June 2022

PILOT 2

SEDIMENT TREATMENT

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About DUAL Ports

DUAL Ports is an Interreg North Sea Region project started in December 2015, with a duration of 3 years. In December 2018, DUAL Ports was extended until 2021 and later it was extended again until 2022 with an increase in partners, pilots and budget. DUAL Ports is based on the operational pilots in Regional Entrepreneurial Ports (REP's). DUAL Ports will be measured in the concrete success of the pilots and the pilots' renderability to other REP's.

DUAL Ports addresses the Interreg Programme's objective of promoting resource efficiency and stimulate the adoption of new products, services and processes to reduce the environmental footprint of regions around the North Sea.

A series of pilot reports

DUAL Ports consists of 16 pilot projects and 17 partners from the port industry, knowledge institutions and tech business within sustainable energy. In a series of publications, we are introducing each of the pilot projects highlighting the experiences, results and learnings from their work. Knowledge sharing is vital for the continuous development of sustainable energy and the publications of DUAL Ports pilot projects will be a source for further work.

For more information about the Pilot 2: Sediment Treatment, please contact the DUAL Ports partner:

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Summary of pilot

The Port of Emden, similarly to many other ports worldwide, faces a challenge concerning the presence of legacy contamination in its sediments due to shipyard activities, where in the past a number of nowadays banned toxic products were still used, such as antifouling ship coatings containing pesticides like TBT (tributyltin).

The potential contamination in those areas prevents the use of water depth conservation measures (with the danger that pollutants are distributed to other port areas) and therefore the long-term use of certain parts of the harbour. For that reason, the Port of Emden sought to experiment with an innovative, economically advantageous, and sustainable concept for the treatment of pollutants in the port's sediments, to maintain port operations there in the long term.

The Pilot Project in the Port of Emden was divided into two separate phases. Firstly, an extensive investigation and evaluation of the contamination scenario in some hotspots areas around the shipyard was commissioned. After this study was completed, it served as the foundation for the test of a suitable sediment treatment alternative in a field test. The pursued alternative in this pilot project was the already established active nautical depth (AND) method in Emden but this time not just as innovative harbour depth maintenance measure but also as a sediment treatment tool in the enhancement of natural attenuation processes.

The first results of the field test are promising and therefore, this approach can be taken advantage of for the clean-up of at least one of the studied areas, which is relatively less problematic in terms of levels and complexity of the contamination. Thanks to the insights gained in the field test, the sediments containing low to moderate levels of TBT can be treated *in Situ*, which represents a reduction in costs of approximately 80% in comparison to traditional clean-up approaches. This will ensure at the same time a regain in productivity for that area of the port due to the restauration of the optimal nautical depth and a valuable gain in environmental quality in the harbour.

Project Description

The Project's Objective

In its first phase, the pilot project in Emden aims to investigate, identify, and document the current sediment pollution scenario in some potential hotspot areas in the harbour and compile this information in a comprehensive pollution register document. In a second phase, based on the information gained from the pollution register, possible decontamination alternatives and technologies will be closer analysed, in order to find an approach that best suits the case of Emden and is able to treat the sediments in a long term, environmentally friendly, low carbon, and low cost way. The pilot culminates in the test of the selected sediment-treating alternative in a field experiment.

Problem Definition

The sediments in some areas of the Port of Emden are affected by contamination that is typically released during shipyard activities. The resulting environmental pollution is a problem that many harbours worldwide face and has a highly complex composition, mixing inorganic (such as heavy metals, which are indestructible) and organic pollutants (highly persistent but potentially degradable), some of which have been banned by now due to their extreme toxicity. Apart from the environmental aspect, this problem also affects the economy and the regular functioning harbour.

The Port of Emden has since 1992 adopted a water depth conservation strategy called Active Nautical Depth (AND), also known as Keep the Sediment Moving (KSM), Keep Sediment Navigable (KSN) or Keep Sediment in the System (KSIS). In this method, the muddy sediment layer that is formed over time and grows above the maintained navigational depth is never removed from the bottom of the harbour basins. Instead, it gets constantly resuspended and conditioned in order to remain navigable, providing more nautical depth for the ships.

To achieve that, a trailing suction hopper dredger is constantly in operation in the port to periodically remove the uppermost layer of the very fine sediment particles, which would otherwise settle and consolidate in a dense layer, pump them into the dredger's cargo room where they come in contact with oxygen in the atmosphere and then finally release them back into the water column, as illustrated in Figure 1.

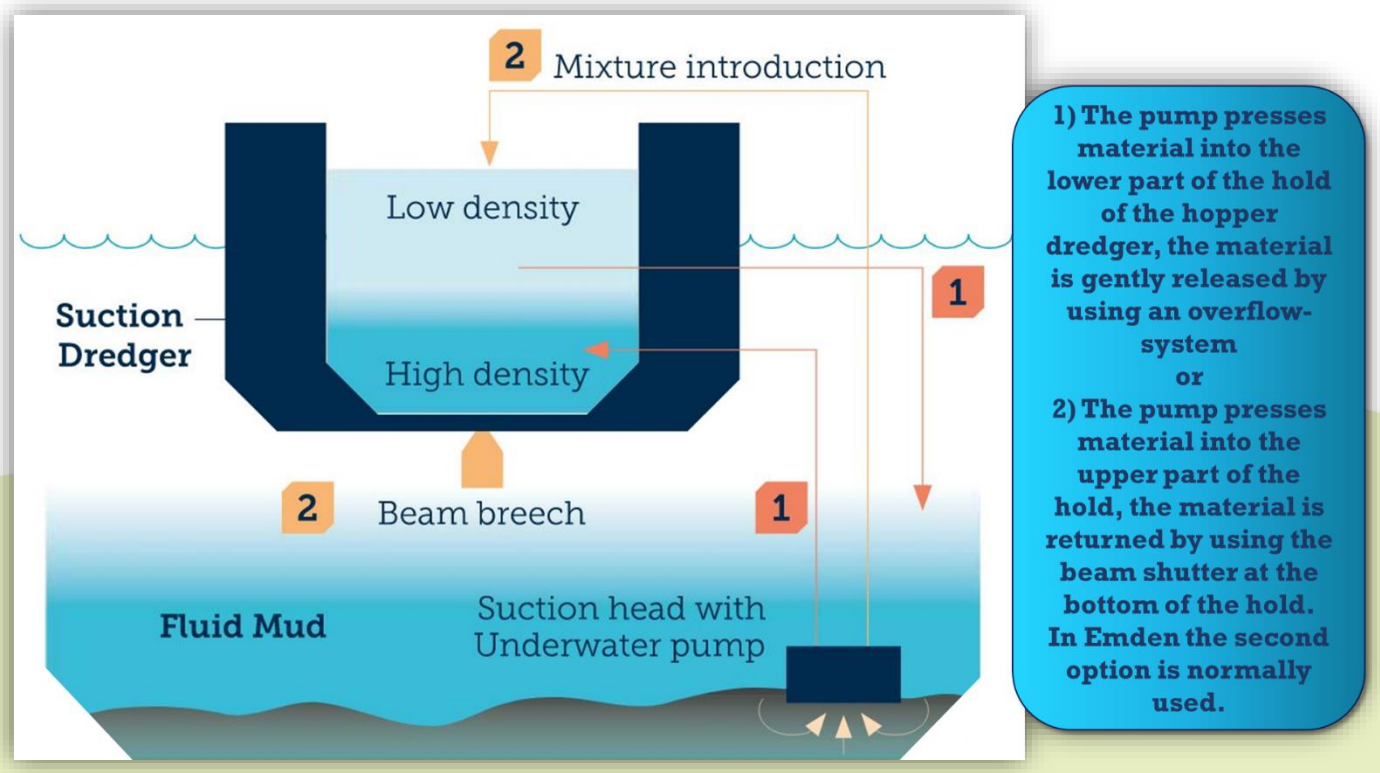


Figure 1 The Active Nautical Depth (AND) Method carried out in the Port of Emden.

