LIFE 09 ENV/FI/000575

ABSOILS

LCA AND LCC VERIFICATION REPORT

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ANNEX 10

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ABSOILS

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APPENDICES

GLOSSARY OF TERMS

Allocation	Partitioning the input or output flows of a process or a product system between the product system under study and one or more other product systems [1].
Data quality	Characteristics of data that relates to their ability to satisfy stated requirements [1].
Functional unit	Quantified performance of a product system for use as a reference unit [1].
Global warming potential	Term used to describe the relative measure of how much heat a greenhouse gas traps in the atmosphere. The coefficients are 1 for carbon dioxide (CO_2), 28 for methane (CH_4) and 298 for nitrous oxide (N_2O) [2]. Coefficients mean that methane effects are 28 times more powerful for climate change than carbon dioxide. With the help of coefficients the emissions are transformed to common units as CO_2-equivalent.
Input	Product, material or energy flow that enters an unit process [1].
Life cycle	Consecutive and interlinked stages of a product system, from raw material acquisition or generation from natural resources to final disposal [1].
Life cycle assessment (LCA)	Methodology based e.g. on the ISO 14040 and 14044 standards. It is a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its lifetime [1]. An incomplete LCA like a Streamlined LCA is possible in case there is a shortage of time, money, data or other necessary resources to carry out a complete study. For the needs of the ABSOILS projects' Verification Action a Streamlined LCA was carried out [3].
Life cycle inventory analysis (LCI)	Phase of life cycle assessment involving the compilation and quantification of inputs and outputs for a product throughout its life cycle [1].
Life cycle impact assessment (LCIA)	Phase of life cycle assessment aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts for a product system throughout the life cycle of the product [1].
Life cycle interpretation	Phase of life cycle assessment in which the findings of either the inventory analysis or the impact assessment, or both, are evaluated in relation to the defined goal and scope in order to reach conclusions and recommendations [1].
Output	Product, material or energy flow that leaves a unit process and a product system [1].
Product	Any good or service [1].
Product system	Collection of unit processes with elementary and product flows, performing one or more defined functions, and which models the life cycle of a product [1].

Process	Set of interrelated or interacting activities that transform inputs into outputs [1].
Scenario	Scenario is an alternative for a pilot structure (in the report, the following abbreviations were used: Alt1, Alt2, Alt3 and Alt4).
Sensitivity analysis	Systematic procedures for estimating the effects of the made choices made regarding methods and data on the outcome of a study [1].
System boundary	Set of criteria specifying which unit processes are part of a product system [1].
Life-cycle cost	LCC (abbrev); is defined as the cost of an asset or its parts throughout its life cycle while the performance requirements [4]. In this report the LCC is studied qualitatively.

1. INTRODUCTION

Surplus clays are a major problem in the capital region of Finland (cities of Helsinki, Espoo and Vantaa). The low quality clay is too soft for geotechnical purposes as such, and the shortage of soil landfills and their distant location from the capital region cause great costs in civil engineering projects. Long transportations also generate vast amounts of carbon dioxide and other greenhouse gas emissions. There is also a shortage of virgin rock materials in the Helsinki region. Aggregates needed in construction are transported from the provinces around Helsinki. This is very expensive and also generates airborne emissions. Crushing of aggregates also demands a lot of energy.

The ABSOILS project (2010-2015) has been funded by the EU Life+ programme (LIFE09 ENV/FI/575) and the project's beneficiaries. The purpose of the project has been to verify the utilisation potential of surplus soils in different civil engineering applications. In other words, ABSOILS demonstrates the practical implementation of different types of civil engineering applications in full-scale pilots based on the use of abandoned (surplus) soils like soft clay. The problem of surplus soils is faced in many urban areas around Europe. This report will verify and demonstrate that the utilisation of soft clays and other surplus soils is environmentally and economically feasible.

The implementation of the ABSOILS project involved the following l actions :

1. Preparations (Action 1): defined the set of criteria to assess the material alternatives (Action 2) for the pilots and the outcome of the pilots (Actions 3 and 4) while carried out the quality control and follow-up of the pilots.
2. Materials (Action 2): carried out with the help of geotechnical and chemical laboratory works to verify appropriate materials for the different pilot applications. The test results were compared with the results from the quality control and follow-up procedures. The results of Materials action were used in Actions 3 and 4.
3. Applications (Action 3): verified that the Piloting Action 4 based on appropriate and efficient plans to produce applications with respect to general civil engineering criteria and that the project achieved all the information and data for the verification procedure of Action 5.
4. Piloting (Action 4): addressed details of the process from the storage, treatment and transports of materials until the construction of the application had been finished. The abandoned soils, additives for stabilisation as well as required aggregates originated from the Uusimaa region. The action used material mixes from Action 2 and plans, designs and instruction from Action 3. Technical and environmental control procedures were carried out as part of Action 5, Verification.
5. Verification (Action 5): gave a proof for the project stakeholders that the methods, materials and applications implemented in the project were environmentally safe and technically and economically feasible. The verification action used instructions from Action 3 and data from Actions 2 and 3. Verification was carried out with the help of quality control and follow-up activities. Environmental life cycle assessment and life cycle costing procedures were carried out.
6. Dissemination (Action 6): disseminated and communicated the project results to the target groups so that the knowledge gained during the project can be benefitted in the whole Europe. The dissemination tools included the project website, DVD-presentation, Guidline's for the European practice, Layman's report and all other published articles, reports and conference papers about the project.

7. Management (Action 7): involved overall management and co-ordination of the project according to the details of the project plan and financial budget.

Actions from 1 to 4 all affect and feed information and data for Action 5, Verification, and their results have been described in detail in the corresponding reports:

- Intermediate Material Reports
- Civil Engineering and Environmental Survey Report
- Technical Report of Piloting

The pilots of the project are shortly described in the following:

- Arcada II (Helsinki, Finland); The project includes the construction of the street Kyläsaarenkuja to a pile slab, the removal of contaminated soils and the existing blasted rock embankment, filling with mass stabilised surplus soils and the construction of a new driveway connection to the Hermanninrantatie road. The area had low stability and load bearing capacity. In the pilot project, the rock aggregate was removed from the site and was replaced with a light weight structure utilising surplus clay.
- Dog Park (Espoo, Finland) covers the area of approximately 4500 m^2 and is located in a zone prone for flooding. The soil of the area which used to be a sea bed was soft clay and the site had been classified as a very difficult constructing target due to its low load bearing capacity. The pilot structure is an embankment raised to the level +2…2.5 meters to prevent flooding. In order to prevent mass exchange and landfilling of the site's soft soils, the original clay and some surplus soils from an adjacent construction site were stabilised.
- Jätkäsaari (Helsinki, Finland); sediments dredged from the sea were mass stabilised and utilised in the nearby park (Hyväntoivonpuisto). This is mainly a theoretical study as the environmental permit applications of the park did not include the use of mass stabilised sediments so in reality, this could not be done. The Jätkäsaari sediments have been utilised in other parks in Helsinki area. The sediments were stabilised in the stablisation basins. The sediments were mildly contaminated and the metal and organic contents exceeded the level 1 limit values of the dredging and dumping instructions [5]. The stabilised sediments were transported to the park was and used there for landscaping purposes.

The activities of the Verification Action have included geotechnical field and laboratory tests to control the performance of the materials and applications in real conditions. The quality control and follow-up tests have been concentrated on the strength and durability properties. The assessment of the environmental permit authorities regarding the environmental quality of the abandoned soils and the material mixes used for the applications relieved the project from environmental sampling and analysis. The Verification includes the Environmental and Economical assessment of the pilots carried out with the help of the methodologies of environmental life-cycle assessment (LCA) and qualitative life-cycle cost assessment (LCC). Additionally, the Verification uses the results of the quality control and follow-up studies (like determined in Action 3) as well as the results of the laboratory tests on materials (Action 2).

The most important target groups for dissemination of these verification results are municipalities, road administrations, contractors, industrial enterprises, politicians and legislative authorities and consultants in Finland and in other European countries.

The report starts with Chapter 2, Methodologies and Assumptions, to describe the methodology of the different procedures applied in the Action (LCA, LCC, QC and Follow-up). Chapters 3-5 give detailed reports on the results of the different pilots' LCA, LCC, and quality control and Follow-up results. Chapter 6 covers the Conclusions and Summary of the Verification including the assessment of the project findings, and the recommendations based on the former. The report includes many annexes, e.g. the copies of excel sheets for the LCA and LCC calculations.

2. METHODOLOGY AND ASSUMPTIONS

2.1 Life Cycle Analyses: LCA and LCC

LCA (Life-cycle assessment) and LCC (Life-cycle costing) are decision support tools which quantify the ecological and economic aspects of products which in the case of ABSOILS are three different civil engineering structures. This document presents the results of the LCA assessment for the different pilots in the ABSOILS project. The model for the LCA is the available standard procedures of EN ISO 14040:2006. LCA has been carried out as a simplified version or as the Streamlined LCA, thus it is not complete. Simplification is in line with the EU project application that stated the foreseen problems of available resources (time and financing) to acquire data for the complete LCA and LCC.

The purpose of the LCA is to determine and compare the potential environmental impacts of different alternatives. Primary attention is paid to the depletion of natural resources and global warming potential. The consumption of energy of the studied processes is the major reason for the global warming potential, and the choice of materials for the depletion of natural resources.

The purpose of the LCC is to compare the alternatives qualitatively and to show that the use of stabilised surplus soils can be a cost-efficient investment. Instead of carrying out calculations for life cycle periods after the initial construction, the project participants have decided to provide a qualitative assessment as the actual life cycle costing method would be significantly too uncertain to obtain reliable results. In addition to short qualitative information about the future use and behaviour of the structures, also some external environmental costs were calculated.

It is expected that the results of the verification procedure prove that stabilised surplus soils are feasible and competitive materials for the construction markets and that their use as construction materials involves significant environmental and economic benefits for the European societies.

The Glossary of Terms describes the LCA as a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life time or over a chosen lifetime period. The product system can be described as a collection of unit processes which perform one or more defined functions and model the life cycle of the product: e.g. production and manufacturing of construction materials, transportation of materials, preparing the construction site, construction, maintenance and repair.

Figure 1 describes that the LCA consists of a goal and scope definition, an inventory analysis and an impact assessment. On the basis of these stages, interpretation of the results can be made. The LCA results may be useful inputs to a variety of decision-making processes like stated in Figure 1.

The LCA addresses potential environmental impacts. It does not predict absolute or precise environmental impacts due to the relative expression of potential environmental impacts to a reference unit and the environmental data is integrated over space and time. [1]

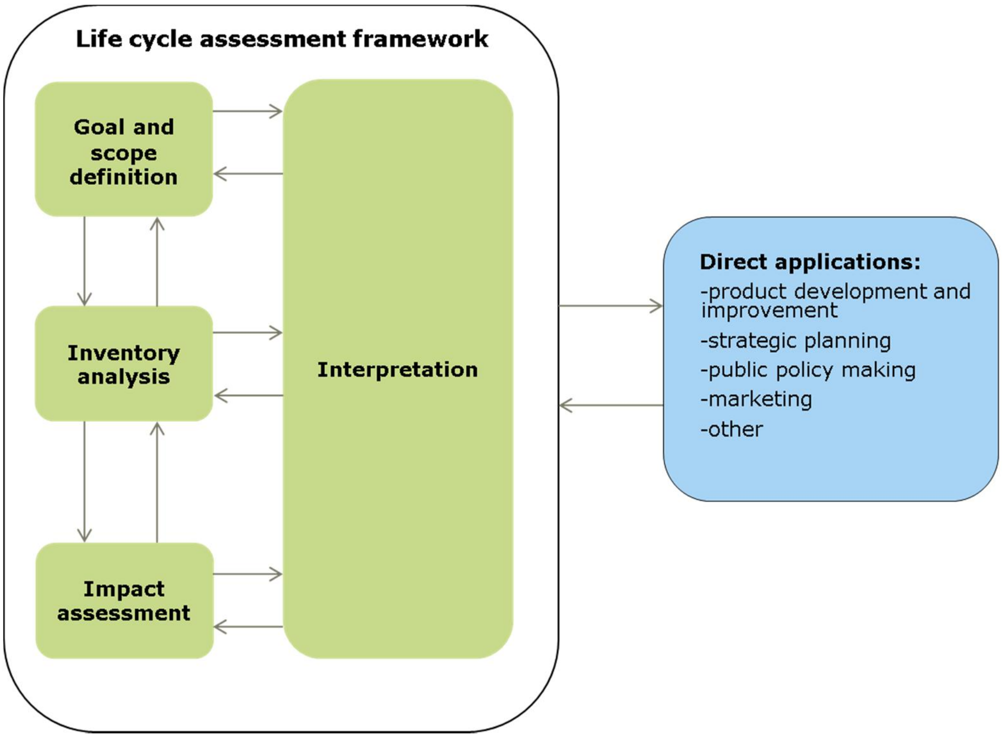

Figure 1. Stages of the Life Cycle Assessment [1].

In the LCA study, the product is a certain structure of a field / road / other earth construction to perform certain technical functions. The product is demonstrated with the help of alternative pilots in the ABSOILS project. The Streamlined LCA compares the results of the alternative pilot structures and a chosen conventional alternative that are predicted to have identical technical performance. The alternatives for the pilot structures have been chosen on the basis of experience, the results of the past studies, and with the help of the experts designing the structures.

