Vopak-EXPERO3 - LIFE09/ENV/B/000407

Final Report - Annex 7266

Report on the benefits of ISCO using perozone in relation to traditional remediation strategies

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List of abbreviations

11-DCA	1.1-dichloroethane
111-TCA	1.1.1-trichloroethane
BATNEEC	Best Available Technology Not Entailing Excessive Costs
BOD	Biological oxygen demand
BTEX	Benzene, toluene, ethylbenzene, xylene
CATOX	Catalytic oxidation
CAH	Chlorinated aliphatic hydrocarbons
COD	Chemical oxygen demand
DOC	Dissolved organic carbon
GAC	Granular Activated Carbon
EC	European Commission
EX	Explosion sensitive
H&S	Health and safety
ISCO	In situ chemical oxidation
LEL	Lower explosion limit
MPE	Multi phase extraction
NAPL	Non aqueous phase liquid
mbgl	Meter below ground level
OVAM	Openbare Vlaamse Afvalstoffenmaatschappij (Public Waste Agency)
PID	Photo ionisation detector
P&T	Pump and treat
RAP	Remedial Action Plan
SVE/BLE	Soil vapour extraction
TOC	Total organic carbon
TPH	Total petroleum hydrocarbons
VOC	Volatile organic chlorocompounds

1 INTRODUCTION

This report discusses the benefits of the ISCO treatment in relation to the traditional remediation strategies. The innovative aspects of ISCO using perozone were identified in the technical proposal of this LIFE+ project as follows:

- No pumping of groundwater is required. Hence, no groundwater treatment is necessary. This means that there is a strong reduction in the use of electricity because no pumps or groundwater treatment installation is required.
- The absence of a groundwater treatment installation also means that no granular activated carbon (GAC) for water treatment is required and no sludge will be formed. Since used activated carbon for water is burned after it is used, this will also be a reduction in carbon dioxide emissions.
- During the project all materials using electricity will be selected to have a capacity as close as possible to the required capacity. By doing this, we can guarantee that almost no excess capacity will be present and therefore no excess electricity consumption will be used and hence no excess carbon emissions will be created.

The benefits are related to the efficiency (energy, time and cost), the emission to the environment and the carbon foot print. For comparison reason, the duration of MPE and ISCO using perozone is taken at 8 years. In annex 7266, the MCA report takes into account a more realistic duration of this in-situ remediation strategy.

The identified remedial strategies are discussed in the following paragraphs:

1. Excavation after a period of hydraulic containment using P&T;
2. Source excavation in combination with in situ chemical oxidation (using perozone);
3. Source excavation in combination with multi-phase extraction (MPE).

Annex 7265 of the final report discusses the technical and economic feasibility of these remedial strategies. Please refer to this document for more details. The latter document concludes that a GAC treatment within remedial strategy 1 and 3 is economical not feasible and can better be replaced by catalytic oxidation. Therefore, we will only discuss the catox treatment for these two remediation strategies in this report. However, a GAC treatment of the vapour phase can still be feasible under certain conditions.

2 EFFICIENCY

2.1 Energy

The energy consumption is calculated based on the information provided by the OVAM CO2 calculator available on the website https://www.ovam.be/batneec-evaluatie-met-co2-calculator. The lists below describe the main activities with regard to energy consumption:

Excavation (6000 m³) after P&T (30 years)

- Excavation and removal (transport) of contaminated soil
- Delivery, backfilling and compaction of sand
- Soil treatment (thermal or physico-chemical)
- Groundwater extracting (1 to 2 m³/hour) is minimised in order to contain any migration of contaminants
- Groundwater treatment installation consisting of sand filter, air stripper unit and catox – 100 m³/hour - for vapour treatment (no GAC treatment).

ISCO treatment using perozone (8 year) and source excavation (300 m³)

- Excavation and removal of contaminated soil
- Delivery, backfilling and compaction of sand
- Soil treatment (thermal)
- Soil vapour extraction (600 m³/hour)
- ISCO injection using perozone (4 Nm³/hour)
- Ozone generation (energy use is between 6 and 10 kW per ISCO container)

MPE (8 year) and source excavation (300 m³)

- Excavation and removal of contaminated soil
- Delivery, backfilling and compaction of sand
- Soil treatment (thermal)
- MPE (water: 2 – 3 m³/hour; air 500 m³/hour) is limited by stability restrictions – no groundwater lowering below peaty or clayey layer.
- Groundwater and soil vapour treatment using sand filter, air stripper unit and a catox – 150 m³/hour (No GAC treatment)..