The process creates a navigable fluid mud cloud that stays in suspension for days or even weeks, before the whole process has to be repeated.

This non-conventional water conservation method can be considered innovative and eco-friendly, as no excess material needs to be transported out of the harbour and no dumping, landfilling or recycling operations are needed. The challenge that the Port of Emden faces is that this process can only be applied in unpolluted areas, because otherwise contaminated sediments would be spread into non-contaminated parts of the harbour. For that reason, the areas close to the shipyard, which contain potentially polluted sediments, remained so far untouched, and because of that less deep, and therefore less productive than their actual capacity.

The Process – From Concept to Completion

Phase 1
In the first phase of the project, the actual pollution scenario in hotspots areas of the Port of Emden was to be established, as summarized in Figure 2. For that purpose, the Port of Emden commissioned an extensive pollution investigation and assessment study, including new bearings and material sampling for chemical analysis in the areas of interest. The gathered information should be organized and compiled in a single document, the Pollutant Register.

Phase 2
In the second phase, with the knowledge gained in Phase 1, suitable sediment clean-up alternatives should be developed and evaluated. The best performing alternative in regards to a number of different criteria would then be tested in a field-scale test.

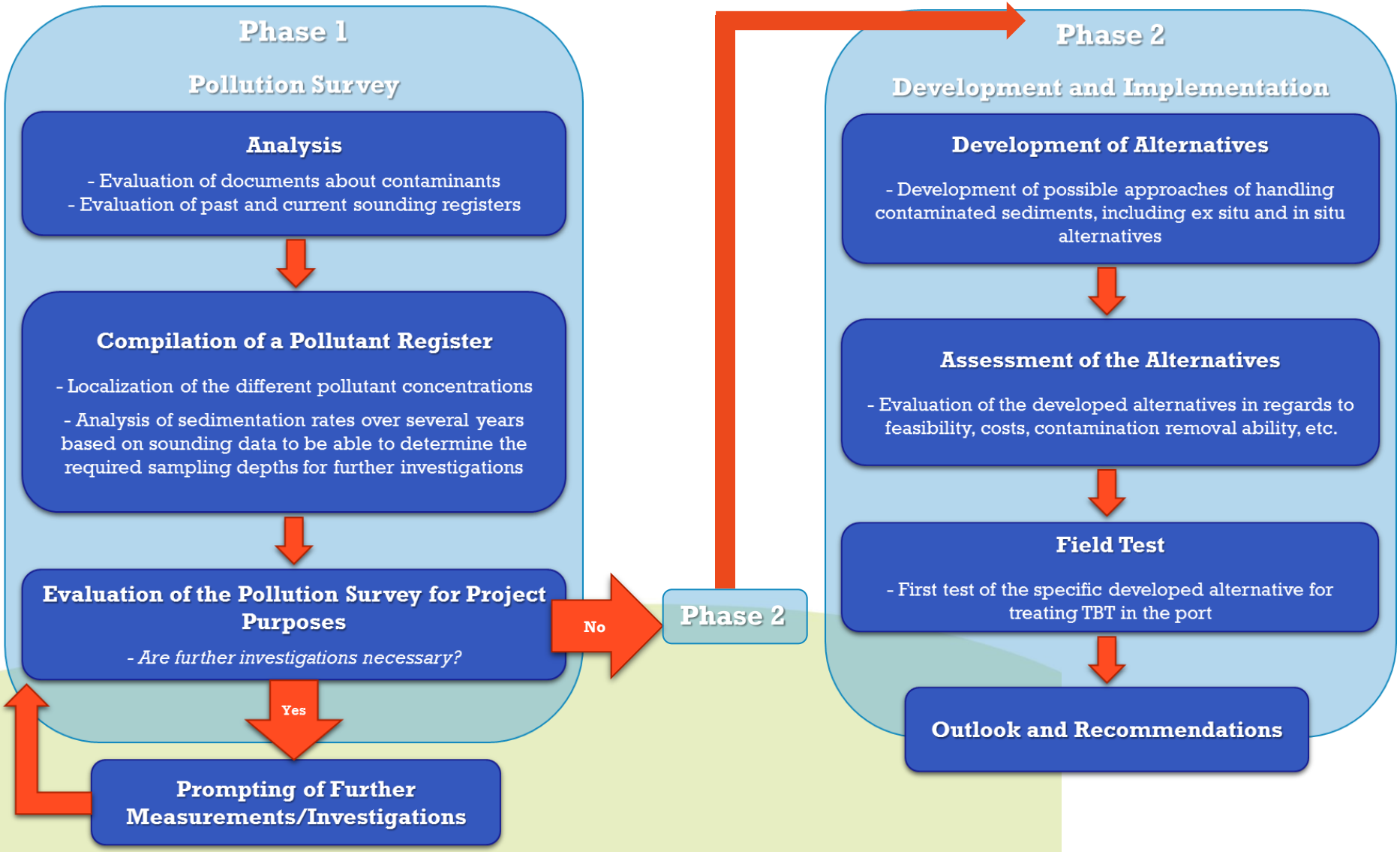


Figure 2 The two Phases of the Pilot Project Sediment Treatment in the Port of Emden.

Results

Phase 1

The investigation of the potentially contaminated areas close to the shipyard (Area 1, 2, and 3) confirmed that these areas are affected by legacy contamination in different degrees (Figure 3).

Sediment samples from Areas 2 and 3 showed moderate to high concentration (the high concentration values mentioned here were found specifically at depths that are not used by the harbour, meaning this contamination will not be released in any way because there is no intention of achieving such depths) of a variety of pollutants (variation depending on location of sampling within each area and depth), including persistent organic pollutants and heavy metals. Due to the high levels and complexity of contamination found in these areas, the treatment options for these materials are limited to *Ex Situ* alternatives, because the danger of contaminant spreading would be too high. That means that the first step for the clean-up and depth restauration of Areas 2 and 3 require the extraction of the contaminated material and transport to a specialized treatment and recycling or depot facility.