2.1.1 The goal definition and scope of the LCA and LCC studies

The reason to carry out the LCA study is the importance to verify that the pilot alternatives are environmentally sound and economically competitive in comparison with the conventional alternatives. The LCA is completed with the results of the laboratory tests, and the quality control and follow-up studies performed at the pilot construction sites. The output of the product system in the LCA (actually the LCI) includes the product itself and energy consumption, emissions in the air, water and soil and depletion of natural resources of the following processes: cement and rock aggregate production, transportation of the materials to the landfill and to the construction site, and construction works. The product system for the LCI calculations has been divided into the mentioned processes (see Figures 2 and 3).

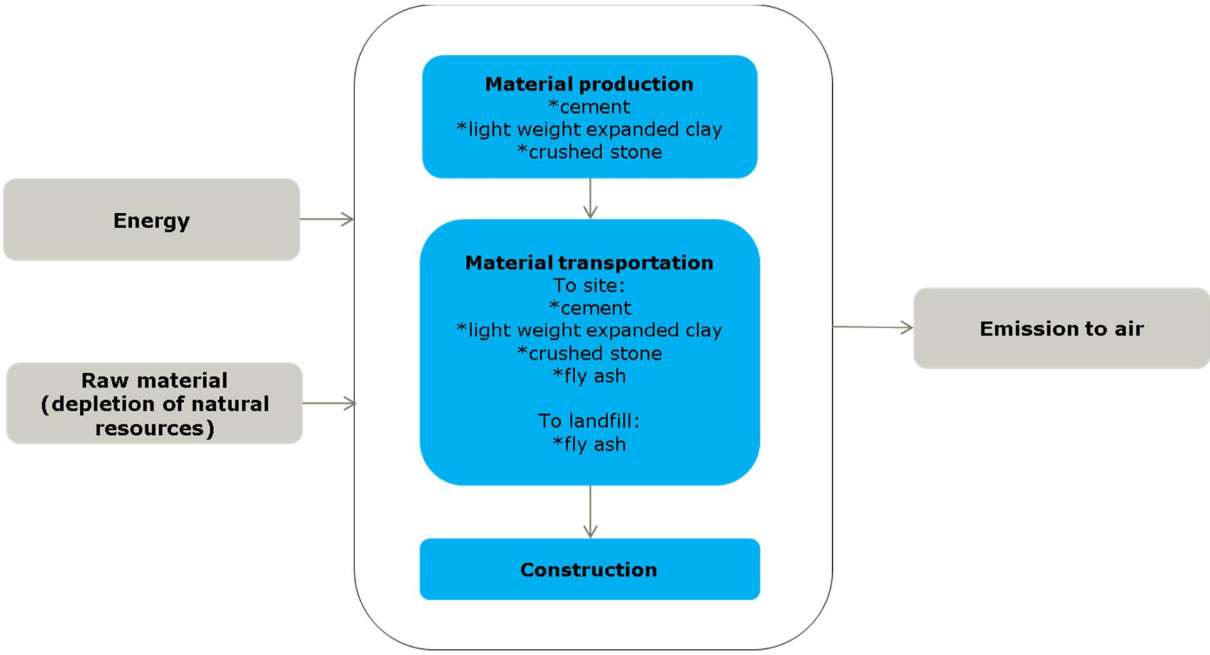

Figure 2. Product system for Arcada II and Dog Park pilots.

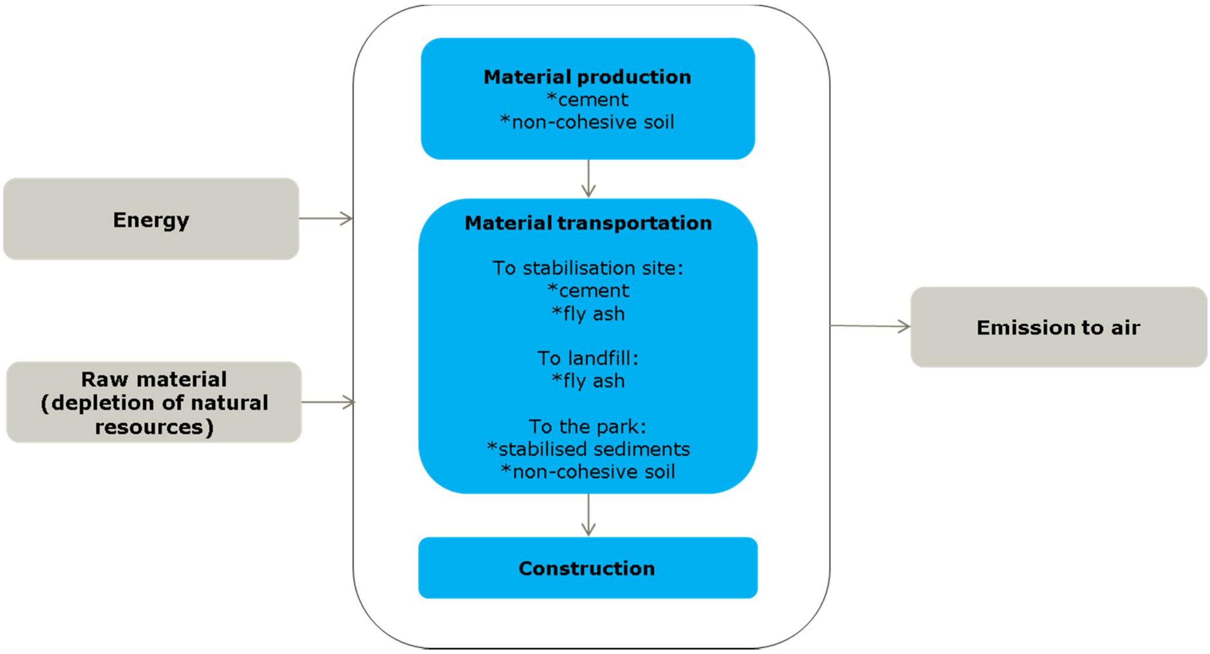

Figure 3. Product system for Jätkäsaari (West Harbour) pilot.

The following environmental impact categories have been chosen for the assessment of the life cycle: global warming potential and depletion of natural resources. The categories were chosen because these are the major impacts from the infrastructure construction and because of the availability of general data about the relevant discharges from the individual processes (mainly because of the energy consumption). Cement is one of the construction materials that need relatively large amounts of natural resources and energy for its production. In this project, fly ash - a byproduct from energy production - is used as a substituent for cement in order to decrease the total global warming potential of some of the demonstrated pilots.

The Functional Unit (FU) for the LCA and LCC calculations has been chosen to be 100 m^2 of the construction for the Arcada II and Dog Park pilots, and 1 m^3 for the Jätkäsaari (West Harbour) pilot.

2.1.2 Assumptions

The short lifetime period, the narrow product system and the few inputs and outputs from the individual processes that have been chosen for practical reasons will result in only rough estimates of the environmental, technical and economical characteristics of the different types of products. This will be emphasised because of certain assumptions for the LCA and LCC studies:

1. Emissions from the by-products and waste (like surplus soil and fly ash) generated by a production process are assumed to be zero as all emissions from the main production are allocated to the actual products.
2. The design works of the projects are not included in these calculations. The design work is carried out in the office as desk work and it is not possible to allocate any energy or space consumption to an individual project of relatively short duration.
3. The laboratory work for ABSOILS purposes is not included in the calculations because we assume that all construction alternatives are based on established methods, thus requiring only minor laboratory checks.
4. The production of factories, production plants and landfills (concerning e.g. production of fuel, materials, transport vehicles and vehicles for works) are not included as these investments have not been made for the needs of this individual project.
5. The production of the vehicles or machines used for transportation and construction has not been included in the product system for the same reason as above.
6. Production and transportation of fuels are not included for the same reason as above. (Note: the fuel consumptions for material transportations and construction are taken into account).

2.1.3 Available data for the LCA and uncertainties

The origin of the data used in the calculations and the basis of calculations are presented in the following paragraphs and tables (Tables 1...3).

Table 1. The data used for diesel fuel in the LCA calculations [6], [7].

Specific weight	0,845
Density	845 kg/m^3
Caloric value	43 MJ/kg
Abiotic material	0,032 kg/MJ
Abiotic material	1,16 kg/l

Abiotic material of diesel is calculated on the basis of caloric value as follows:

1 liter diesel/energy: 43 MJ/kg x 0,845 kg/l = 36,34 MJ/l

➔ abiotic material/1 liter diesel: 0,032 kg/MJ x 36,34 MJ/l = 1,16 kg/l

The resulting numeric value of 1,16 kg/l is used for calculation of depletion of natural resources in the processes consuming diesel fuel.

Global warming potential coefficients (GWP100) used in the calculations are presented in Table 2.

Table 2. Coefficients used for calculating global warming potential [2].

Greenhouse gas	Coefficient
Carbon dioxide CO_2	1
Methane CH_4	28
Nitrous oxide N_2O	298

These coefficients are used when calculating global warming potential with the following equation: [CO_2 g/FU x 1] + [CH_4 g/FU x 28] + [N_2O g/FU x 298] = CO_2 equivalent kg/FU.

The emissions from the vehicle usage are calculated on the basis of the LIPASTO database by Technical Research Centre of Finland (LIPASTO) [7]. Figures are defined for a typical machine in each working machine category in Finland (in terms of power use and the age of fleet). The emissions are calculated as follows: [fuel consumption, l] x [emission factor, g/l].

Table 3. Emission data for used vehicles [7].

Machine, diesel	Average power [kWh]	Average load factor	Emissions [g/l]							
			CO	HC	NO_x	PM	CH_4	N_2O	SO_2	CO_2
Tractor	61	0,27	7,3	2,1	19	0,9	0,15	0,071	0,017	2624
			Emissions [g/km] (average of empty and full load)							
Vehicle			CO	HC	NO_x	PM	CH_4	N_2O	SO_2	CO_2
Earth moving truck, capacity 19 tons			0,195	0,115	5,75	0,063	0,007	0,033	0,005	774,5
Lorry trailer truck, capacity 40 tons (used for tank truck values)			0,21	0,09	7,7	0,074	0,009	0,031	0,007	1036

The software used in the calculations is Microsoft Excel.

The results of the LCA calculations present the consumption of energy, the emissions to air from the different structures (for the assessment of the global warming potential), and the depletion of natural resources.

The LCA is calculated according to the following sections:

1. Materials
2. Material transportation
3. Construction
4. Sum of the previous

There are some uncertainties in emissions of light weight expanded aggregate as there is no information available on the manufacturer of the used light weight material. The available data originates from two different sources – Weber [8] as a producer of light weight material and the unconfirmed environmental declaration of the European Expanded Clay Association (EXCA) [9].

Some of the emissions are lacking. For example, the data concerning light weight expanded clay aggregate lacks the information on CH_4 and N_2O and this has some effect on the result of global warming potential as these emissions are needed for the calculation. It is assumed that the lacking data has only a minor effect on the final result when the amount of carbon dioxide emissions is already so high from the production of light weight clay aggregate.

3. ARCADA II

3.1 Structural Alternatives

The ABSOILS pilot application called Arcada II includes the construction of the street Kyläsaarenkuja to a pile slab, the removal of contaminated soils and the existing blasted rock embankment, filling with mass stabilised surplus soils and the construction of a new driveway connection to the Hermanninrantatie road. The area had low stability and load bearing capacity. Some information on the site is presented in the Appendix 1.1.

In the pilot project, the rock aggregate was removed from the site and it was replaced with a light weight structure utilising surplus clay. The density of the surplus clay was adjusted by water addition (which was found naturally in the stabilisation basins) so that the density of the clay was approximately 1500 kg/m^3. The soft clay was mixed with cement for stabilisation.

In the LCA calculation, three alternative structures are compared with each other. The first alternative is the one actually executed in the site and the two other are alternatives which could be built on site. The alternatives are;

- Alt 1 - cement stabilised clay,
- Alt 2 - cement and fly ash stabilised clay,
- Alt 3 – the light weight structure with light expanded clay aggregate (LWA)

The construction processes are described in Table 4. The construction processes in Alt1 and Alt2 are similar as change of the binder does not affect the actual construction process. The structure alternatives are also presented in Figure 4.

The functional unit (FU) of the LCA/LCC studies for Arcada II is <u>100 m^2 of the road structure</u>.

Table 4. The construction process alternatives in Arcada II. Italic fonts describes the phase that is equal to all alternatives and is not taken into account.

Structure alternatives		Construction process
Alt 1	Mass stabilisation with cement	*Removal of the old aggregate material.* Filling with clay. Homogenisation of clay. Stabilisation of clay with cement. *Surface structures; compaction embankment 700 mm.*
Alt 2	Mass stabilisation with fly ash and cement	*Removal of the old aggregate material.* Filling with clay. Homogenisation of clay. Stabilisation of clay with cement and fly ash. *Surface structures; compaction embankment 700 mm.*

Alt 3	Light weight structure made of light expanded clay aggregate	*Removal of the old aggregate material.* Filling with light expanded clay aggregate. Compaction in layers. *Surface structures; embankment 700 mm*.