The energy consumption (expressed as MJ) is presented on next page for the three remediation strategies.

Estimated energy consumption an carbon foot print for Excavation after 30 year P&T

Description	consumption	type	Quantity	energy (MJ)	Carbon foot print (ton CO_2)
Excavation/backfill	40.700	liter gasoil	-	1.465.000	10
Transport	82.000	liter gasoil	-	2.952.000	260
Soil treatment	1.100	MJ/m³	6000 m³	6.600.000	570
P&T					
Groundwater extraction	25.700	MJ/year	30 year	771.000	80
Groundwater treatment	77.300	MJ/year	30 year	2.319.000	230
Soil vapour treatement by catox*	95.700	MJ/year	30 year	2.871.000	10
Total energy consumption				16.978.000	1.160
Total energy consumption P&T				6.557.100	352
*2100 ton CO_2 if GAC treated					

*3,6 MJ/kWh; 36 MJ/liter gasoil

Estimated energy consumption and carbon foot print for source excavation, ISCO and SVE

Description	consumption	Unit	Quantity	energy (MJ)	Carbon foot print (ton CO_2)
Excavation/backfill	2.400	liter gasoil	-	85.000	0,8
Transport	4.100	liter gasoil	-	188.000	13
Soil treatment (thermal)	3.100	MJ/m³	300 m³	930.000	82
ISCO and SVE					
Blower - 600 m³/uur	378.400	MJ/year	8 year	3.027.200	299
Vapour treatment	9.500	MJ/year	8 year	76.000	7
Ozone production	201.400	MJ/year	8 year	1.611.200	159
Injection ozone	22.100	MJ/year	8 year	176.800	17
Total energy consumption				6.094.200	578
*3,6 MJ/Kwh; 36 MJ/liter gasoil: 235000 kWh during 4,2 year for ozone generation					

*3,6 MJ/kWh; 36 MJ/liter gasoil

Estimated energy consumption and carbon footprint for source excavation and MPE

Description	consumption	Unit	Quantity	energy (MJ)	Carbon foot print (ton CO_2)
Excavation/backfill	2.400	liter gasoil	-	85.000	0,8
Transport	4.100	liter gasoil	-	148.000	13
Soil treatment (thermal)	3.100	MJ/m³	300 m³	930.000	82
Multi Phase Extraction					
MFE extraction	220.100	MJ/year	8 year	1.760.800	174
Groundwater treatment	146.600	MJ/year	8 year	1.172.800	140
Soil vapour treatment by catox	157.700	MJ/year	8 year	1.261.600	120
Total energy consumption				5.358.200	530

*3,6 MJ/kWh; 36 MJ/liter gasoil

The full scale excavation after P&T consumes a lot of energy for the soil treatment and for the transport (by truck). The catox incinerator uses 50% of the energy of P&T. Total energy consumption for 30 years of P&T is estimated at 6.5 million MJ. The soil excavation and treatment consumes 10.4 million MJ.

The soil vapour extraction of the ISCO system consumes 50% of the total energy. 25 % is used for ozone generation and another 25 % for the perozone injection. Total energy consumption for ISCO using perozone and SVE (8 year) is estimated at 6.1 million MJ.

The extraction unit of the MPE consumes annually 42% of the total energy of the Multi-phase extraction. The catox incinerator uses 52% of the energy of the groundwater and soil vapour treatment. Total energy consumption for MPE is estimated at 5.4 million MJ.

Both ISCO and MPE remediation strategies have equivalent total energy consumption, being half of the energy consumption for the full scale excavation after P&T.

However, the annual consumption of the in-situ remediation technique (excluding excavation) is 0.5 million, MJ for MPE, 0.6 million, MJ for ISCO and 0.2 million for P&T. The total energy consumption is strongly related to the duration of the in-situ remediation.

2.2 Time

We are referring to the report on the technical and economic feasibility (annex 7265 of the final report).

Full-scale excavation, in absence of industrial activities, can be carried out in a few months. However, the duration of the hydraulic contaminant containment is determined by the duration of the industrial activities. This timeframe is currently unknown but expected to be at least several decades. For calculation reasons, a timeframe of 30 years is considered. This makes the estimation of the remediation cost or energy efficiency of this remediation strategy very uncertain in case that P&T is required for hydraulic contaminant containment. However, P&T contaminant containment could be replaced by groundwater monitoring if the absence of contaminant migration can be demonstrated.