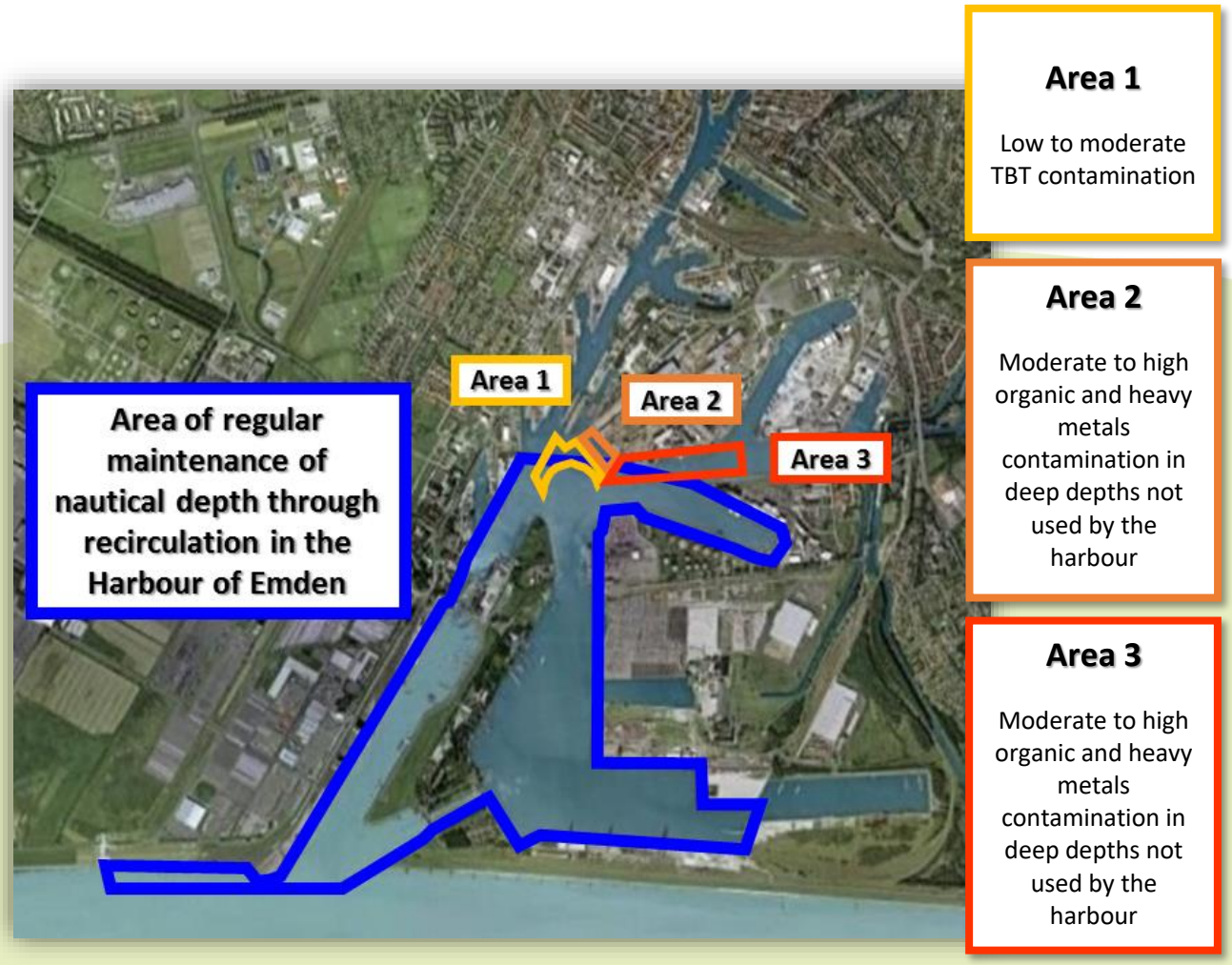


Figure 3 The Port of Emden and the investigated areas in the scope of the Pollutant Register.

Area 1 in contrast presents relatively low contamination and only by organic substances, which can potentially over time be degraded, especially tributyltin (TBT). These characteristics from Area 1 enable that the materials from that area are treated onsite.

In short, the findings of Phase 1 can be summarized as follows:

Outcome	Different degrees of different contamination in the 3 studied areas. Area 1 is the most suitable and therefore the designated area for the onsite treatment trial.
New Question	What treatment alternatives are there? What is the most suitable? ➔ Phase 2: Test of one alternative and subsequent monitoring.

Phase 2

The results from Phase 1 indicate that Areas 2 and 3 can only be treated by conventional methods, whereas Area 1 can be approached in a more innovative, environmentally friendly, and low carbon way. With this newly gained knowledge about the contamination in the harbour, treatment alternatives could be closely analysed and considered for the treatment of materials from Area 1. For that purpose, a master's thesis was written on the topic of typical harbour contamination scenarios worldwide and current trends in the technologies for sediment remediation. The findings of this work served as support in the decision-making and conceptualization of the adopted treatment alternative by the Port of Emden.

At first, a literature review on the topic of source, behaviour, and fate of TBT in harbour sediments was carried out. The goal was the understanding of the dynamics and establishing which factors influence the degradation of TBT once it is released into the environment. Figures 4, 5, and 6 summarize the findings of this review.

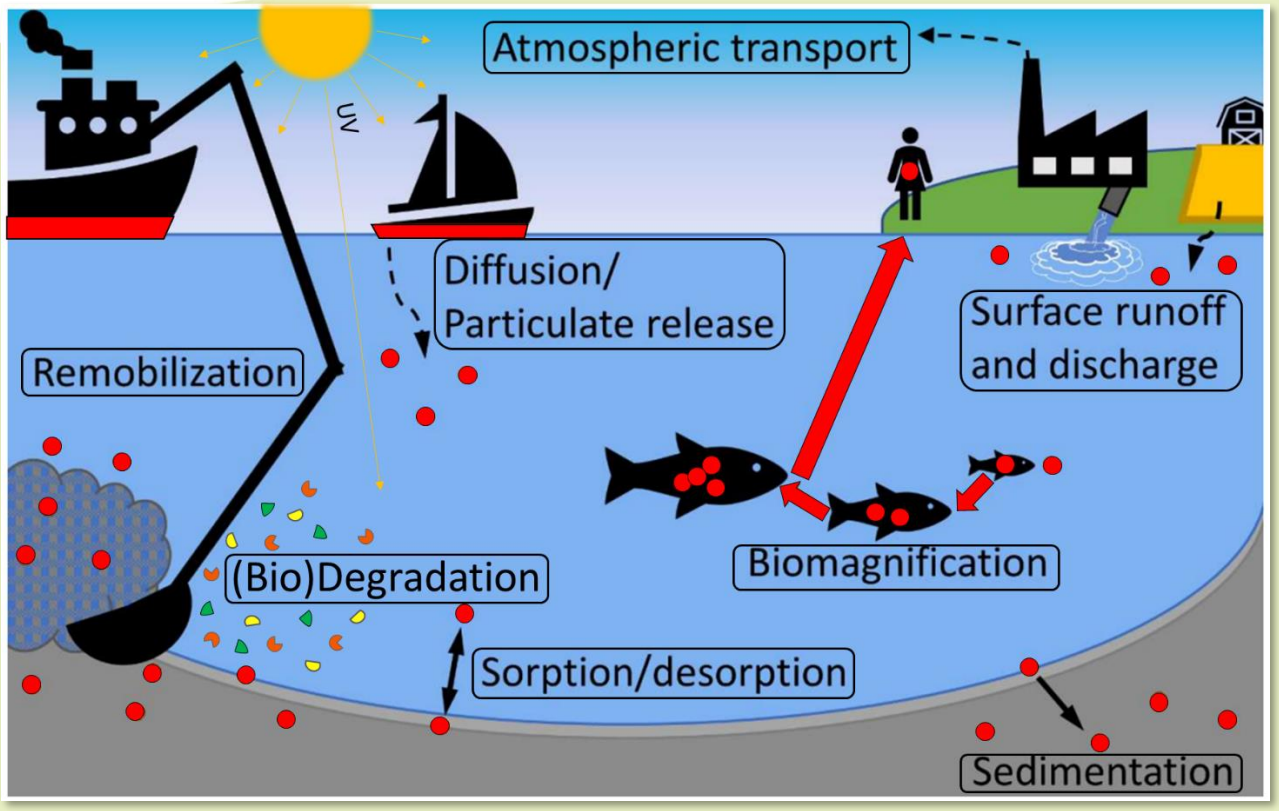


Figure 4 Sources, behaviour, and fate of TBT in the environment.
Adapted from: Norén (2021).