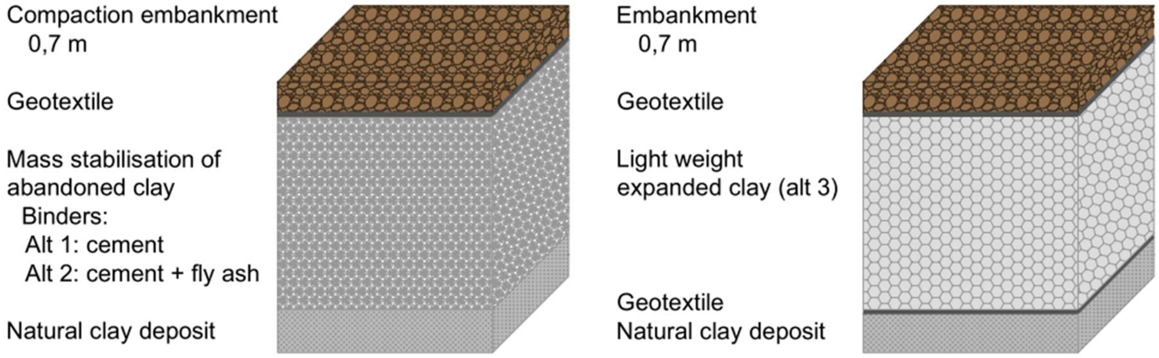

Figure 4. The structure alternatives in Arcada II pilot.

3.2 Inventory

3.2.1 Material production

The materials and material amounts used in the structures are presented in Table 5. The total area of the site is 7163 m^2. The amount of fly ash used in Alt2 is based on the laboratory studies carried out for the site. The studies suggested that the sufficient strength levels could be achieved when 60 kg/m^3 of cement and 100 kg/m^3 of fly ash were used [4]. The double amount of geotextile in Alt3 is due to the two different layers where the geotextile would be needed (under and over the LWA-layer). The total calculation sheet is presented in Appendix 1b.

Table 5. The materials used in the different structure alternatives in Arcada II.

	Material	Amount [m^3]	density [t/m^3]	m^3/m^2 Thickness [m]	Amount [t/FU]	Amount [m^2]
Alt 1	Clay	32 000	1,5	4,5	670	
	Cement [t]	3 697	1,2	0,5	62	
	Removed rock aggregate	32 000	2,2	4,5	983	
	Geotextile [m^2]				0,3	7163
	Compaction embankment; crushed rock	5 014	2,2	0,7	154	
	Sum				1 869	
Alt 2	Clay	32 000	1,5	4,5	670	
	Cement [t]	1 920	1,2	0,3	32	
	Fly ash [t]	3 200	1,2	0,4	54	
	Removed rock aggregate	32 000	2,2	4,5	983	
	Geotextile [m^2]			0,0	0,3	7163
	Compaction embankment; crushed stone	5 014	2,2	0,7	154	
					1 893	
Alt 3	Light expanded clay aggregate	31 935	0,344	4,5	154	
	Removed rock aggregate	31 935	2,2	4,5	981	
	Geotextile [m^2]			0,0	0,6	14326
	Compaction embankment; crushed stone	5 014	2,2	0,7	154	
	Sum				1 289	

3.2.2 Transportation

The vehicles used in transportation, transportation distances and the fuel consumptions are presented in Table 6. The distances are calculated on the basis of the locations of the sources of cement (production site), fly ash (power plant), light expanded clay aggregate, etc. Fuel consumptions and emissions to air are calculated as an average of a two-way trip of a loaded and empty vehicle. The fuel consumptions [l/km] and emissions to air [g/km] are based on the Lipasto database of traffic emissions made by the VTT Technical Research Institute of Finland [7]. As there was no data available for a tank truck, the data used in the tank truck transportation calculations is based on the data of a lorry trailer with the same load capacity of 40 tons. The total calculation sheet is presented in Appendix 1c.

Table 6. The vehicles used in transportation, transportation distances and fuel consumption per functional unit. Arcada II.

			Vehicle	Distance [km]	Total fuel consumption [l]/FU
Alt 1	Clay	to site	Dump Truck (19t)	25	547
	Cement	to site	tank truck (40t)	175	228
	Removed rock aggregate	to re-use	Dump Truck (19t)	5	160
	Geotextile [m2]				
	Rock aggregate for embankment	to site	Dump Truck (19t)	5	25
	Fly ash	to landfill	tank truck (40t)	25	28
	SUM				988
Alt 2	Clay	to site	Dump Truck (19t)	25	547
	Cement	to site	tank truck (40t)	175	118
	Fly ash	to site	tank truck (40t)	12	14
	Removed rock aggregate	to re-use	Dump Truck (19t)	5	160
	Geotextile [m2]				
	Rock aggregate for embankment	to site	Dump Truck (19t)	5	25
	SUM				864
Alt 3	Light expanded clay aggregate	to site	Dump Truck (19t)	130	652
	Removed rock aggregate	to re-use	Dump Truck (19t)	5	160
	Geotextile [m2]				
	Rock aggregate for embankment	to site	Dump Truck (19t)	5	25
	Fly ash	to landfill	tank truck (40t)	25	28
	SUM				865

3.2.3 Construction

The construction stages and vehicles used in the construction process, vehicle capacities and fuel consumptions are presented in Table 7. Mass stabilisation is presented as one stage without separating its work phases from one another because the phase is the same in the alternatives Alt1 and Alt2 and in Alt3 it does not occur at all. The capacities are based on the Building Information Cards and the real capacities on the site. The total calculation sheet is presented in Appendix 1d.

Table 7. The construction stages, capacities and fuel consumption per functional unit. Arcada II.

		Total fuel consumption [l/FU]
Alt 1	Mass stabilisation	209
	Spreading of loading embankment and compaction, compactor +wheel loader (1:1)	49
	Spreading of geotextile [0,004 tth/m2]	12
	SUM	258
Alt 2	Mass stabilisation	209
	Spreading of loading embankment and compaction, excavator	49
	Spreading of geotextile [0,004 tth/m2]	12
	SUM	258
Alt 3	Spreading of leca, wheel loader	108
	Compaction of light weight aggregate	75
	Spreading of loading embankment and compaction, compactor +wheel loader (1:1)	52
	Spreading of geotextile [0,004 tth/m2]	24
	SUM	235

3.3 Results: Environmental Impacts

3.3.1 Global warming potential

Global warming potential describes the relative potency of the greenhouse gases, taking into account how long the gas remains active in the atmosphere. Figure 5 and Table 8 present the global warming potential for different alternatives. The high GWP value in alternative 1 is due to high CO_2 emissions from cement production. In Alt3 the production of light weigh aggregate generates a lot of emissions and this results in a high GWP value. The differences in material transportation are not of big significance. There is no difference between Alt1 and Alt2 in mixing and construction because it is the same work as when stabilising with cement or fly ash. Alt3 has the highest global warming potential, although Alt1 (cement stabilisation) shows almost equal result.

Table 8. Global warming potential in different alternatives in Arcada II.

Arcada II Global warming potential [CO_2 kg equivalent/FU]				
Alternative	Material production	Material transportation	Mixing and construction	Total
Alt 1	42 138	2 486	410	45 034
Alt 2	22 022	2 178	410	24 610
Alt 3	44 913	2 185	639	47 737

Energy consumption is not an environmental impact as such but it causes environmental impacts like emissions and consumes natural resources. The total energy consumption from different steps (material production, material transportation, mixing and construction) are depicted in Table 9 and Figure 5.

Table 9. Energy consumption in different alternatives in Arcada II.

Arcada II Energy consumption [MJ/FU]				
Alternative	Material production	Material transportation	Mixing and construction	Total
Alt 1	184 637	35 288	4 415	224 341
Alt 2	98 419	31 865	4 415	134 698
Alt 3	276 632	32 058	2 319	311 009

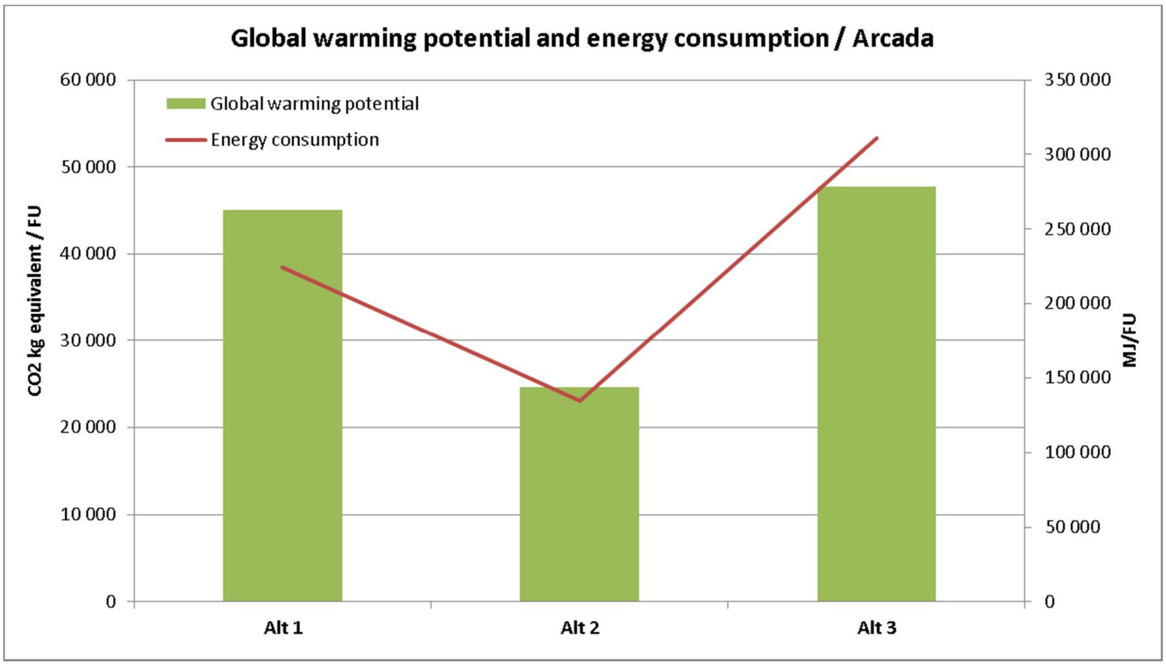

Figure 5. Global warming potential and energy consumption in the Arcada II alternatives.

3.3.2 Depletion of natural resources

Depletion of natural resources is highest in Alt3. This is due to the production of light weight aggregate. Also cement production consumes a lot of natural resources when clinker - the raw material of cement - is mined and this is shown from the result of Alt1. The differences in material transportation are very small. The depletion of natural resources is lowest in Alt2 as the cement is partly replaced with fly ash and thus the need of natural resources is lower. The results are presented in Table 10 and in Figure 6.

Table 10. Depletion of natural resources of different alternatives in the Arcada II project.

Arcada II Depletion of natural resources [kg/FU]				
Alternative	Material production	Material transportation	Mixing and construction	Total
Alt 1	244 660	3 613	314	248 587
Alt 2	201 504	3 167	314	204 985
Alt 3	358 925	3 180	301	362 406

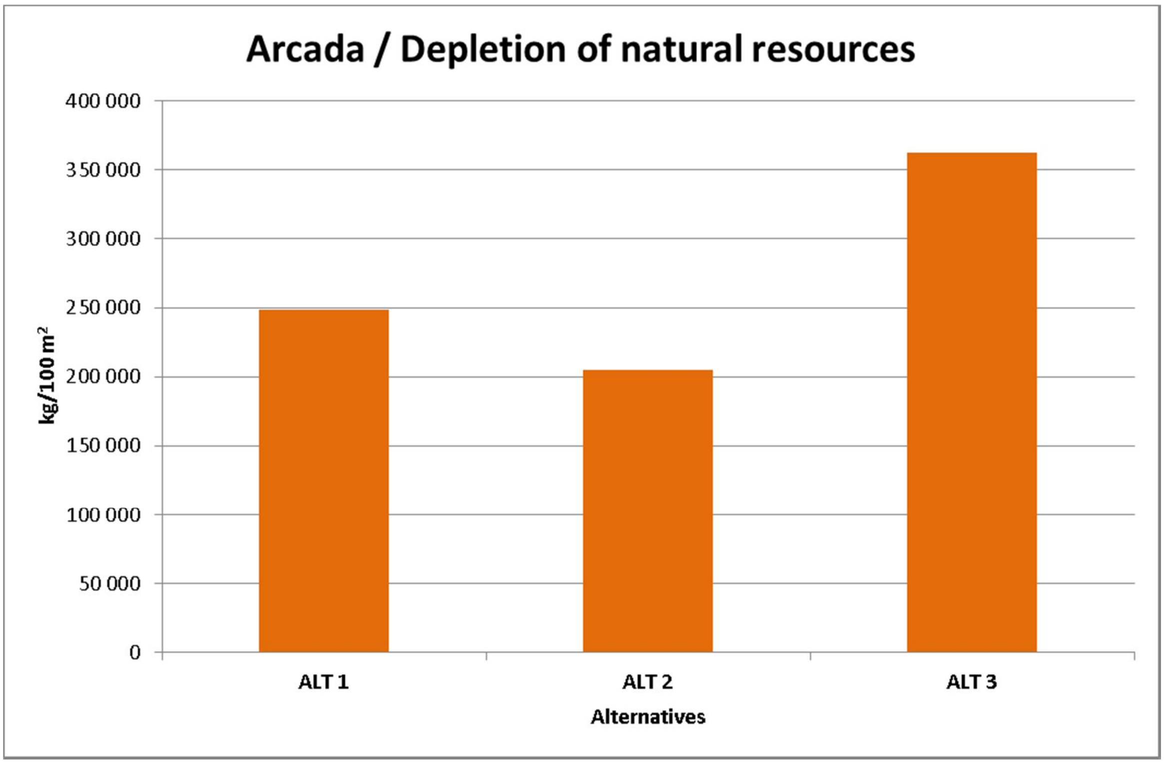

Figure 6. Depletion of natural resources in the Arcada II alternatives.

Final results are presented in Appendix 1e.