The contaminant removal rate of ISCO using perozone is proportional to the ozone injection rate. The latter is restricted because of safety precautions. ISCO treatment in source zones could last longer than MPE depending upon the presence of NAPL. Duration should be re-evaluated on the basis of contaminant mass evaluation using soil samples analyses. Therefore, the estimation of the energy use, carbon foot print and remediation cost are uncertain. In plume zone areas, the remediation strategy applied at the VOPAK site demonstrated to be successful in achieving project goals in less than 4 years.

MPE contaminant rate removal is proportional to the contaminant concentration levels. We assume that an estimation of less than 6 to 8 years for the MPE remediation of source and plume zone areas is realistic.

2.3 Cost

We are referring to the report on the technical and economic feasibility (annex 7255 of the final report) for the cost details of the estimation below.

Remediation strategy	Excavation	ISCO*	MPE-Katox*
P&T (30 year)	1.906.764,50 €	- €	- €
Excavation	1.077.000,00 €	82.447,50 €	82.447,50 €
ISCO / BLE	- €	1.101.761,38 €	- €
MPE	- €	- €	1.660.974,52 €
Env Ass	170.000,00 €	230.000,00 €	150.000,00 €
Safety	44.000,00 €	68.200,00 €	38.000,00 €
Total (excl VAT)	3.197.764,50 €	1.482.408,88 €	1.931.422,02 €
*inclusif source excavation			
annual cost - in-situ remediation	62.598,40 €	133.987,79 €	152.024,32 €

*inclusive source excavation

3 EMISSION

Emission is defined as direct transfer of contaminants to other environmental compartments such as the atmosphere and surface water.

Excavated soil is transported to a treatment centre. The soil is treated thermally or physically and chemically. The treatment of heavily contaminated soil degrades hydrocarbons to CO_2 and water. A small part of the hydrocarbons will be present in sludge waste of the water treatment plant which will be deposited on a landfill.

Contaminant containment using P&T requires only a minimal groundwater extraction for containment purposes. This extraction rate is estimated at an average of 2 m³/hour. Based on contaminant concentrations in the influent water it is estimated that 13 ton of hydrocarbon will be extracted during 30 years. The contaminant mass is transferred to the vapour phase and treated by a catox. An estimated 10 % of this mass could emitted to the atmosphere, i.e. 1.3 ton.

ISCO using perozone also degrades the (chlorinated) hydrocarbons. Using the optimal injection scheme, only a small part of these hydrocarbons are sparged to the vadose soil and removed by soil vapour extraction. The soil vapour is treated by a GAC filter so that no direct emission of hydrocarbons to the atmosphere is occurring. The GAC filter is recycled or burned degrading the hydrocarbons to products such as CO_2 and water. The major part of the contamination is degraded in-situ by perozone. This remediation technique has a quasi-zero contaminant emission under optimal ISCO injection regime.

MPE extracts volatile organics of which 90-95% are oxidised by a catox and emitted as CO_2 and water to the atmosphere. 5-10% of these organics are not incinerated. Of the 121 ton of hydrocarbons extracted by MPE, 6 to 12 ton hydrocarbons and 232 to 244 ton CO_2 are emitted to the atmosphere.

ISCO using perozone has nearly no emission. The other remediation techniques emit 90% of the extracted organic compounds as CO_2 and water. 1.3 ton and 10.7 ton contaminant mass would be emitted directly to the atmosphere by the P&T and MPE systems.

4 CARBON FOOTPRINT

The carbon foot print of the remediation strategy by excavation after 30 year of P&T is 1160 ton CO_2 if vapour treated by catox. If the vapour is treated by GAC an additional 2100 ton for GAC removal by burning should be accounted. The water treatment using catox for the soil vapour phase is responsible for $1/3^{rd}$ of the carbon foot print.

The carbon foot print of the remediation strategy by ISCO during 8 years is estimated at 578 ton CO2. The remediation strategy has neither groundwater pumping nor treatment. Ozone generation and injection, soil vapour extraction and treatment is responsible for more than $2/3^{rd}$ of the carbon foot print. However, the duration of the remediation could take a much longer time than remediation by MPE. A slower ozone injection rate extends the remediation time. The extra carbon foot print increases with more than 60 ton CO_2 per extra year remediation.

The carbon foot print of the remediation strategy by MPE during 8 years is estimated at 530 ton CO_2. The multi-phase extraction pump consumes a lot of energy (7 kW) and is responsible for more than $1/3^{rd}$ of the carbon foot print. Moreover, 90-95% of the organic compounds are incinerated and emitted as $CO_{2.}$ CO_2 emission after 8 year could be y 530 ton CO_2.