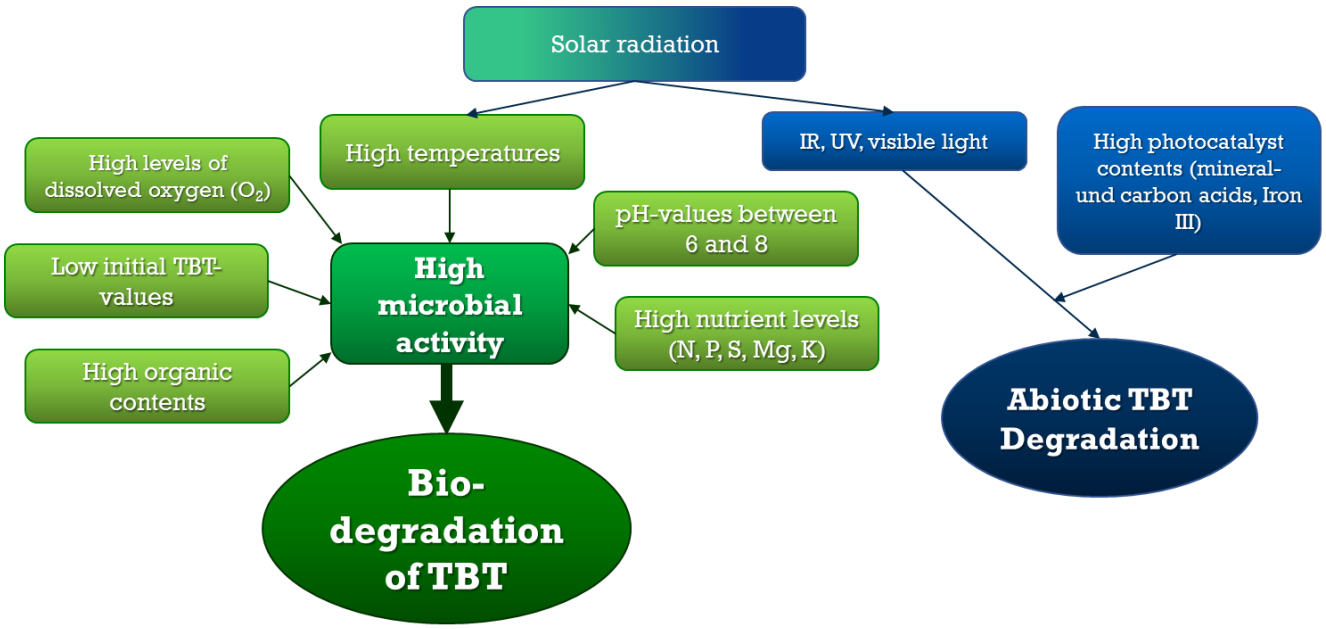


Figure 5 Environmental Parameters that affect the TBT Degradation positively in Sediments.

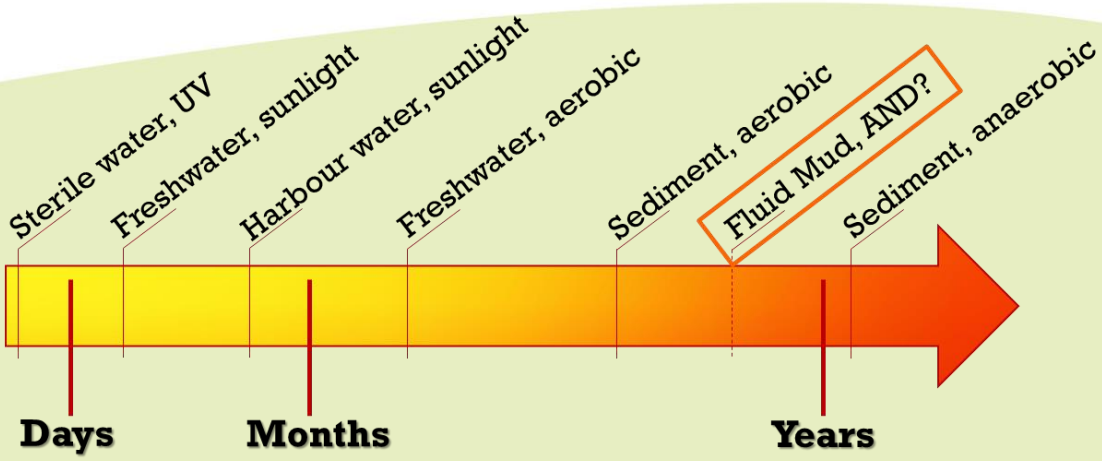


Figure 6 Half-life Values of TBT under various Environmental Conditions.
Adapted from: GALAB.

A review on sediment treatment methods and technologies was also carried out and the different options were compared taking into consideration relevant criteria, with focus on eco-friendly, low-carbon, and economically advantageous approaches.

The review and evaluation of sediment treatment alternatives had the contribution from the DUAL Ports partners, highlighting the international/transnational cooperation context of this pilot project. The DUAL Ports progress meetings as well as other networking opportunities made possible for a constant exchange and communication about the status and development of the pilot project with colleagues from national and international ports, universities, and research institutions.

The Active Nautical Depth (AND) method was later included in the list of considered alternatives, since it has been recently studied as not only port maintenance strategy but also regarding its potential as sediment decontamination tool (Table 1).

Table 1 Comparison of different disposition and treatment alternatives for sediments affected by TBT contamination regarding multiple criteria.

	Costs	Transport/ CO_2 Emissions	Innovation	Pollutant Removal
Landfilling	☹	☹	☹	☹
Sediment Washing	😐	☹	😐	☺
Phytoremediation	😐	☹	☺	☺
Bioreactor	😐	☹	☺	☺
Active Nautical Depth (AND)	☺	☺	☺	☺

✓

Field Test

In the context of sediment treatment, this is an emerging strategy that has not yet been extensively studied and not very well documented, especially in regards to results from practical field experiments. At the same time, this is a highly promising strategy, because in this method the sediments are exposed to atmospheric oxygen and solar radiation, which are important factors in abiotic and biological degradation of TBT by specialized microorganisms. Because of that, AND can be considered a good tool that contributes to the acceleration of the natural degradation of contaminants. That means that the already naturally existing clean-up processes that take place at very low rates in deep sediments can be enhanced when offered more optimal conditions.

The evaluation of the alternatives showed that the AND method had the most potential in the case of Emden. Based on this finding, a field test was planned next, where the effectiveness of this approach in the remediation of the sediment materials from Area 1 could be assessed. If this alternative proves to be effective, Area 1 could be treated *in Situ* and later incorporated into the area of regular maintenance of the harbour without the need for further financial and environmentally costly treatment measures.

The Field Test

In this field test, a limited amount of material from Area 1 with relatively low contamination levels (below national pollution limits) was brought into the Oil Harbour area. There, the material would be recirculated together with the originally existing material from the oil harbour with the same frequency or turnover rate as usual, i.e. whenever needed for the normal harbour operation.

For the implementation of this field test the Oil Harbour was periodically investigated and monitored before, during, and after the sediment reallocation operations.

The field test was designed in such a way as to minimize the potential risk of contamination spreading in the section of the semi-enclosed harbour that would serve as "bioreactor", the oil harbour (Figure 7). Therefore most process parameters were set to low.