4. DOG PARK

4.1 Structural alternatives

The second ABSOILS pilot is the Dog Park area in Perkkaa, Espoo. The area of approximately 4500 m^2 is located in a zone prone for flooding. The soil of the area which used to be sea bed was soft clay. The thickness of the clay layer is 11...14 m and the site was classified as a very difficult constructing target due to its low load bearing capacity. The pilot structure is an embankment raised to level +2...2.5 meters to prevent flooding. In order to prevent mass exchange and landfilling of the soft soils, the original clay and some surplus soils from an adjacent construction site were stabilised. Some information about the site is presented in Appendix 2.2.

The structural alternatives are (Figure 7):

- Alt 1, stabilisation with cement
- Alt 2, stabilisation with cement and fly ash
- Alt 3, filling with light weight material

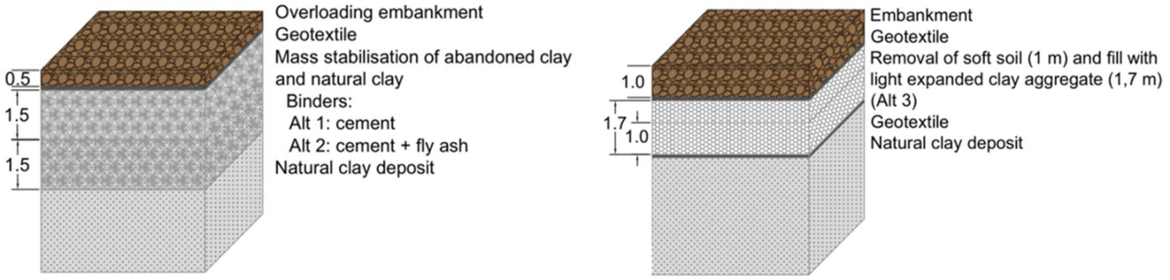

Figure 7. The structure alternatives in the Dog Park pilot.

The redundant clays from the neighbouring street were transported to the pilot site where the materials were stockpiled in the area and surrounded with an embankment to prevent the escape of the fluid clay material from the stabilisation area. Transportation and construction of the embankment took place between January and March 2012. The transportation distance in this case was only 200...500 meters. The transportation distance to the landfill would have been about 25 km had it not been possible to use the redundant masses in the construction process of the Perkkaa Dog Park. Surplus soft clay is a very troublesome and expensive material to dispose at landfill.

The functional unit (FU) is 100 m^2 of the structure.

The construction processes and the principles of the structural alternatives are presented in Table 11. As previously stated, the removal of topsoil and the formation of surface layer are not taken into account in the LCA calculations as the procedure is the same for all alternatives.

Table 11. The construction processes with different alternatives in Dog Park.

	Three alternative str	Materials for the structure	Processes for the construction
Alt 1	Mass stabilisation with cement	Clay and cement	Filling with surplus soil. Mass stabilisation of the surplus soil with cement. Spreading of compaction embankment. Surface layer formation.
Alt 2	Mass stabilisation with fly ash (+deSOx) and cement	Clay, cement and fly ash (deSOx)	Filling with surplus soil. Mass stabilisation of the surplus soil with cement and fly ash. Spreading of compaction embankment. Surface layer formation.
Alt 3	Light weight structure with light expanded clay aggregate	Light expanded clay aggregate	Removal of 1 m of soft soil. Filling with light expanded clay aggregate (1.7 m). Spreading of the embankment (1.0 m). Surface layer formation.

In the first two structure alternatives, the surplus soil was brought to the area and stabilised together with the clay of the site. The binders were either cement or a mixture of cement and fly ash. In the third alternative, the existing clay was removed and transported to the landfill before filling with light expanded clay aggregate. The use of the light expanded clay aggregate involves a risk; when the water level rises during flooding season the structure might start to float because of the buoyant force of the water.

4.2 Inventory

4.2.1 Material production

The materials and material amounts used in the structures are presented in Table 12. The total area of the site is 4 500 m^2. The total calculation sheet is presented in Appendix 2b.

Table 12. The materials used in the different structure alternatives in Dog Park.

	Materials	Amount [t/FU]	Amount [m^2]
Alt 1	Cement [t]	29	
	Surplus clay	225	
	Geotextile, [m^2]	0,3	4500
	Compaction embankment	95	
	Sum	349	
Alt 2	Cement [t]	22	
	Surplus clay	225	
	Fly ash [t]	36	
	Geotextile, [m^2]	0,3	4500
	Compaction embankment	95	
	Sum	378	
Alt 3	Filling, light weight material	58	
	Embankment	95	
	Sum	153	

4.2.2 Transportation

The vehicles used in transportation, transportation distances and the fuel consumptions are presented in Table 13. The distances are based on the knowledge about the locations of the factories producing cement, fly ash, etc. The fuel consumptions [7] are presented as an average of the two way trip with a full and empty vehicle. The total calculation sheet is presented in Appendix 2c.

Table 13. The vehicles used in transportation, transportation distances and fuel consumption per functional unit. Dog Park.

		Destination	Total mass [ton / FU]	Vehicle	Distance [km]	total fuel consumption [l/FU]
Alt 1	Cement	to site	8	tank truck (40t)	170	29
	Surplus clay	to site	225	Dump truck (19 t)	0,5	4
	Geotextile, [m2]		45			
	Fly ash	to landfill	36	tank truck (40t)	25	19
	Compaction embankment	to site	95	Dump truck (19 t)	20	62
	SUM		409			113
Alt 2	Cement		6	tank truck (40t)	170	21
	Surplus clay	to site	225	Dump truck (19 t)	0,5	4
	Fly ash	to site	36	tank truck (40t)	-15	-11
	Geotextile, [m2]		45			
	Compaction embankment	to site	95	Dump truck (19 t)	20	84
	SUM		407			98
Alt 3	Filling light weight material	to site	54	Dump truck (19 t)	130	231
	Fly ash	to landfill	36	tank truck (40t)	25	19
	Surplus clay	to landfill	225	Dump truck (19 t)	25	184
	Excavated clay	to landfill	160	Dump truck (19 t)	25	131
	Embankment	to site	95	Dump truck (19 t)	20	62
	SUM		570			626

4.2.3 Construction

The construction processes are presented in Table 14. As mentioned previously, the excavation of top soil is not taken into account as it is the same procedure in all alternatives. The construction processes in Alt1 and Alt2 are similar as the difference in the binder does not have any impact on the actual construction process. The total calculation sheet is presented in Appendix 2d.

Table 14. The construction stages, capacities and fuel consumption per functional unit. Dog Park.

		Total fuel consumption [l]/FU
Alt 1	Clearing of topsoil	29,1
	Mass stabilisation	67,5
	Spreading of geotextile [0,004 tth/m2]	5,4
	Spreading of compaction embankment (excavator)	33,3
	SUM	135
Alt 2	Clearing of topsoil	29,1
	Mass stabilisation	67,5
	Spreading of geotextile [0,004 tth/m2]	
	Spreading of compaction embankment (excavator)	33,3
	SUM	130
Alt 3	Excavation of clay	81,5
	Spreading of light weight clay (excavator)	41,2
	Rock aggregate (excavator)	74,4
	Compaction of structure (puskutraktori)	64,4
	SUM	262

4.3 Results: Environmental Impacts

4.3.1 Global warming potential

The results of the LCA calculations are presented in Table 15. As the table shows, Alt2 has the smallest environmental impacts in energy consumption, global warming potential and depletion of natural resources. Alternatives Alt1 and Alt2 are otherwise the same structures, yet Alt1 uses only cement for mass stabilisation. These calculations show that by replacing part of the cement with fly ash the environmental impacts can be reduced.

Alt3 needs almost three times more energy than Alt2. Also the depletion of natural resources is much higher in Alt3. These are due to long transportation distances to the site and the high use of energy in production of light expanded clay aggregate.

The sum of the steps shows the total LCA of the different structure alternatives. Because of the high energy consumption of cement production, Alt1 has the highest energy consumption. When the amount of cement is decreased the energy consumption is diminished. On the basis of the results it can be conclued that Alt2, mass stabilisation with cement and fly ash, is environmentally the best alternative for the Dog Park.

The high energy demand in production stage of light weight material causes also high global warming potential as the emissions in production stage are high. As there is no need for fly ashes landfill transportation in Alt2, this results in lowest global warming potential.

Table 15. Global warming potential in different stages. Dog Park.

Dog Park Global warming potential [CO2 kg equivalent/FU]				
Alternative	Material production	Material transportation	Mixing and construction	Total
Alt 1	19 639	284	207	20 130
Alt 2	14 772	191	208	15 171
Alt 3	20 853	1 583	692	23 128

Energy consumption is highest in Alt3 (Table 16). The manufacturing of light weight expanded clay aggregate requires a lot of energy which results in a high energy consumption in the material production stage. The high need for energy affects also the emissions in the production of light weight material (see Figure 8).

Table 16. Energy consumption in different stages. Dog Park.

Dog Park Energy consumption [MJ/FU]				
Alternative	Material production	Material transportation	Mixing and construction	Total
Alt 1	867	4	1 987	2 857
Alt 2	626	3	1 987	2 616
Alt 3	3 061	23	3 117	6 201

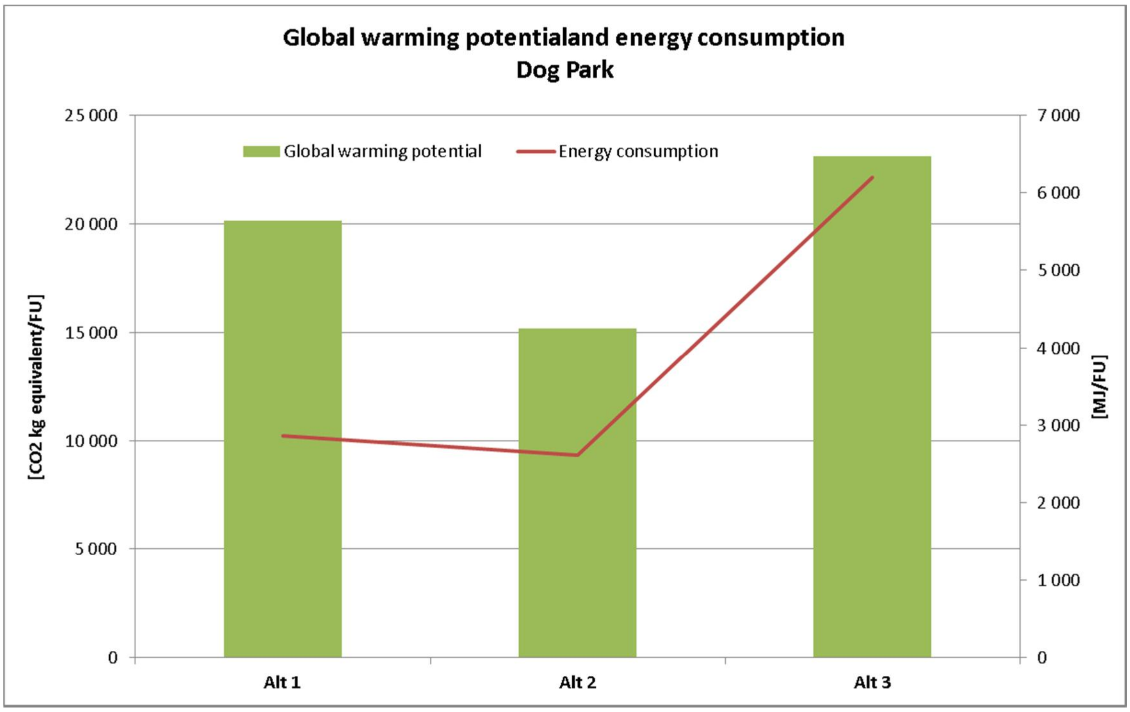

Figure 8. Global warming potential and energy consumption in Dog Park alternatives.

4.3.2 Depletion of natural resources

Alt3 resulted in highest depletion of natural resources (Table 17 and Figure 9). This is also because of the production of light weight material. Since the amount of needed material is high, this results in high depletion of natural resources.

Table 17. Depletion of natural resources in different stages. Dog Park.

