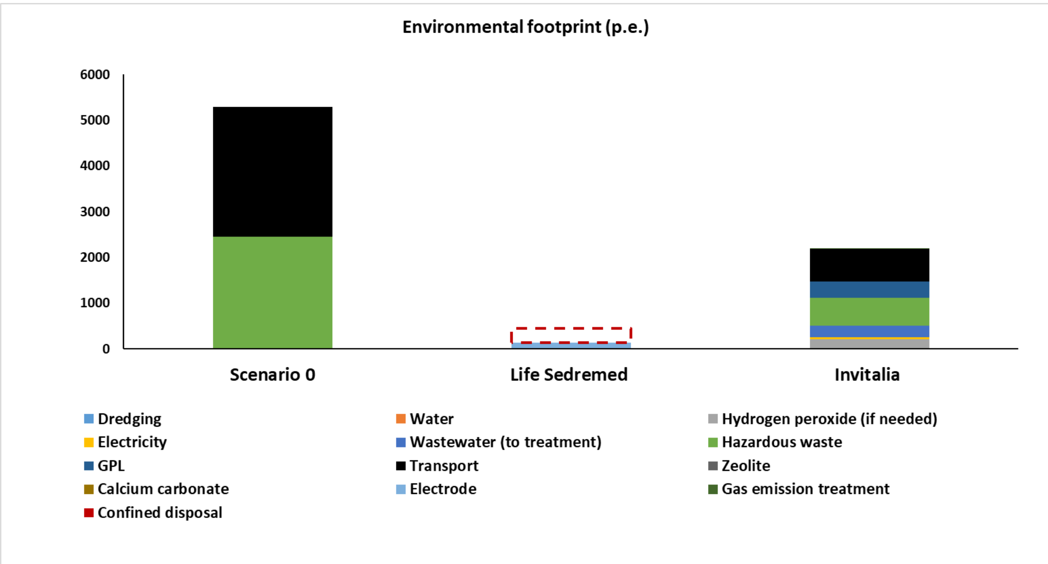

Figure 5. Effect of excluding the confined disposal construction from the evaluation of the EF.

The effect is much more evident for the social indexes, with a decrease higher than 99% which makes the Sedremed scenario the best option definitely.

Table 2. Estimation of social indexes of the three scenarios. (Functional unit: 100,000 tons of sediment)

Index	Scenario 0	Life Sedremed (without confined disposal for sensitivity analysis)	Invitalia scenario
GQL A [hours worked]	3	0.02	1
GQL B [hours worked]	51	0.3	23
GQL C [hours worked]	62	0.4	28
GQL D [hours worked]	86	0.6	39
GQL E [hours worked]	37	0.3	17
Qualified working time (QWT) - internal [hours worked]	**238**	1.6	**109**
Lethal accidents - internal [cases]	**0**	0	**0**
Serious non-lethal accidents - internal [cases]	**36**	0.2	**16**
Job positions at Bagnoli site	**9**	11	**11**

11. Conclusions

The analysis evaluated all the aspects of sustainability of the three considered scenarios, including environmental, economic and social. Overall, Sedremed scenarios showed promising results on all counts, showing an impact saving up to 95%, in terms of environmental and economic sustainability. On the other hand, Scenario 0 showed the greatest environmental burdens and a number of non-lethal accidents higher than Invitalia option.

www.life-sedremed.eu | info@life-sedremed.eu

Invitalia solution sounds promising from environmental and social point of views, despite of relevant operative costs, mainly due to the thermal desorption.
It is clear that sustainability and technical aspects are complementary, and they cannot stand without each other, so further work is needed to demonstrate the operative efficiency of LIFE Sedremed technology.
Overall, the present analysis was essential to define the potential benefits resulting from the implementation of Sedremed technology (assuming its effectiveness), in the perspective of the realization of green innovation.

12. References

1. Morra, L.; Salvia, A. APPALTO MISTO DI SERVIZI DI INGEGNERIA E ARCHITETTURA PER LA PROGETTAZIONE DEFINITIVA E COORDINAMENTO DELLA SICUREZZA IN FASE DI PROGETTAZIONE PER APPALTO INTEGRATO, COMPRENSIVO DI SERVIZI DI INDAGINI E DI LAVORI DI TEST DI DIMOSTRAZIONE TECNOLOGICA, OLTR; 2023.
2. Abromaitis, V.; Ochmanaite, V.; Denafas, G.; Martuzevicius, D. LCA-based comparison of VOC removal from exhaust gases by plasma and "conventional" ned-of-pipe methods. In Environmental Engineering, The 8th Conference; Vilnius, Lithuania, 2011.
3. Lu, W.; Chen, N.; Feng, C.; Deng, Y.; Zhang, J.; Chen, F. Treatment of polluted river sediment by electrochemical oxidation: Changes of hydrophilicity and acute cytotoxicity of dissolved organic matter. Chemosphere 2020, 243, 125283. doi:10.1016/j.chemosphere.2019.125283.
4. Autorità di Sistema Portuale del Mare Adriatico Meridionale. PORTO DI BRINDISI: COMPLETAMENTO DELLA INFRASTRUTTURAZIONE PORTUALE MEDIANTE BANCHINAMENTO E REALIZZAZIONE DELLA RETROSTANTE COLMATA TRA IL PONTILE PETROLCHIMICO E COSTA MORENA CONDOTTE, PIANO DI INDAGINE AI FINI DELLA VERIFICA E SUCCESSIVA CONFERMA DELL'; 2019.

www.life-sedremed.eu | info@life-sedremed.eu