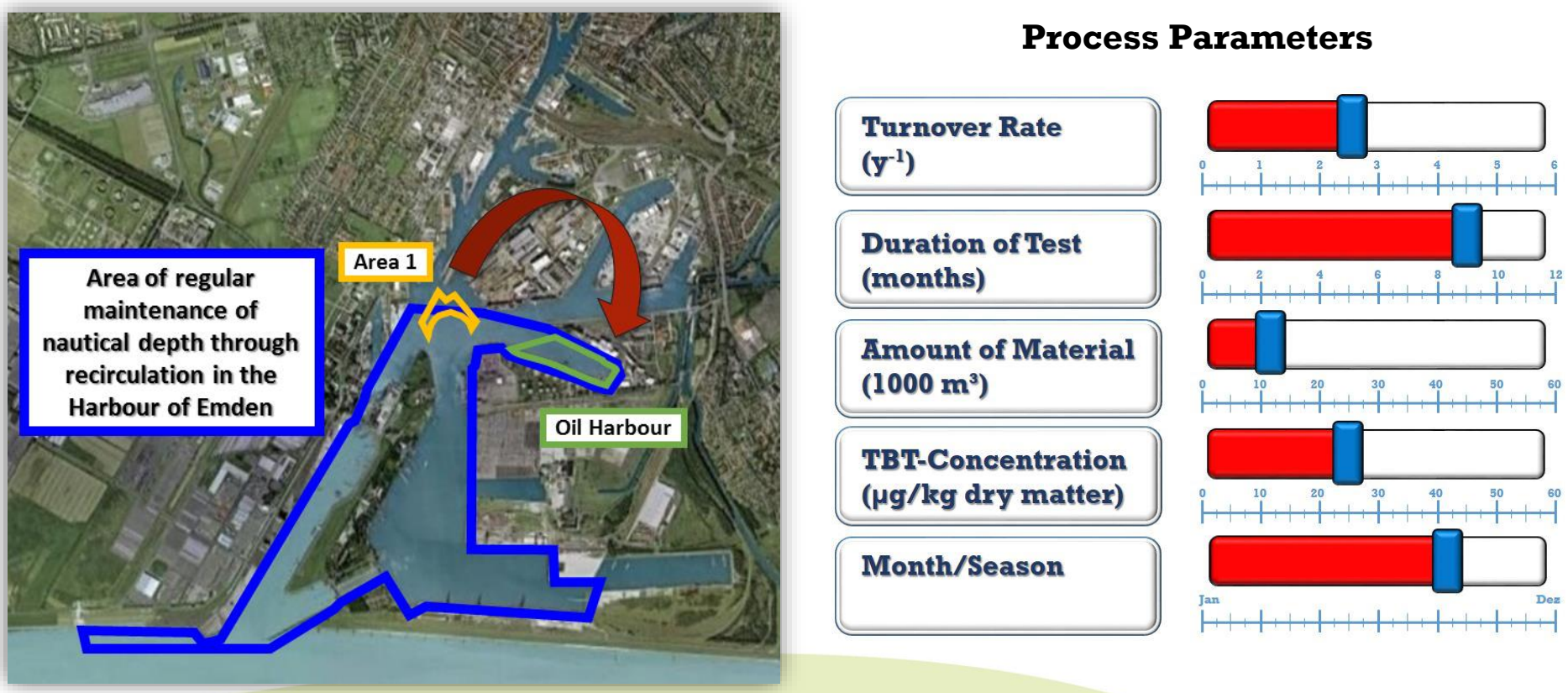


Figure 7 Field Test Concept on the left hand side and its Process Parameters on the right hand side.

During the first reallocation operation, approximately 12% of the total material to be extracted from Area 1 to achieve the desired navigational depth was transported into the Oil Harbour. The activities for that operation were carried out over two days (two red data points on the left hand side of Figure 8). The initial goal was a more significant increase in the measured TBT values for a better evaluation of this first test (e.g. double the initial value of 0,026 mg/kg dry matter), which was later not verified in the monitoring. For that reason, a second reallocation operation with additional approximately 2,5% of material was later planned and carried out (third red data point at around week 8). An increase in TBT values could still not be immediately observed in the Oil Harbour.

It was decided to carry on with the monitoring in the area without further material additions and expecting a decrease in the number over time, independently from the initial value.

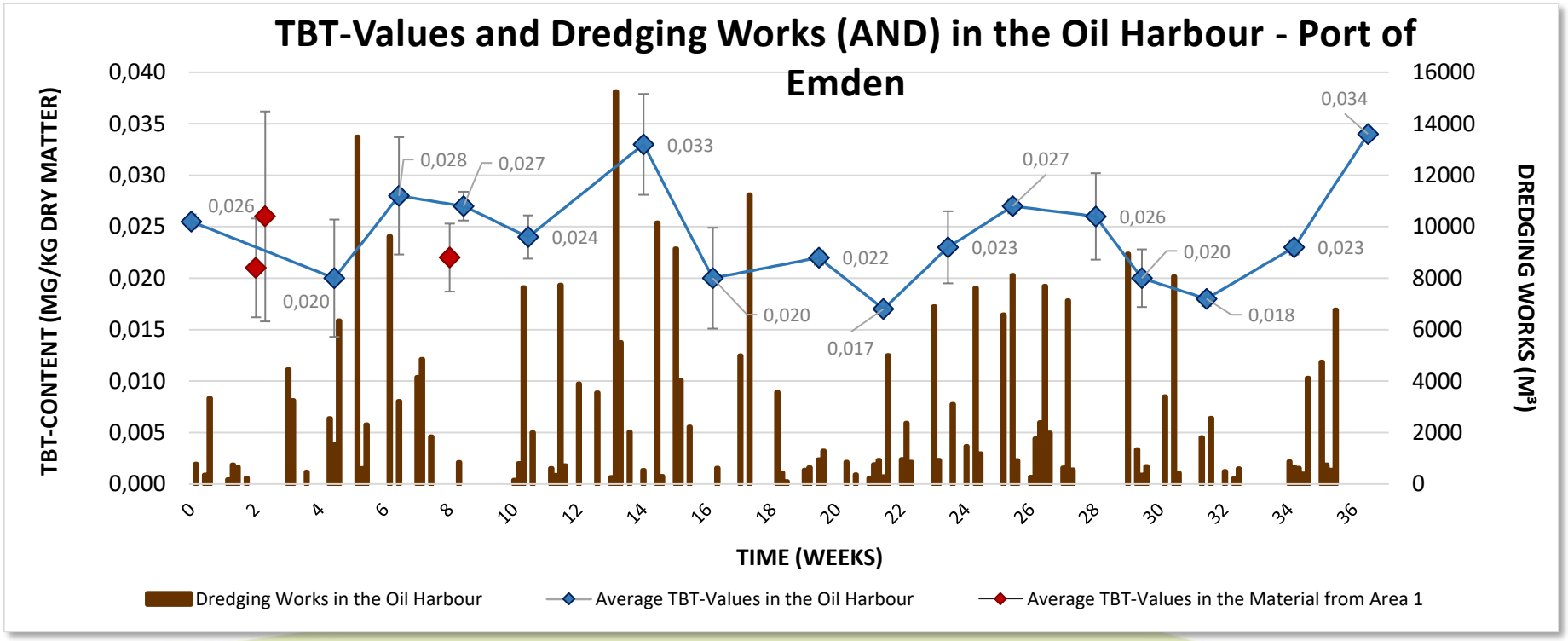


Figure 8 Development of TBT Concentration Values in the Field Test Area over Time.

A field test in a highly dynamic environment such as the Oil Harbour delivers results much harder to evaluate than lab experiments that are carefully carried out under controlled conditions. Unfortunately, it is not yet possible to draw a clear conclusion regarding the TBT degradation from the results generated so far in the Oil Harbour (test area).

One reason for the fluctuations in the results is the high dynamicity in the test area. The Oil Harbour is a basin in the Port of Emden where relatively intense vessel traffic takes places, which together with the dredging works causes high rates of mixing of the sediment materials.

As a consequence of the use of AND method in the port, the sediment bed and its limits are not clearly defined. Because of that, sediment samples that are taken in different sample points at the same depth often have varying ratios of water content to total solids, which also affects the TBT results from the sample analysis. Usually if a sample has a higher total solids content, the TBT concentration will also be higher, because it means it came from a deeper layer of more consolidated sediment in that particular sample point, where TBT tends to migrate and become bound and immobile.