Dog Park Depletion of natural resources [kg/FU]				
Alternative	Material production	Material transportation	Mixing and construction	Total
Alt 1	137 732	224	157	138 113
Alt 2	127 443	141	151	127 735
Alt 3	199 226	1 122	303	200 651

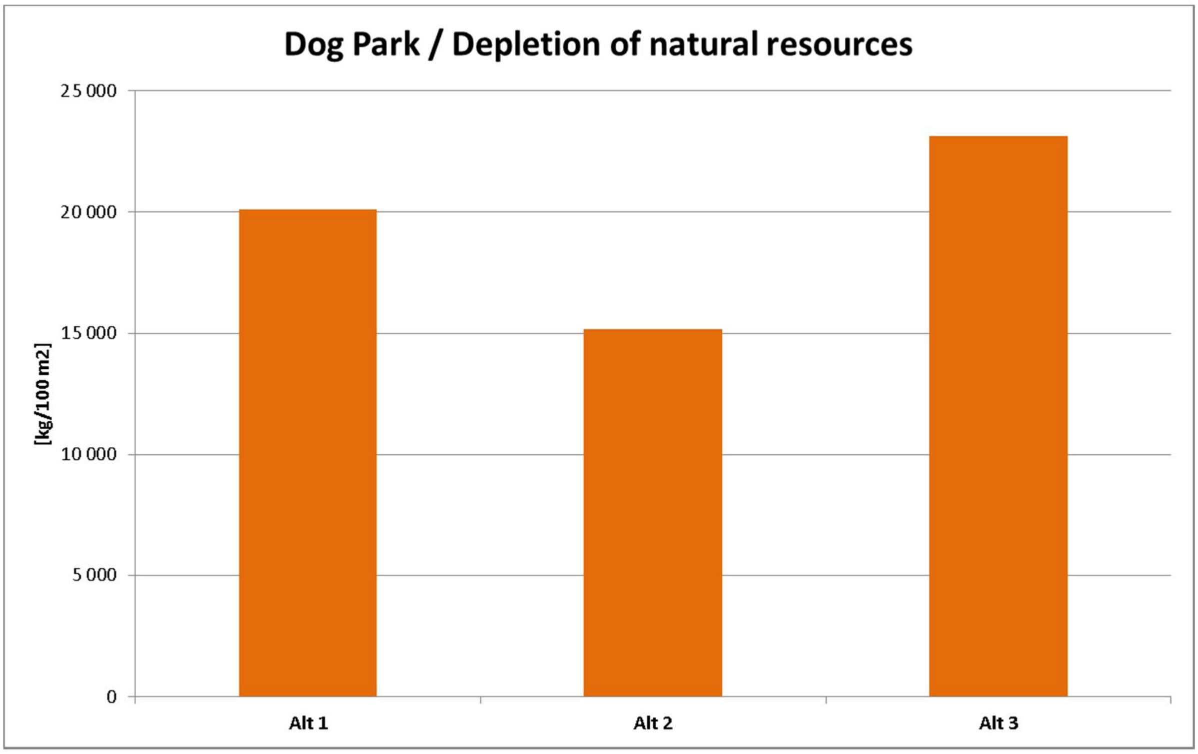

Figure 9. Depletion of natural resources in the Dog Park alternatives.

Final results are presented in Appendix 2e.

5. JÄTKÄSAARI (WEST HARBOUR)

5.1 Structural alternatives

The Jätkäsaari Pilot (West Harbour) is located in Helsinki, Finland. In Jätkäsaari, sediments dredged from the sea were mass stabilised and utilised in the nearby park (Hyväntoivonpuisto). This study is mainly therotical as the environmental permit did not include stabilised sediments as material for the park filling. The area of the park was reserved for the utilisation of more contaminated soils. As for the stabilised sediments, it was possible to utilise them in other parks in Helsinki.

The sediments were stabilised in the stablisation basins made of non-cohesive soils (Figure 10). The sediments were mildly contaminated and the metal and organic contents exceeded the level 1 limit values of dredging and dumping instructions (Instructions for dredging and depositing dredged material, Ministry of the Environment, Environmental Guide 117). The stabilised sediments were transported to the park in Helsinki and used there as material for landscaping purposes. Figure 11 shows the utilisation area in the Hyväntoivonpuisto Park. Some information about the site is presented in Appendix 3.1.

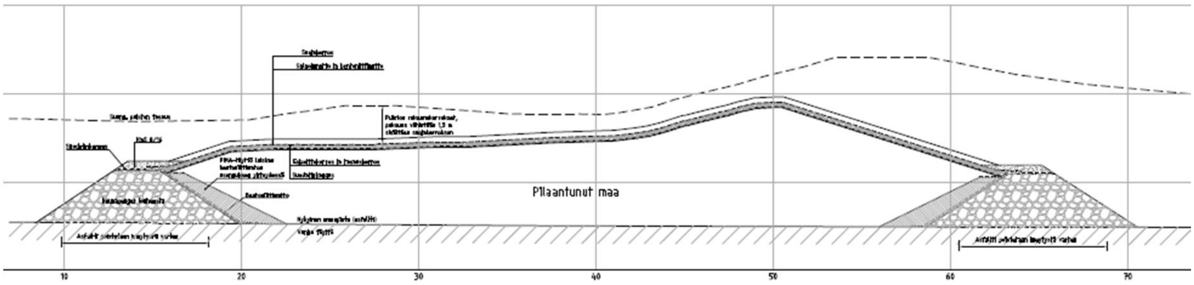

Figure 10. The principle of utilisation of the contaminated sediment in the park of Hyväntoivonpuisto. Jätkäsaari (West Harbour)

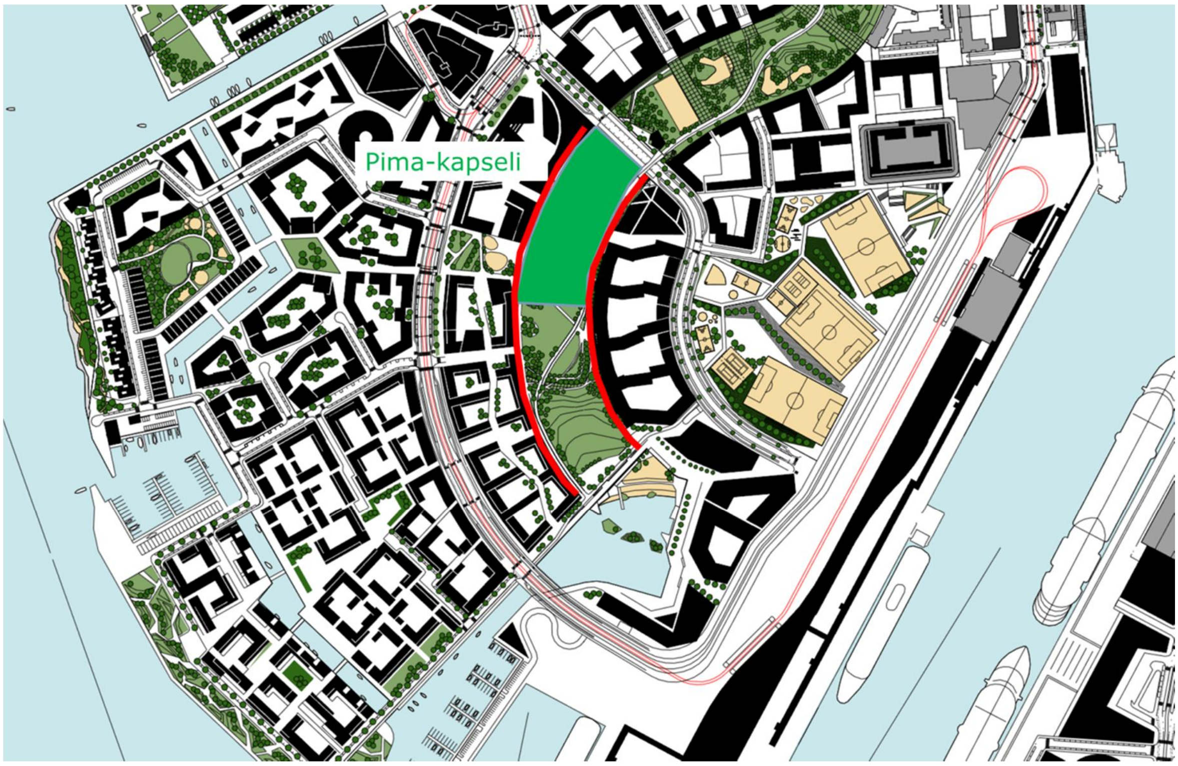

Figure 11. Theoretical utilisation of Jätkäsaari (West Harbour) sediments in the park, coloured in green.

In the LCA calculations, two different binder options are studied (cement / cement + fly ash) for the mass stabilisation of dredged sediments. The 3rd alternative describes the situation where the contaminated sediments are transported to landfill as sea dumping was not an option due to contamination with metals and organic substances. Theoretically, the sediments could have been dumped in the sea if the contamination would have been between level 1 and level 2, but the sediments exceeding the level 2 limit values would anyway have to be removed from the sea. Since the sediments were contaminated, the transportation distance to the suitable landfill would be very big, 50…100 km. In the LCA calculations, the value of 50 km has been used.

It was possible to use part of the stabilised masses in the Jätkäsaari harbour structures but the city of Helsinki or the harbour did not choose so. The stabilised sediments were transported to Hyväntoivonpuisto (park) for landscaping purposes. In Alt3 the landscaping in the park is carried out with non-cohesive soils from the harbour area.

5.2 Inventory

5.2.1 Material Production

The materials and the material amounts used in the alternative structures are presented in Table 18. The examined basin is the basin number 2 where the total volume of mass stabilisation is 26 570 m^3. The average amount of binder according to the work report was 65 kg/m^3, which is used in the calculations (Alt1). In Alt2 cement is partly replaced with fly ash and the amount of ash is 200 kg/m^3. Fly ash originates from the Helsingin Energia power plant. In Alt3 the dredged sediments are lightly stabilised (35 kg/m^3 of cement) to make the transportation to landfill possible. As the amount of dredged sediments is the same in all alternatives, the sediments are not taken into account in the calculations. The total calculation sheet is presented in Appendix 3b.

Table 18. The materials used in the different structure alternatives in Jätkäsaari (West Harbour).

	Material	Amount [m3]	Amount [t/m3 of mass stabilised clay]	Amount [t]
Alt 1	Sediment	26570	1,5	39855
	Cement [40...80 kg/m3, average 65 kg/m3]		0,065	1727
	Non-cohesive soil, basin	13000	1,9	24700
Alt 2	Sediment	26570	1,5	39855
	Cement [40 kg/m3]		0,04	1063
	Fly ash [200 kg/m3]		0,2	5314
	Non-cohesive soil, basin	25180	1,9	47842
Alt 3	Sediment	26570	1,5	39855
	Cement [35 kg/m3]		0,035	930
	Non-cohesive soil, park	26570	1,9	50483

5.2.2 Transportation

The vehicles used in transportation, transportation distances and the fuel consumptions are presented in Table 19. The distances are calculated on the basis of the locations of the sources of cement (production site), fly ash (power plant), etc. Fuel consumptions [7] are presented as an average of the two-way trip of a loaded and empty vehicle. The fuel consumptions are based on the Lipasto database of traffic emissions made by the VTT Technical Research Institute of Finland. The database is updated annually and the calculations are based on statistics from the year 2012.

As the fly ash is transported to landfill in alternatives Alt1 and Alt3, the transportation distance is taken into account in Alt2 as a minus because the fly ash is utilised in stabilisation. The total calculation sheet is presented in Appendix 3c.

Table 19. The vehicles used in transportation, transportation distances and fuel consumption per functional unit (m^3). Jätkäsaari (West Harbour)

			total mass [tonnes/m3]	Total mass [t] (when stabilised area 26 570 m3)	vehicle	Distance [km]	Fuel consumption /FU
Alt 1	Cement	to site	0,065	1 727	tank truck (40t)	175	0,758
	Fly ash	to landfill	0,200	5 314	tank truck (40t)	25	0,333
	Mass stabilized sediment	to park	1,5	39 855	Dump Truck (19t)	0,5	0,063
	SUM						
Alt 2	Cement	to site	0,04	1 063	tank truck (40t)	175	0,467
	Fly ash	to site	0,2	5 314	tank truck (40t)	-21	-0,280
	Mass stabilized sediment	to park	1,5	39 855	Dump Truck (19t)	0,5	0,063
	SUM						
Alt 3	Fly ash	to landfill	1,90	5 314	tank truck (40t)	25	0,333
	Cement	to site	0,035	930	tank truck (40t)	175	0,408
	Mass stabilized sediment	to landfill	1,5	39 855	Dump Truck (19t)	25	3,166
	Non-cohesive soil, park	to park	1,9	50 483	Dump Truck (19t)	20	3,208
	SUM						

5.2.3 Construction

The vehicles used in construction, vehicle capacities and fuel consumptions are presented in Table 20. The stages similar in all alternatives are excluded from the calculations. These stages include dredging of the sediments, transportation of the sediments to the shore, building the stabilisation basins, and mass stabilising of the sediments. Therefore, only spreading of the sediments (Alt1 and Alt2) and the non-cohesive soils (Alt3) in the park is taken into account, and in addition, excavating of the non-cohesive soils in the Jätkäsaari area. Spreading of the masses were done with a caterpillar that simultaneously compacted the masses. The total calculation sheet is presented in Appendix 3d.

Table 20. The construction stages, capacities and fuel consumption per functional unit (m^3). Jätkäsaari (West Harbour)

		Capacity [h/m3]	Capacity [m3/h]	Fuel consumption [l/m3]	Fuel consumption [l/h]	Working hours [h]	Total consumption [l]	Consumption [l/FU]
Alt 1	Spreading of stabilized mass to the park		70	0,450	31,5	379,6	11959	0,450
	SUM							
Alt 2	Spreading of stabilized mass to the park		70	0,450	31,5	379,6	11959	0,450
	SUM							
Alt 3	Excavating the non-cohesive soil from Jätkäsaari	0,013		0,410	31,5	345,4	10883	0,410
	Spreading of the non-cohesive soil to park		45	0,700	31,5	590	18604	0,700
	SUM							

5.3 Results: Environmental Impacts

5.3.1 Global warming potential

Global warming potential is highest in Alt1 as it requires cement most and cement production generates a lot of airborne emissions (see Table 21 and Figure 12). In the transportation stage, Alt3 generates most of the emissions resulting in the highest GWP. Alt2 has the lowest GWP values as cement is partly substituted with fly ash (secondary product) instead of dumping the fly ash to the landfill. There were no significant differences between the alternatives in the mixing and construction stages.