However, the duration of this remediation in source and migration zones could be less than 8 year. In this case, the final carbon foot print could be lowered with more than 50 ton per year.

5 SUMMARY AND CONCLUSION

Excavation after P&T has the less efficient remediation strategy if active P&T hydraulic containment measures have to be implemented. If hydraulic containment by P&T is not necessary, excavation after stopping industrial activities has the most benefits: the highest energy efficiency, the lowest emission and carbon foot print.

ISCO using perozone compared to MPE has a lower annual remediation cost and a better emission. However, annual energy efficiency and carbon foot print of both remediation techniques don't differ very much if remediation time is the same. This ISCO could be advantageous in plume zones with lower concentrations and no NAPL. In this case, remediation time is limited (less than 4 year) as demonstrated during the ISCO treatment at the VOPAK site. The benefits of ISCO using perozone could be higher in plume zone areas with relative low contaminant concentration levels and no NAPL.

Most likely, the remediation efficiency of MPE in source zones would be better due to shorter remediation duration than the efficiency of ISCO using perozone. MPE efficiency increases with the concentration level while for ISCO treatment, the efficiency depends upon the oxidant injection rate. The benefits of MPE are most likely higher in source zone areas with high concentration levels and/or presence of NAPL.

ANNEX

ANNEX 1
CARBON FOOT PRINT CALCULATION

Rekenmodel CO_2 bij bodemsaneringen — versie 1.3.1

Uitvoerscherm
De resultaten op het uitvoerscherm betreffen gemiddelde waarden,
de minimale en maximale waarden zijn per onderdeel gegeven op het tabblad berekeningen.

Projectnaam	150974
Saneringsvariant	Excavation after migration control by P&T during 30 years
Datum	17 augustus 2017
Model ingevuld door	DVL

Ontgraven landbodem — 929 ton CO_2

Ontgraven	28 ton CO_2
Verwerken	644 ton CO_2
Materialen	0 ton CO_2
Transport	257 ton CO_2

Grondwater onttrekken — 80 ton CO_2

Aanleg systeem	5 ton CO_2
Onttrekken	75 ton CO_2
Transport	0 ton CO_2

Grondwater zuiveren — 289 ton CO_2

Zuiveringsonderdeel	268 ton CO_2
Hulpstoffen / chemicaliën	0 ton CO_2
Afvalstoffen	0 ton CO_2
Transport	21 ton CO_2

PLI en BLE (in situ) — 0 ton CO_2

Aanleg systeem	0 ton CO_2
Instandhouden systeem	0 ton CO_2
Oxidatiereactie	0 ton CO_2
Transport	0 ton CO_2

MFE (in situ) — 0 ton CO_2

Aanleg systeem	0 ton CO_2
Instandhouden systeem	0 ton CO_2
Transport	0 ton CO_2

ISCO — 0 ton CO_2

Aanleg systeem	0 ton CO_2
Instandhouden systeem	0 ton CO_2
Oxidator	0 ton CO_2
Oxidatiereactie	0 ton CO_2
Transport	0 ton CO_2

Biostimulatie — 0 ton CO_2

Aanleg systeem	0 ton CO_2
Instandhouden systeem	0 ton CO_2
Substraat en hulpstoffen	0 ton CO_2
Substraatreactie	0 ton CO_2
Transport	0 ton CO_2

Thermisch — 0 ton CO_2

Aanleg systeem	0 ton CO_2
Instandhouden systeem	0 ton CO_2
Transport	0 ton CO_2

Toezicht en Nazorg — 0 ton CO_2

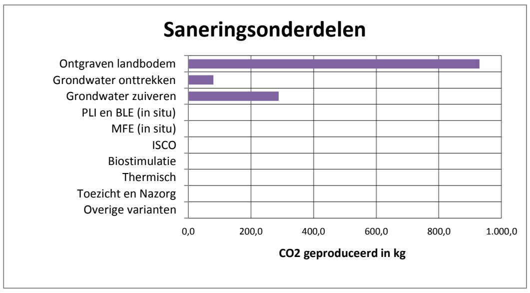
Toezichthouder	0 ton CO_2
Directievoerder	0 ton CO_2
Milieukundig begeleider	0 ton CO_2
Onderhoudsmonteur	0 ton CO_2
Veldmedewerker	0 ton CO_2