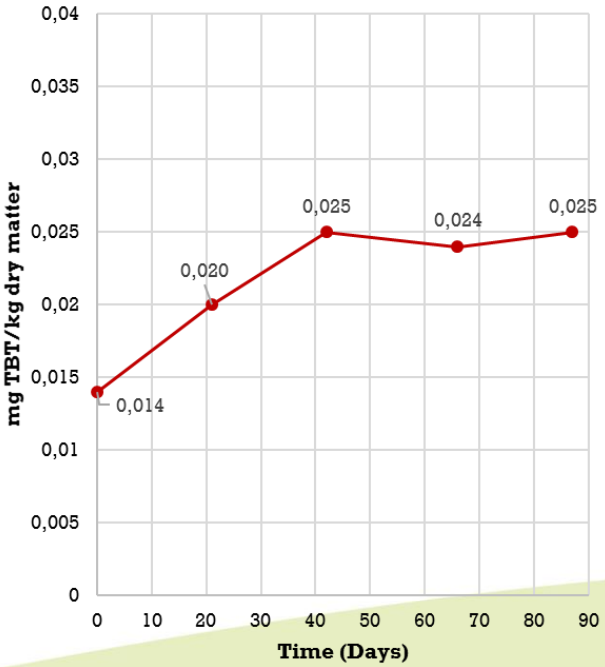
Another possible cause for the variation in results and presence of the two peaks in the diagram is the fact that the dredging activities in the harbour not only facilitate biodegradation processes, but also remobilization of TBT, as already illustrated in Figure 4. TBT has great affinity for sediment particles and therefore it can be found in sediments in the bound form, which is not available to microorganisms to degrade. The mixing that occurs during dredging works makes the first step of the degradation possible: the remobilization, which is a necessary part of the degrading process that can cause temporary rises in the TBT values that are detected in the sediment samples.

The correlation between dredging works and mixing with the occurrence of TBT peaks was also verified in an additional experiment that was carried out between January and April 2022 with material from the studied areas in Emden (Figures 9 and 10).

Figure 9 Setup of the Experiment where the Oil Harbour and the Dredging Works were recreated.

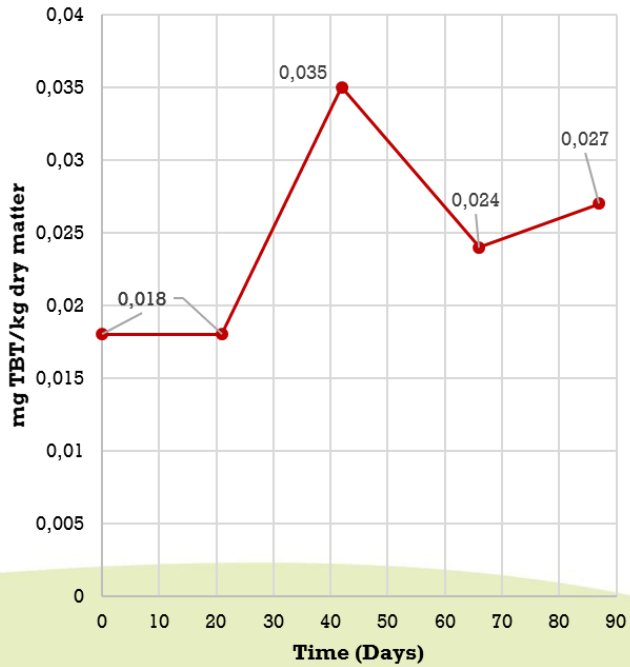
62% Fluid Mud from Oil Harbour
38% Material from Area 1

⊘ Mixing



62% Fluid Mud from Oil Harbour
38% Material from Area 1

✓ Mixing



10% Fluid Mud from Oil Harbour
90% Material from Area 1

⊘ Mixing

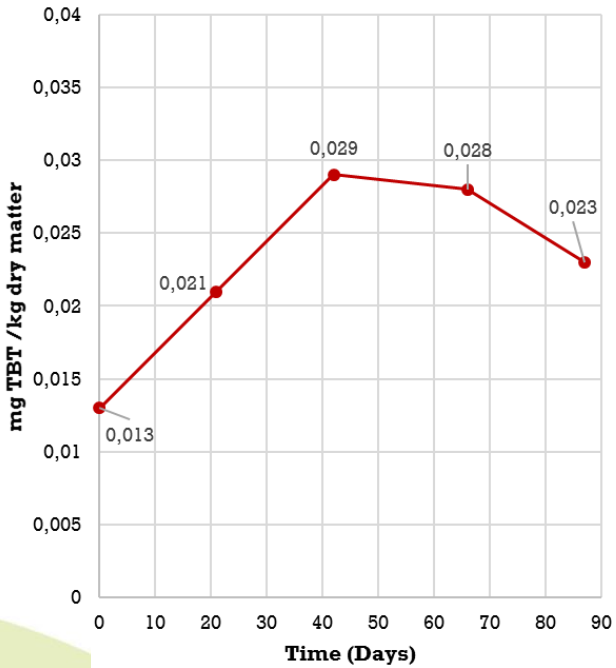


Figure 10 Results from the Experiment where the Oil Harbour and the dredging works were recreated.

For all of those reasons, punctual variations in the measured TBT values over time are to be expected. The observed variation does not signify sudden increases in the average total TBT content in the harbour. The test period of nine months (within running time of DUAL Ports) was too short to prove a reduction, scientifically.

Nevertheless, further reductions in the TBT values over time are to be expected (Figure 11), because there are no known current sources for new input of TBT in the harbour and also due to the degrading activity of microorganisms that is enhanced by the effects of the AND approach. In fact, when the Port of Emden has been observing a steady decrease in the overall background TBT values in the harbour, which is likely related to the positive effects of AND as a tool for natural attenuation enhancement. This method has to be considered a long-term treatment method for the degradation of TBT-pollutants *in Situ*.