Table 21. Global warming potential in different stages. Jätkäsaari (West Harbour)

Jätkäsaari Global warming potential [CO2 kg equivalent/FU]				
Alternative	Material production	Material transportation	Mixing and construction	Total
Alt 1	44	0,9	1,18	46
Alt 2	27	0,2	1,18	28
Alt 3	24	6,8	2,92	33

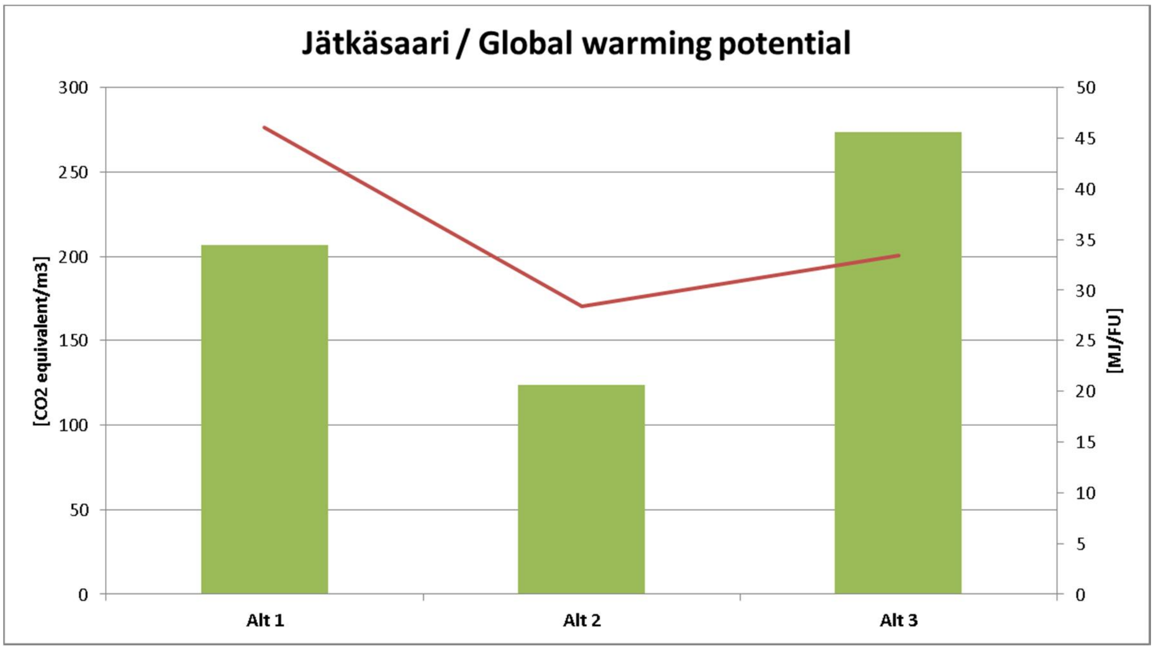

Figure 12. Global warming potential and energy consumption in different alternatives per functional unit (m^3) in Jätkäsaari (West Harbour) pilot.

Energy consumption is highest in Alt3 (Table 22). This is because of transportation, as transportation requires a lot of energy and depositing the stabilised masses to the landfill needs a lot of transportation kilometres. Alt2 has the lowest energy consumption. Cement is partly replaced with fly ash and there is no need for transporting and depositing the fly ash to the landfill.

Table 22. Energy consumption in different stages. Jätkäsaari (West Harbour)

Jätkäsaari Energy consumption [MJ/FU]				
Alternative	Material production	Material transportation	Mixing and construction	Total
Alt 1	188	13	5	207
Alt 2	116	3	5	124
Alt 3	101	100	13	214

5.3.2 Depletion of natural resources

Alt1 has the highest depletion of natural resources (Table 23 and Figure 13). This results from the use of 65 kg/m^3 of cement in mass stabilisation. Alt2 and Alt3 have the same magnitude results as part of the cement is substituted in Alt2 and the local non-cohesive soils are re-used in the park filling in Alt3. In Alt3 the depletion of natural aggregates is not taken into account as the use of non-cohesive soil is not regarded as the use of natural aggregates.

Table 23. Depletion of natural resources in different stages. Jätkäsaari (West Harbour)

Jätkäsaari Depletion of natural resources [kg/FU]				
Alternative	Material production	Material transportation	Mixing and construction	Total
Alt 1	93	0,4	0,52	94
Alt 2	57	0,1	0,52	58
Alt 3	50	3,1	1,29	54

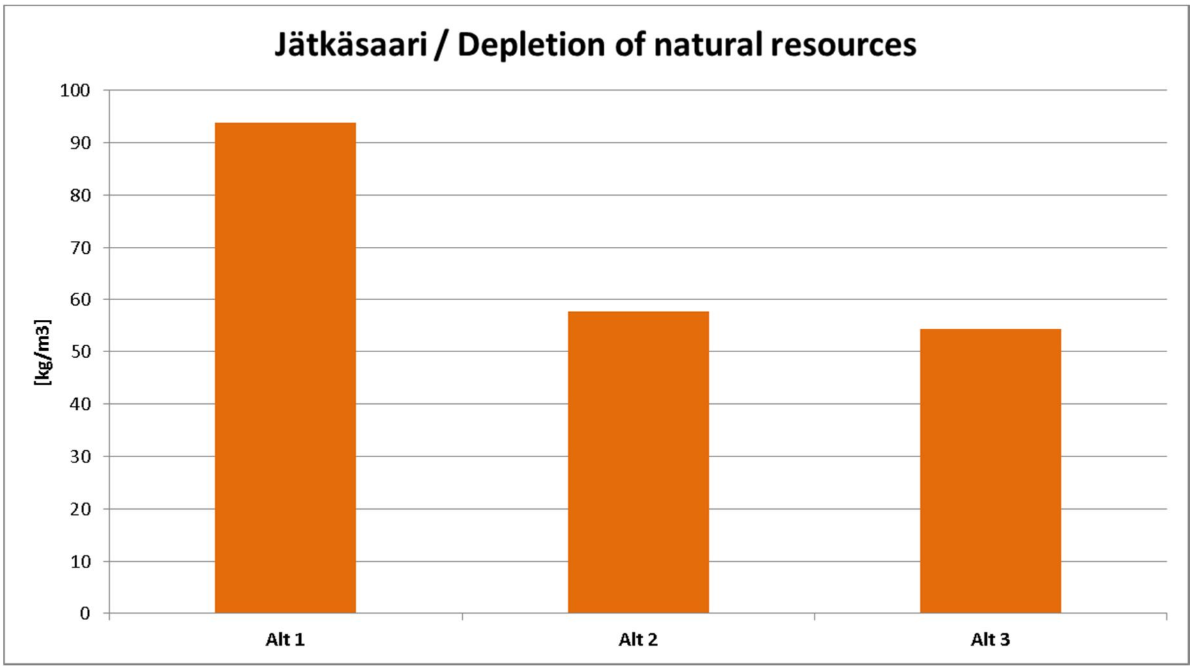

Figure 13. Depletion of natural resources in the Jätkäsaari (West Harbour) different alternatives. Jätkäsaari (West Harbour)

Final results are presented in Appendix 3e.

6. SUMMARY OF ENVIRONMENTAL IMPACTS

According to the LCA results of the three studied pilots, by substituting part of the cement with fly ash or with other industrial by-product, the environmental impacts can be significantly decreased. Cement manufacturing consumes a lot of energy and natural resources. In Finland, cement manufacturing constitutes 1,2 % of all greenhouse gas emissions. The environmental impacts from cement manufacturing are centralised especially to the area where the main ingredient, limestone, is quarried. Moreover, cement transportations and high temperatures (~1400-1500 °C) in rotary kilns generate a lot of airborne emissions and consume a lot of energy [10].

The utilisation of surplus soils significantly decreases the depletion of natural resources, energy consumption and global warming potential. In Finland, the annual use of natural aggregates is approximately 22 ton/person. There is a shortage of rock material in the capital region, so the natural aggregates are transported from other counties. The transportation distances can be over 30 km. Transportation of 1 ton of natural aggregates consumes 7 kWh energy. As 1 kWh energy produces approximately 0,27 kg CO_2 emissions, 1 km more of a transportation distance results in 7 million kg of CO_2 emissions [11]. The amount of surplus soils generated annually in Helsinki is approximately 100 000 – 150 000 m^3. The landfill capacity for surplus soils has been exhausted and part??? of the surplus soils are transported outside Helsinki. As the results of this study indicate, stabilisation of soft surplus soils that allows for their utilisation as earth construction materials is an environmentally feasible solution.

The environmental impacts are both local and global. The local environmental impacts include changes in land use, especially in the Dog Park case, as the area was previously unbuilt. According to the nature survey made in the area in 2007, there were no such nature values that would have prevented building actions. In the Arcada II case, the old structure already existed and in the

Jätkäsaari case, the pilot took place in a vast regional building area so the total impact of it was quite small.

The airborne release of greenhouse gases from the different unit processes in each pilot affects globally, e.g. the climate change that is indicated by the Global Warming Potential (GWP).

The studied environmental impacts were lower in the pilot structures compared to the alternatives with more conventional structures. This indicates that surplus soils utilisation should always be considered as an alternative when planning civil engineering projects where earth construction is included. Surplus soils can be used in new regional development projects, road and field structures, railway areas, landscaping, harbour structures, noise barriers, and any other structure where natural aggregates are normally used.

7. QUALITATIVE LCC

The purpose of the LCC is to compare the alternatives and to show that the use of stabilised surplus soils can be a cost-efficient investment. Instead of carrying out calculations for the life cycle periods after the initial construction, the project participants decided to give a qualitative assessment about the pilot structures future use as the actual life cycle costing method would be significantly too uncertain to obtain reliable results.

In addition to the qualitative assessment, external environmental costs were also studied. The environmental LCC methodology takes into account the four main categories (investment, operation, maintenance, end-of-life) plus external environmental costs (Figure 14). The latter may come from LCA analyses on environmental impacts, which measure for example the external costs of global warming contribution associated with emissions of different greenhouse gases. Environmental costs can be calculated also in respect of acidification (grams of SO_2, NO_x and NH_3), eutrophication (grams of NO_x and NH_3), land use (m^2*year) or other measurable impacts [12].

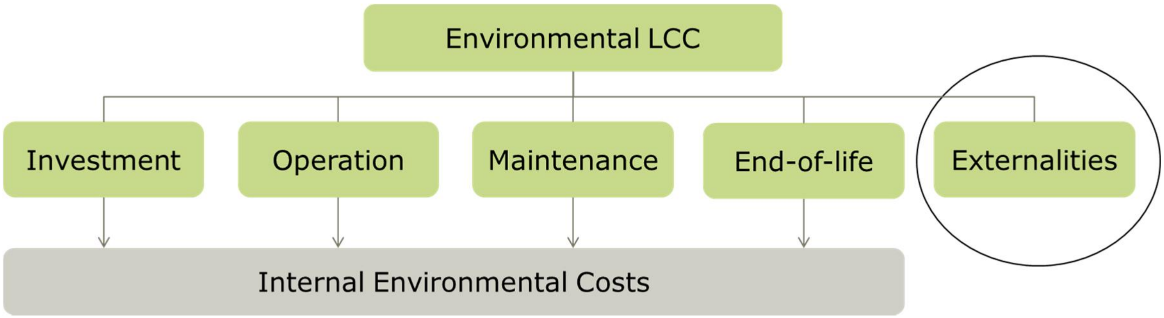

Figure 14. Externalities according to environmental LCC methodology.

The Finnish Transport Agency has carried out studies on the environmental costs of transport. The cost estimations presented by the report “Environmental costs of transport, 2012” [13] are included in Table 24. The costs cover the impacts of pollutants on health (increased mortality and morbidity) and flora (crop losses and decreased forest growth) as well as the cost of climate change. The environmental costs of primary particles, sulphates and nitrates vary geographically and between transport modes. The differences are particularly distinctive for particle emissions from road transport. The environmental unit costs of hydrocarbons and greenhouse gases are the same for all transport modes in all traffic environments and all parts of the country [13].

Table 24. Unit prices for transportation emissions (converted to match for year 2012 costs) [13].

	PM	NOx	HC	CO_2	CH_4	N_2O
Average unit cost, eur/ton	59 230	567	32	39	828	12 201

Although the unit prices in Table 26 are the unit costs for traffic, the environmental costs of the pilot structures of the ABSOILS pilots are calculated on the basis of these numbers. The majority of the greenhouse gas emissions in the pilot structures are generated by the transportations. In the environmental data of cement manufacturing , the transportation emissions from excavating the raw material is also included.

7.1 Arcada II

7.1.1 Qualitative assessment

As the mass stabilised structure is placed under the slab with the end-bearing piles and buildings and a yard area will be constructed on its top , this part of the structure will not be renewed. Because the structure is permanent, no maintenance, renovation periods or costs related to such can be calculated for this.

7.1.2 Environmental costs

The environmental costs from greenhouse gases in the Arcada II pilot are presented in Figure 15. Alt2 has the lowest environmental costs and Alt1 has the highest. Cement production generates a lot of airborne emissions thus causing also high environmental costs (Alt1). When the CO_2 emission are compared, Alt3 generates most environmental costs for CO_2. There are also clear differences between the alternatives in the particle expenses as Alt1 and Alt2 have more particle expenses. When inspecting other emissions, the differences are insignificant.