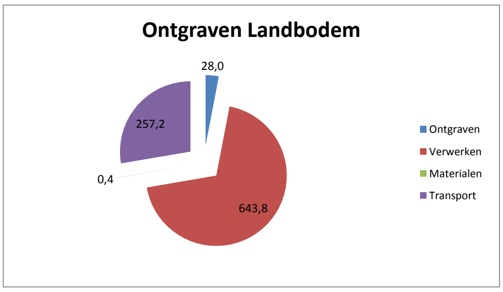
Overige varianten — 0 ton CO_2

Transport	0 ton CO_2
Materiaal	0 ton CO_2
Boorwerk	0 ton CO_2

Verwijderde vracht 86.869 kg
Behandeld volume grond 6.000 m³

EMISSIE : 1.298,1 ton CO_2
142,6 Huishoud equivalenten
0,0 ton CO_2 per kg verwijderde verontreiniging
0,2 ton CO_2 per m³ verontreinigde grond





Rekenmodel CO_2 bij bodemsaneringen versie 1.3.1

Uitvoerscherm

De resultaten op het uitvoerscherm betreffen gemiddelde waarden,
de minimale en maximale waarden zijn per onderdeel gegeven op het tabblad berekeningen.

Projectnaam	150974
Saneringsvariant	In situ chemical oxidation using perozone
Datum	17 augustus 2017
Model ingevuld door	DVL

Ontgraven landbodem 116 ton CO_2

Ontgraven	1 ton CO_2
Verwerken	90 ton CO_2
Materialen	12 ton CO_2
Transport	13 ton CO_2

Grondwater onttrekken 5 ton CO_2

Aanleg systeem	5 ton CO_2
Onttrekken	0 ton CO_2
Transport	0 ton CO_2

Grondwater zuiveren 0 ton CO_2

Zuiveringsonderdeel	0 ton CO_2
Hulpstoffen / chemicaliën	0 ton CO_2
Afvalstoffen	0 ton CO_2
Transport	0 ton CO_2

ISCO 498 ton CO_2

Aanleg systeem	3 ton CO_2
Instandhouden systeem	336 ton CO_2
Ozon productie	159 ton CO_2
Transport	0 ton CO_2

MFE (in situ) 0 ton CO_2

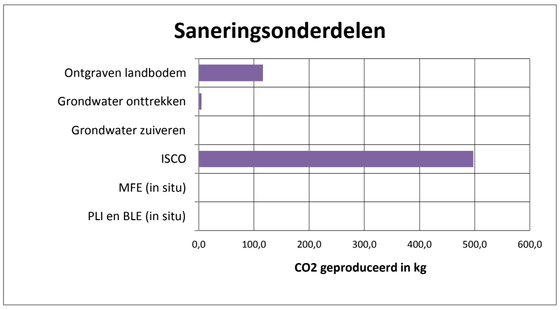
Aanleg systeem	0 ton CO_2
Instandhouden systeem	0 ton CO_2
Transport	0 ton CO_2

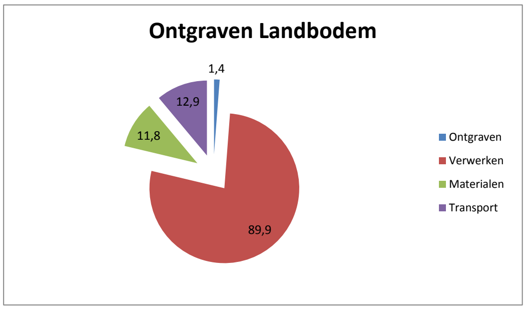
PLI en BLE (in situ) 0 ton CO_2

Aanleg systeem	0 ton CO_2
Instandhouden systeem	0 ton CO_2
Oxidator	0 ton CO_2
Oxidatiereactie	0 ton CO_2
Transport	0 ton CO_2

Verwijderde vracht 86.869 kg
Behandeld volume grond 6.000 m^3

EMISSIE : 618,7 ton CO_2
68,0 Huishoud equivalenten
0,0 ton CO_2 per kg verwijderde verontreiniging
0,1 ton CO_2 per m^3 verontreinigde grond





Rekenmodel CO_2 bij bodemsaneringen

versie 1.3.1

Uitvoerscherm

De resultaten op het uitvoerscherm betreffen gemiddelde waarden,
de minimale en maximale waarden zijn per onderdeel gegeven op het tabblad berekeningen.