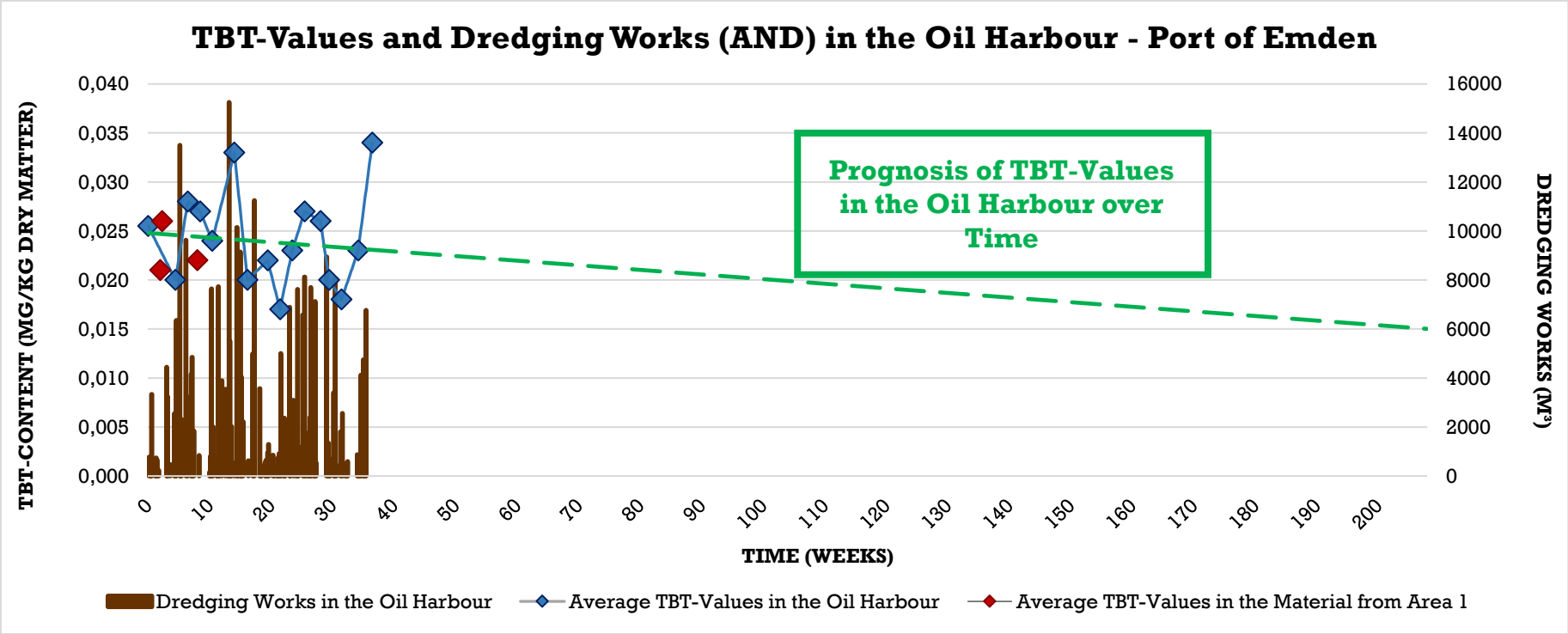


Figure 11 Prognosis of Development of TBT Concentration Values in the Field Test Area over Time.

Deliverables and milestones

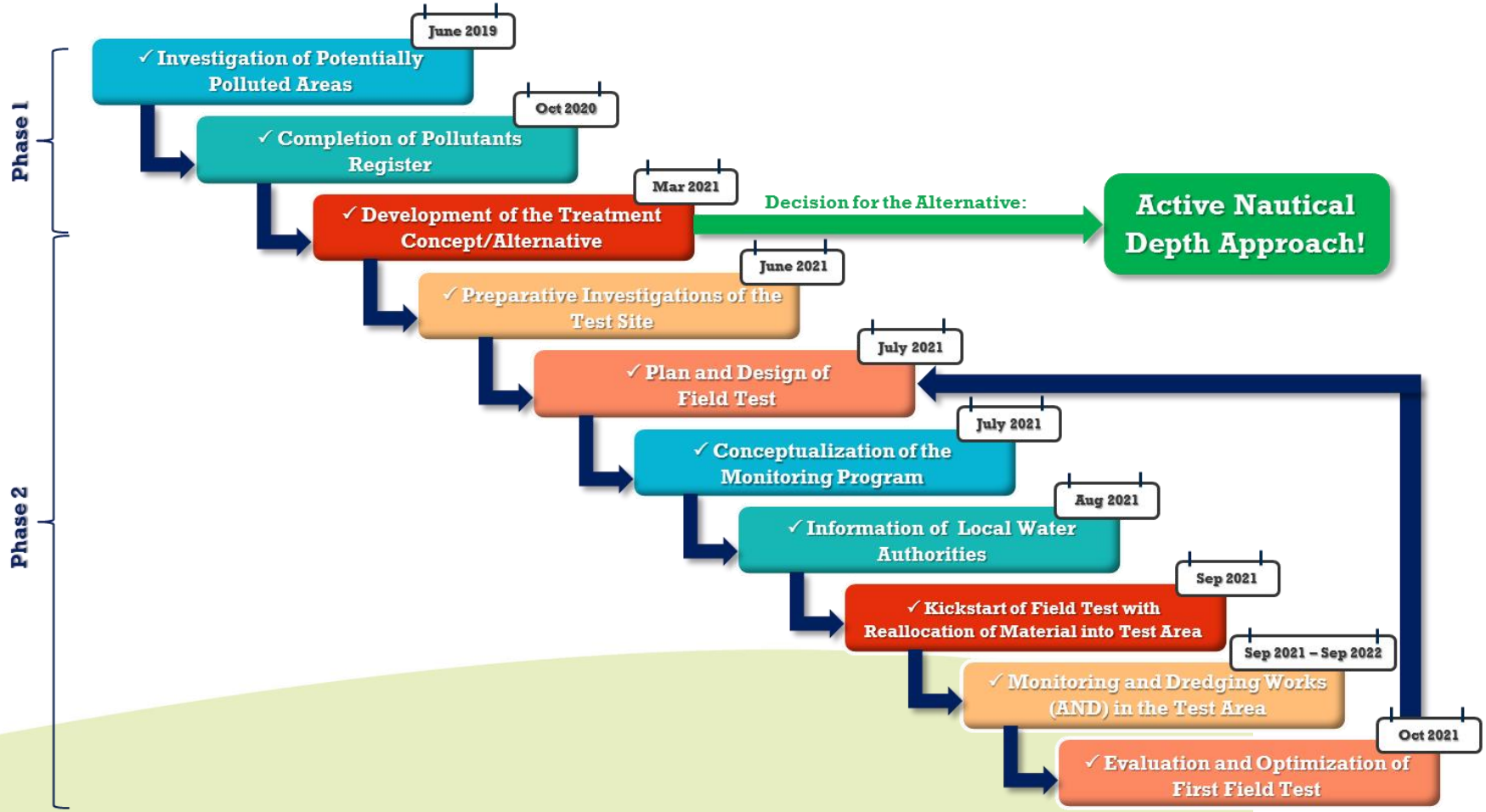


Figure 12 Activities in each Phase of the Pilot Project in the Port of Emden.

What makes this project sustainable?

Bioremediation: this project makes use of a very innovative and eco-friendly remediation alternative, which relies solely on the natural recovery capacity of contaminated environments. It promotes and enhances the naturally occurring biodegradation processes without causing additional damage.

***In Situ* Approach:** our clean up strategy does not require the extraction and transport of the contaminated material into its final destination, where it would then be treated or landfilled. Alone this step that we are skipping is responsible for massive reductions in costs and CO_2 emissions. This also means more benefits for the local community.

Innovative Green Alternative: it does not require the use of chemical reagents, which would generate huge amounts of wastewater to be treated. It does not rely on the usage of landfills, which have limited capacity and are an environmental problem.

Effective Clean-up: in the method that we propose, the contaminant is ultimately fully destroyed in the harbour and degraded into non-toxic products and not only transferred from one phase to another or from one location to another.

A summary of all of the sustainability aspects of the pilot project in the Port of Emden is shown in Figure 13.