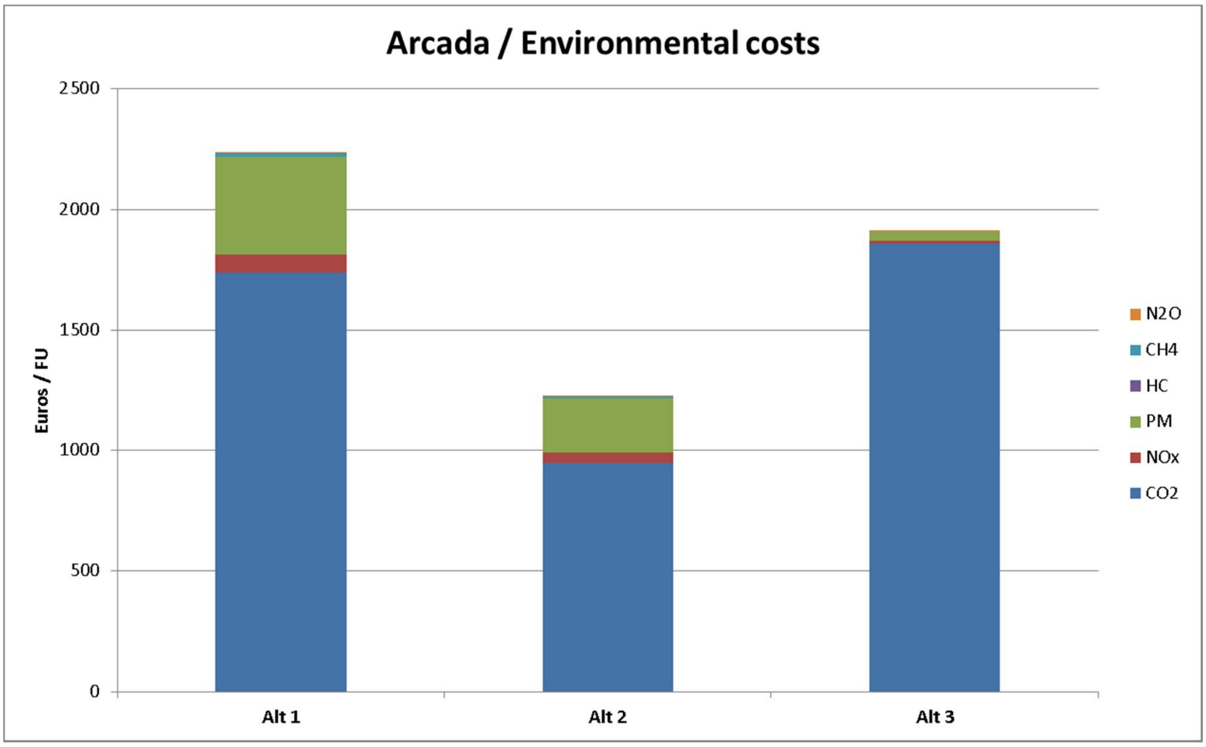

Figure 15. Environmental costs per FU (100 m^2) in the Arcada II pilot.

7.2 Dog Park

7.2.1 Qualitative assessment

The structure in the Dog Park is a settling structure. If the settlement is bigger than expected, raising will be done by placing new material over the existing embankment. As the ground under the mass stabilised layer is very soft, the new structure has to be a light weight structure, . made of e.g. light weigth expanded clay aggregate or foamed glass. Because the structure is permanent, no maintenance, renovation periods or costs related to such can be calculated for this.

7.2.2 Environmental costs

The environmental costs for the Dog Park are presented in Figure 16. Alt2 has the lowest environmental costs and Alt1 has the highest. Cement production generates a lot of airborne emissions thus causing also high environmental costs (Alt1). When the CO_2 emission are compared, Alt3 generates most environmental costs for CO_2. There are also clear differences between the alternatives in the particle expenses as Alt1 and Alt2 have more particle expenses. When inspecting other emissions, the differences are insignificant.

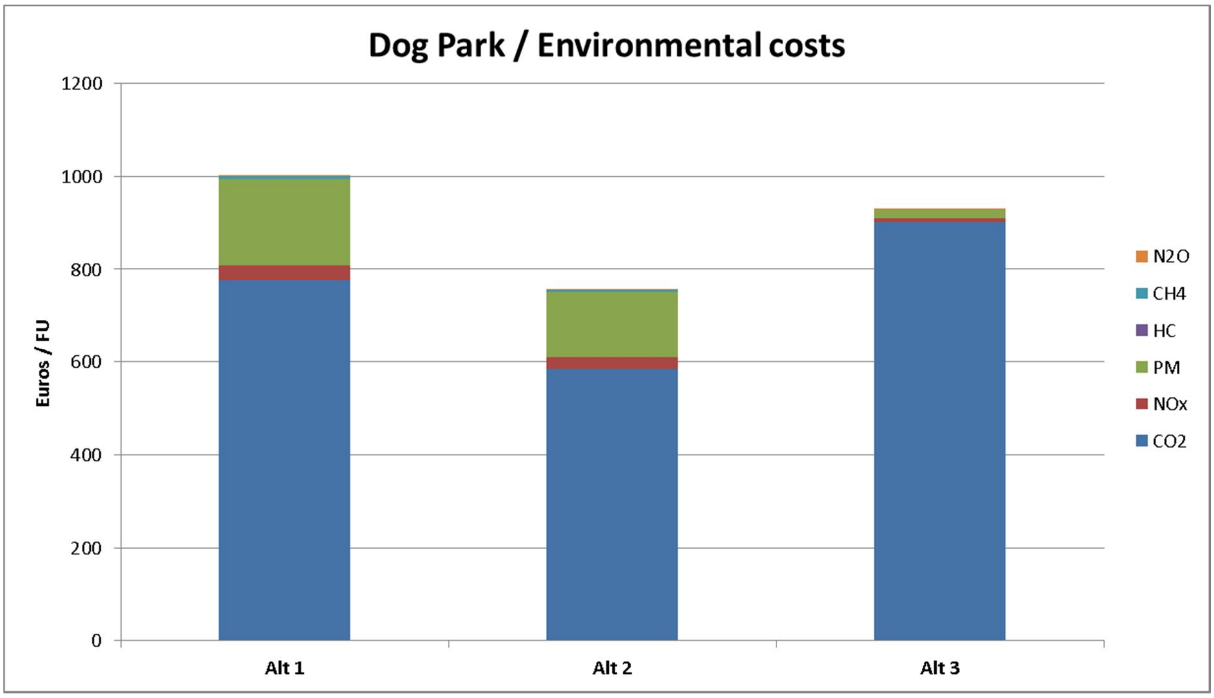

Figure 16. Environmental costs per FU (100 m^2) in Dog Park pilot.

7.3 Jätkäsaari (West Harbour)

7.3.1 Qualitative assessment

Notice: the Jätkäsaari case is just a theoretical alternative. The stabilised masses from Jätkäsaari (West Harbour) are placed under the sealing structure in the Hyväntoivonpuisto park, so also this structure is permanent and no maintenance or renovation periods, neither maintenance or renovation costs can be calculated for this. The principle of the utilisation of the stabilised sediments is presented in Figure 17.

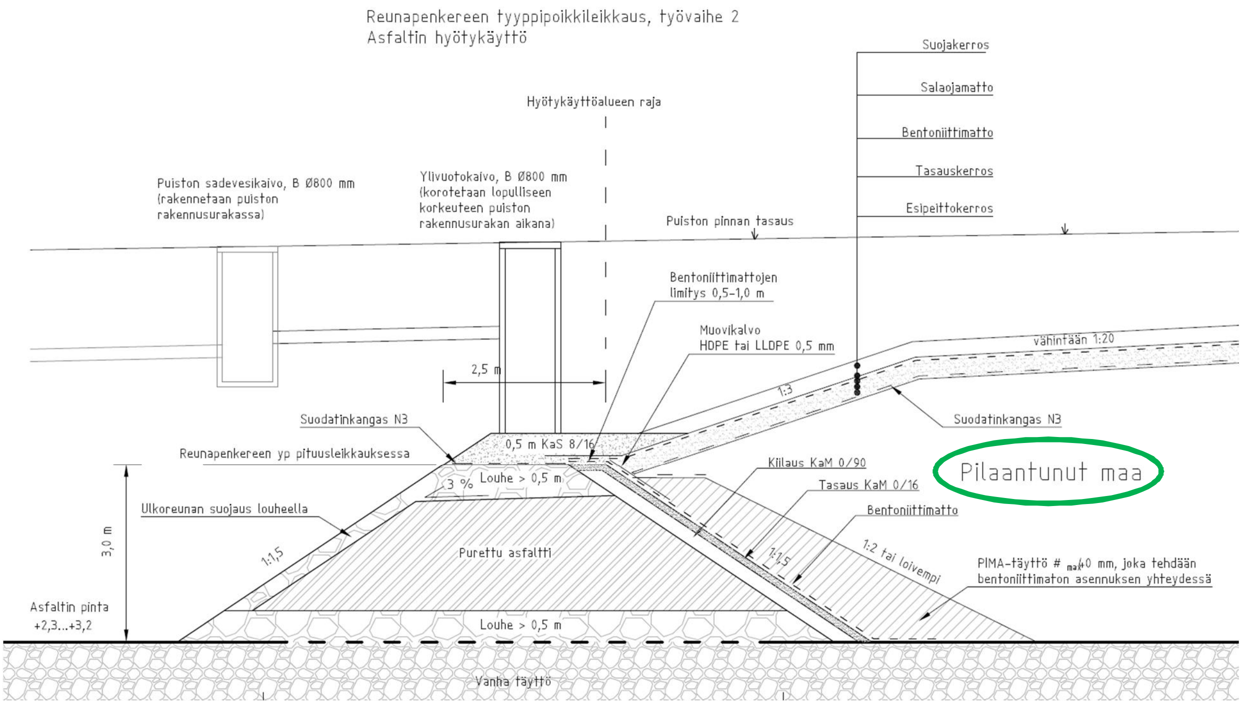

Figure 17. The principle of the surface and slope structures in Jätkäsaari (West Harbour). (Green circle = contaminated soils = stabilised sediments in the theoretical study).

7.3.2 Environmental costs

The environmental costs for Jätkäsaari (West Harbour) are presented in Figure 18. Alt2 has the lowest environmental costs and Alt1 has the highest. This is caused by the use of cement in mass stabilisation. The costs for NO_x are quite equal. Also the particulate matter (PM) causes a lot of environmental costs.

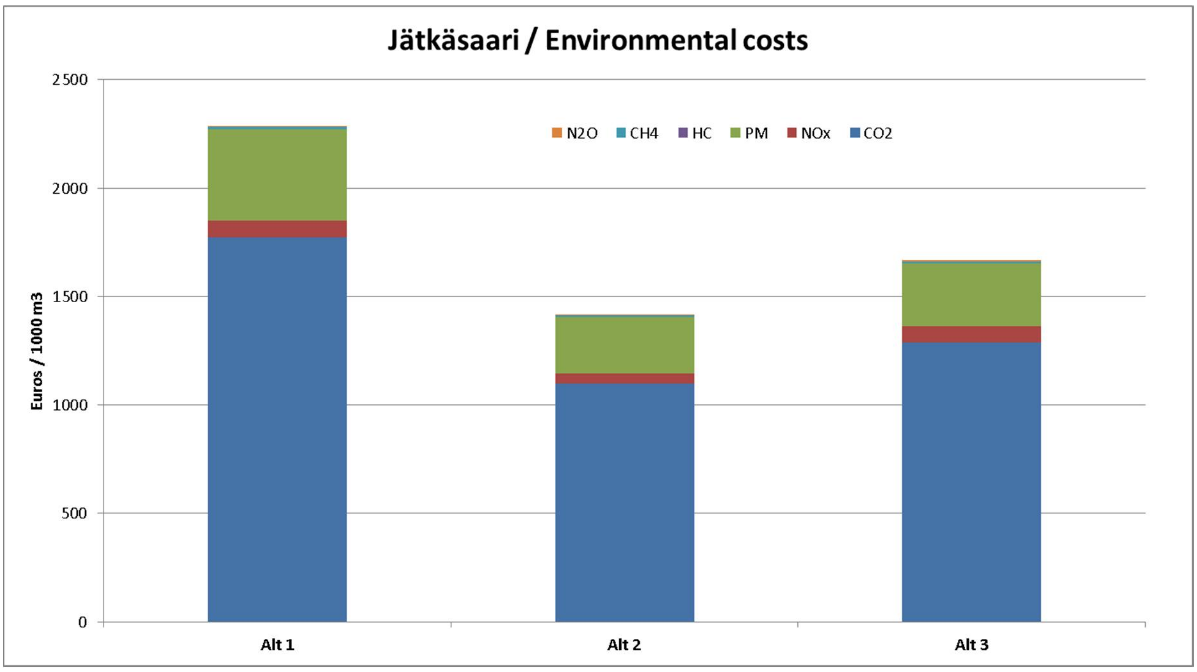

Figure 18. Environmental costs per 1000 m^3 (FU = m^3) in the Jätkäsaari (West Harbour) pilot. The functional unit (1 m^3) has been multiplied by the coefficient 1000 to obtain more comparable numbers.

7.4 Conclusions LCC

When the environmental costs are examined, the following issues have to be noticed:

- The environmental costs of the different alternative structures describe only the average costs from greenhouse gases in Finland. The results do not allow to draw conclusions on the basis of environmental costs.
- As the environmental costs differ a lot regionally, it is not possible to draw direct conclusions on the superiority of other structure alternatives.
- These environmental costs tell only the differences between the presented alternative structures.
- The regional emphasis among the emissions vary a lot, e.g. the costs for particle matters in the capital region is 233 417 eur/ton and in the municipalitis with less than 10 000 inhabitants, the cost is only 7 974 eur/ton.