Projectnaam	150974
Saneringsvariant	Source excavation and multi phase extraction - catox treatment
Datum	17 augustus 2017
Model ingevuld door	DVL

Ontgraven landbodem — 115 ton CO_2

Ontgraven	0 ton CO_2
Verwerken	90 ton CO_2
Materialen	12 ton CO_2
Transport	13 ton CO_2

Grondwater onttrekken — 0 ton CO_2

Aanleg systeem	0 ton CO_2
Onttrekken	0 ton CO_2
Transport	0 ton CO_2

Grondwater zuiveren — 144 ton CO_2

Zuiveringsonderdeel	144 ton CO_2
Hulpstoffen / chemicaliën	0 ton CO_2
Afvalstoffen	0 ton CO_2
Transport	0 ton CO_2

PLI en BLE (in situ) — 0 ton CO_2

Aanleg systeem	0 ton CO_2
Instandhouden systeem	0 ton CO_2
Oxidatiereactie	0 ton CO_2
Transport	0 ton CO_2

MFE (in situ) — 364 ton CO_2

Aanleg systeem	2 ton CO_2
Instandhouden systeem	362 ton CO_2
Transport	0 ton CO_2

ISCO — 0 ton CO_2

Aanleg systeem	0 ton CO_2
Instandhouden systeem	0 ton CO_2
Oxidator	0 ton CO_2
Oxidatiereactie	0 ton CO_2
Transport	0 ton CO_2

Biostimulatie — 0 ton CO_2

Aanleg systeem	0 ton CO_2
Instandhouden systeem	0 ton CO_2
Substraat en hulpstoffen	0 ton CO_2
Substraatreactie	0 ton CO_2
Transport	0 ton CO_2

Thermisch — 0 ton CO_2

Aanleg systeem	0 ton CO_2
Instandhouden systeem	0 ton CO_2
Transport	0 ton CO_2

Toezicht en Nazorg — 0 ton CO_2

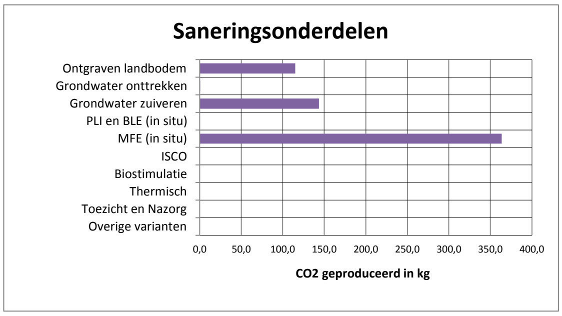
Toezichthouder	0 ton CO_2
Directievoerder	0 ton CO_2
Milieukundig begeleider	0 ton CO_2
Onderhoudsmonteur	0 ton CO_2
Veldmedewerker	0 ton CO_2

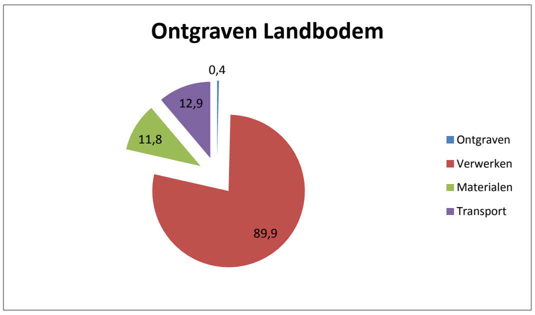
Overige varianten — 0 ton CO_2

Transport	0 ton CO_2
Materiaal	0 ton CO_2
Boorwerk	0 ton CO_2

Verwijderde vracht 86.869 kg
Behandeld volume grond 6.000 m³

EMISSIE :
622,8 ton CO_2
68,4 Huishoud equivalenten
0,0 ton CO_2 per kg verwijderde verontreiniging
0,1 ton CO_2 per m³ verontreinigde grond





ANNEX 2
OZON PRODUCTION AND ENERGY

Energy consumption of the ozone generator during the life project

Start	Stop	installation	Ozone production (hour)	Ozone production (kg)	Energy (kWh)	Hydrogen peroxide (kg)	O_3/ H_2O_2 ratio
18-june-2014	27-january-2015	1 ozone generator	3033	139	18198	8.370	16
27-march-2013	27-january-2015	2 ozone generators Incl oxymat*	8067	1410	112938		
27-january-2015	5-june-2017	1 ozone generator Incl oxymat *	9440	630	103840	25.081	4
Total during 4.2 year				2.179	234976	33.451	
*for oxygen production; at 50% of capacity related to stripping effect							