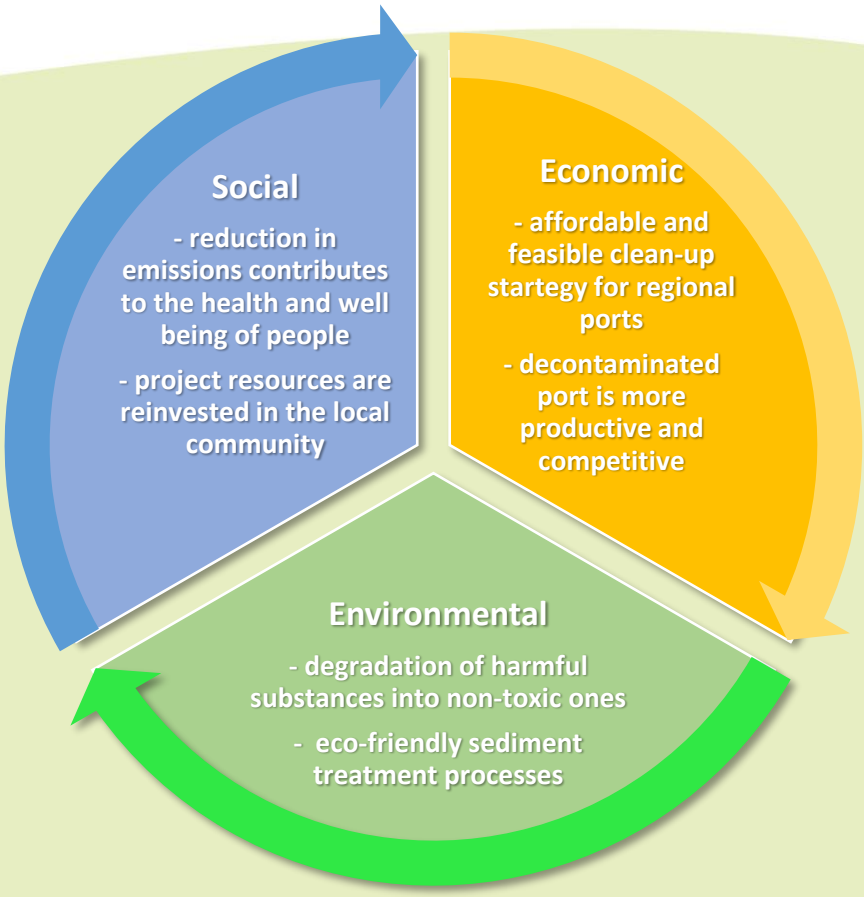


Figure 13 The three Aspects of Sustainability encompassed in the Pilot Project in the Port of Emden.

Data, facts and figures

- Within the scope of the pilot project, approximately 15% of the total material from Area 1 to be treated could already be bioremediated and incorporated into the normal harbour maintenance area. This also represents a step closer to achieving the most productive nautical depth in that area.

- The approach tested in this pilot proved to be in terms of costs and CO_2 emissions highly advantageous in comparison to conventional alternatives like landfilling. The reduction in costs can achieve up to 80% and reduction in emissions up to 90% provided that the TBT reduction proceeds as assumed (Figure 14).

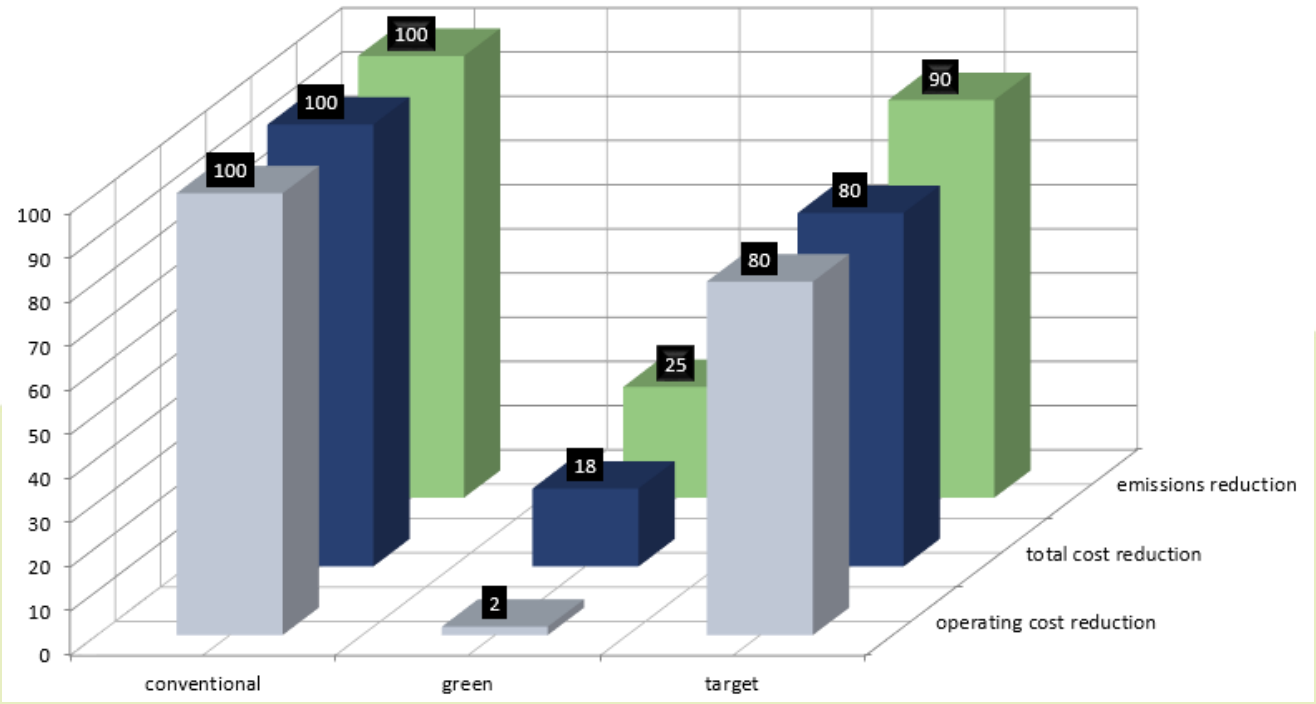


Figure 14 Costs and Emission Comparison between the Tested Green Alternative (Active Nautical Depth Method) and a Conventional Approach (Landfilling).
Credits: *Hamburgisches Weltwirtschaftsinstitut Gemeinnützige GmbH* (HWWI)

Take Home Message

Transfer

The use of the AND Method as a sediment clean-up alternative presents great potential, as exemplified in the results of this pilot project as well as in recent scientific publications (see Polrot 2021 and Fragkou 2021).

The successful implementation of it in other ports is possible and facilitated when certain boundary conditions are present, such as:

☑ ports located in estuaries with fine sediments

☑ low to moderate sediment contamination

☑ contamination consists of organic substances, such as TBT and PHAs

☑ the port already makes use of AND as its water depth maintenance strategy

☑ the sediments can be conditioned into a navigable fluid mud layer

Conclusions & lessons learned

Pollutant Register: Being a DUAL Ports project partner made it possible to carry out important studies and investigations regarding the contamination situation in some of the hotspots in the Port of Emden. This important document with valuable insights made later a field test of an innovative suitable sediment treatment alternative possible. The pollutant register delivered not only important findings that supported later activities in the DUAL Ports Project, but also is a legacy for the Port of Emden and base for further environmental projects in the future.

Innovation in Harbour Clean-up Technology: Thanks to DUAL Ports, the Port of Emden was a pioneer in the field test of AND as a sediment treatment alternative. Our experience offers valuable insights for other harbours with similar boundary conditions as well as for the research in this field.

From the Field Test into Practice: The results from our field test demonstrate that our already established harbour maintenance approach (AND) produces good results as a natural attenuation enhancement tool as well. This finding supports the decision to adopt this measure fully in order to pursue the clean-up and ultimately the integration of the rest of the material from Area 1 into the regular harbour maintenance plan.

The Method takes its Time: Since the contaminants that are being dealt with are the so-called persistent organic pollutants and have very high half-life times, it is to be expected that with a natural gentle *in Situ* treatment approach the complete degradation will still take quite a long time. This can be seen as a drawback of this method, however the AND approach delivers excellent results regarding other criteria, especially in costs and CO_2 reductions.

Further Green Potential: With the advancement and development of green technologies in the maritime and nautical sectors, especially in terms of green fuels, the AND method will become even more attractive due to potential further reductions in its carbon footprint.

Acknowledgments

We would like to express our sincere gratitude to all DUAL Ports partners for their valuable support and interesting discussions in this pilot project. We would also like to thank the INTERREG secretariat for their supportive and constructive assistance in the development of this pilot project, both financially as well as in terms of content.

Lastly, we would also like to thank all partners and colleagues who have helped in the preparation of the project and supported its implementation and management.

Project Collaborators

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