8. SUMMARY

According to the results achieved in the ABSOILS Verification Action, it can be concluded that the structure alternatives implemented in the ABSOILS pilots had less environmental effects than the structure alternatives considered in the study. Even a partial substitution of cement with fly ash significantly affects the environmental impacts by diminishing them. Manufacturing of cement consumes a lot of energy, produces big amounts of greenhouse gases and depletes natural resources. The use of natural aggregates such as rock and gravel involves long driving distances as the crushing plants are located far from the capital region and its construction targets. Moreover, the suitable landfills for surplus soil are located at least 20...30 km from Helsinki. These long driving distances naturally result in vast diesel consumption and generate greenhouse gas emissions. As the fuel price is high, the construction costs rise remarkably when crushed rock and surplus soils are transported into and off the construction site.

Based on the LCA results achieved, it can be proved that utilising surplus soils is environmentally feasible. In this project, the studied structures included soils that are mass stabilised with cement or with the mixture of cement and fly ash. However, other industrial by-products, such as desulpurization agent, blast furnace slag or gypsum, can also be utilised in mass stabilisation. The suitability of a binder is always studied case by case. By using industrial by-products for improving the quality of surplus soils that allows for their utilization as material, the costs and environmental effects can be reduced significantly.

It has to be noticed that these results cannot be compared to some other external calculations. The life cycle analysis executed in this project is a Streamlined LCA and has been performed according to the project budget.

In general, there is an urgent need to develop ways of utilising surplus soils. In the Helsinki region as well as in other European countries, landfills decrease in size and in number. Also the number of permissions for natural aggregate intake has been simultaneously diminishing. Utilising of surplus soils follows the European Union Waste Hierarchy, where the prevention of waste is priority number one and landfilling is the last phase if recycling and energy recovery cannot be done.

This study shows that the environmental impacts due to construction can be reduced by optimising the use of construction materials.

The LCC part was studied mainly qualitatively. This was discussed first with the project participants and the decision of qualitative assessment was unanimous. The environmental costs were calculated for each pilot and the results showed that the structures that had less environmental impacts in the LCA calculations had also lowest environmental costs.

Although the environmental costs are quantified, it is not possible to draw conclusions on the construction costs on the bases of environmental costs. As the maintenance and renovation stages are only qualitatively evaluated, no conclusions can be drawn on the costs of the structures.

The results achieved in the Verfication Action of ABSOILS are in line with the expected end-result – utilising surplus soils is feasible in a technical and in environmental way. The environmental impacts of construction can be decreased by paying attention to construction materials, recycling materials and transportation distances.

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Appendix 1 Arcada II LCA calculation sheets

1a Starting point

	Three alternative structures	Materials for the structure	Processes for the construction
Alt 1	Mass stabilisation with cement	Clay and cement, embankment material	Removal of the old aggregate material. Filling with clay. Homogenisation of clay and extra water. Stabilisation of clay with cement. Surface structures; compaction embankment 700 mm.
Alt 2	Mass stabilisation with fly ash and cement	Clay, cement and fly ash, embankment material	Removal of the old aggregate material. Filling with clay. Homogenisation of clay and extra water. Stabilisation of clay with cement and fly ash. Surface structures; compaction embankment 700 mm.
Alt 3	Light weight structure with light expanded clay aggregate	Light expanded clay aggregate, embankment material	Removal of the old aggregate material. Filling with light expanded clay aggregate in layers. Compaction in layers. Surface structures; embankment 700 mm.

1b Material production

	Material	Amount [m³]	density [t/m³]	m³/m² Thickness [m]	Amount [t/FU]	Amount [m²]	Emissions [g/ton]									Energy consumption [MJ/100 m²]	Depletion of natural resources [kg/100 m²]	Reference
							CO_2	NOx	PM	SO_2	CO	VOC	CH_4	HC	N_2O			
Alt 1	Clay	32 000	1,5	4,5	670		No emissions from the clay as it is not produced nut is a waste that would be otherwise stored in a landfill.											
	Cement [t]	3 697	1,2	0,5	62		668 000	1828	103	271		113	265		1,8	179 401	88 493	[10]
	Removed rock aggregate	32 000	2,2	4,5	983		Not taken into account											
	Geotextile [m²]				0,3	7163											627	
	Compaction embankment; crushed rock	5 014	2,2	0,7	154		1 800	2	1	1	1	3	1	0		5 236	155 540	[17]
	Sum				1 869											184 637	244 660	
Alt 2	Clay	32 000	1,5	4,5	670		No emissions from the clay as it is not produced and is a waste that would be otherwise stored in a landfill.											
	Cement [t]	1 920	1,2	0,3	32		668 000	1828	103	271		113	265		1,8	93 183	45 964	[10]
	Fly ash [t]	3 200	1,2	0,4	54		Not taken into account as the emissions from fly ash are included into the emissions of the main product of the energy											
	Removed rock aggregate	32 000	2,2	4,5	983		Not taken into account.											
	Geotextile [m²]			0,0	0,3	7163											627	
	Compaction embankment; crushed stone	5 014	2,2	0,7	154		1 800	2	1	1	1	3	1	0		5 236	155 540	[17]
					1 893											98 419	201 504	
Alt 3	Light expanded clay aggregate	31 935	0,344	4,5	154		290 418									271 396	202 131	[8], [9]
	Removed rock aggregate	31 935	2,2	4,5	981		Not taken into account.											
	Geotextile [m²]			0,0	0,6	14326											1 254	
	Compaction embankment; crushed stone	5 014	2,2	0,7	154		1 800	2	1	1	1	3	1	0		5 236	155 540	[17]
	Sum				1 289											276 632	358 925	

1c Material transportation

						Emissions [g/km]								Non-renewable material [kg/l]	Energy consumption [MJ/km]	Abiotic material consumption [kg/km]
			Total mass [ton/FU]*	Full load [tons]	Vehicle	CO_2	NOx	PM	SO_2	CO	VOC + HC	CH_4	N_2O			
Alt 1	Clay	to site	670	19	Dump Truck (19t)	774,5	5,75	0,063	0,00525	0,195	0,115	0,007	0,033	1,16	11,5	0,58
	Cement	to site	62	40	Tank truck (40t)	1036	7,7	0,074	0,00705	0,21	0,09	0,009	0,0305	1,16	15	0,58
	Removed rock aggregate	to re-use	983	19	Dump Truck (19t)	774,5	5,75	0,063	0,00525	0,195	0,115	0,007	0,033	1,16	11,5	0,58
	Geotextile [m2]		100													
	Rock aggregate for embankment	to site	154	19	Dump Truck (19t)	774,5	5,75	0,063	0,00525	0,195	0,115	0,007	0,033	1,16	11,5	0,58
	Fly ash	to landfill	54	40	Tank truck (40t)	1036	7,7	0,074	0,00705	0,21	0,09	0,009	0,0305	1,16	15	0,58
	SUM															
Alt 2	Clay	to site	670	19	Dump Truck (19t)	774,5	5,75	0,063	0,00525	0,195	0,115	0,007	0,033	1,16	11,5	0,58
	Cement	to site	32	40	Tank truck (40t)	1036	7,7	0,074	0,00705	0,21	0,09	0,009	0,0305	1,16	15	0,58
	Fly ash	to site	54	40	Tank truck (40t)	1036	7,7	0,074	0,00705	0,21	0,09	0,009	0,0305	1,16	15	0,58
	Removed rock aggregate	to re-use	983	19	Dump Truck (19t)	774,5	5,75	0,063	0,00525	0,195	0,115	0,007	0,033	1,16	11,5	0,58
	Geotextile [m2]		100													
	Rock aggregate for embankment	to site	154	19	Dump Truck (19t)	774,5	5,75	0,063	0,00525	0,195	0,115	0,007	0,033	1,16	11,5	0,58
	SUM															
Alt 3	Light expanded clay aggregate	to site	154	19	Dump Truck (19t)	774,5	5,75	0,063	0,00525	0,195	0,115	0,007	0,033	1,16	11,5	0,58
	Removed rock aggregate	to re-use	981	19	Dump Truck (19t)	774,5	5,75	0,063	0,00525	0,195	0,115	0,007	0,033	1,16	11,5	0,58
	Geotextile [m2]		200													
	Rock aggregate for embankment	to site	154	19	Dump Truck (19t)	774,5	5,75	0,063	0,00525	0,195	0,115	0,007	0,033	1,16	11,5	0,58
	Fly ash	to landfill	54	40	Tank truck (40t)	1036	7,7	0,074	0,00705	0,21	0,09	0,009	0,0305	1,16	15	0,58
	SUM															

Emissions [kg/100 m2]								Non-renewable material [kg/100 m2]	Energy consumption [MJ/100 m2]	Abiotic material consumption [kg/100 m2]	Non-renewable total [kg/100 m2]	Reference
CO_2	NOx	PM	SO_2	CO	VOC + HC	CH_4	N_2O					
1 366	10,1	0,1	0,0	0,3	0,2	0,0	0,1	634,1	20 280	1023	1657	[7]
561	4,2	0,0	0,0	0,1	0,0	0,0	0,0	264,0	8 128	314	578	
401	3,0	0,0	0,0	0,1	0,1	0,0	0,0	186,0	5 949	300	486	
63	0,5	0,0	0,0	0,0	0,0	0,0	0,0	29,1	932	47	76	
69	1	0	0	0	0	0	0	32,6		39	72	
2 460	18	0,2	0,0	0,6	0,3	0,0	0,1	1 146	35 288	1723	2869	
1 366	10,1	0,1	0,0	0,3	0,2	0,0	0,1	634,1	20 280	1023	1657	[7]
292	2,2	0,0	0,0	0,1	0,0	0,0	0,0	137,1	4 222	163	300	
33	0,2	0,0	0,0	0,0	0,0	0,0	0,0	15,7	482	19	34	
401	3,0	0,0	0,0	0,1	0,1	0,0	0,0	186,0	5 949	300	486	
63	0,5	0,0	0,0	0,0	0,0	0,0	0,0	29,1	932	47	76	
2 154	16	0,2	0,0	0,5	0,3	0,0	0,1	1 002,1	31 865	1552	2554	
1 629	12,1	0,1	0,0	0,4	0,2	0,0	0,1	756,2	24 184	1220	1976	[7]
400	3,0	0,0	0,0	0,1	0,1	0,0	0,0	185,6	5 937	299	485	
63	0,5	0,0	0,0	0,0	0,0	0,0	0,0	29,1	932	47	76	
69	1	0	0	0	0	0	0	32,6	1 005	39	72	
2 161	16,0	0,2	0,0	0,5	0,3	0,0	0,1	1 003,7	32 058	1605	2609	

1d Construction

		Labour input [h/FU]	Capacity [m3/h]	Volume [m3/ FU]	Fuel consumption [l/m3]	Fuel consumption [l/h]	Total fuel consumption [l/FU]	Emissions g/l								Non-renewable material [kg/l]	Energy consumption [MJ/h]
								CO_2	NOx	PM	SO_2	CO	N_2O	CH_4	HC		
Alt 1	Mass stabilisation		64	447	0,469	30	209									1,160	
	Spreading of loading embankment and compaction, compactor +wheel loader (1:1)		45	70	0,700	31,5	49	2607	22	1,1	0,017	7,8	0,071	0,15	2,5	1,160	341
	Spreading of geotextile [0,004 tth/m2]	0,4				30,0	12	790	5,4	0,22	0,0051	1,9	0,021	0,045	0,52	1,160	355
	SUM						258										
Alt 2	Mass stabilisation		64	447	0,469	30	209									1,160	
	Spreading of loading embankment and compaction, excavator		45	70	0,700	31,5	49	2607	22	1,1	0,017	7,8	0,071	0,15	2,5	1,160	341
	Spreading of geotextile [0,004 tth/m2]	0,4				30,0	12	790	5,4	0,22	0,0051	1,9	0,021	0,045	0,52	1,160	355
	SUM						258										
Alt 3	Spreading of leca, wheel loader		130	447	0,242	31,5	108	2607	22	1,1	0,017	7,8	0,071	0,15	2,5	1,160	341
	Compaction of light weight aggregate		200	447	0,168	33,5	75	2607	20	1,3	0,017	9	0,068	0,14	3,1	1,160	149
	Spreading of loading embankment and compaction, compactor +wheel loader (1:1)		45	70	0,744	33,5	52	2607	21	1,2	0,017	8,4	0,069	0,15	2,8	1,160	341
	Spreading of geotextile [0,004 tth/m2]	0,8				30,0	24	790	5,4	0,22	0,0051	1,9	0,021	0,045	0,52	1,160	355
	SUM						235										

Emissions [kg/100 m2]								Non-renewable material [kg/100 m2]	Energy consumption [MJ/100 m2]	Reference:
CO_2	NOx	PM	SO_2	CO	N_2O	CH_4	HC			
269	2	0,1	0,002	1	0,01	0,02	0,2	242,9	3742	[16], [22]
128	1,08	0,05	0,001	0,38	0,003	0,01	0,12	56,8	531	
10	0,068	0,003	0,000	0,024	0,000	0,001	0,007	13,9	142	
406	3	0,1	0,0	1,1	0,0	0,0	0,3	314	4415	
269	2	0,1	0,002	0,6	0,0	0,0	0,2	242,9	3742	[16], [22]
128	1,08	0,05	0,001	0,38	0,00	0,01	0,12	56,8	531	
10	0	0	0	0	0	0	0	13,9	142	
406	3,00	0,13	0,00	1,06	0,01	0,02	0,30	314	4415	
282	2,4	0,1	0,0	0,8	0,0	0,0	0,3	125,6	1173	[16], [22]
195	1,5	0,1	0,0	0,7	0,0	0,0	0,2	86,8	332	
136	1,09	0,06	0,00	0,44	0,00	0,01	0,15	60,4	531	
20	0,136	0,006	0,000	0,048	0,001	0,001	0,013	27,8	284	
633	5,1	0,3	0,004	2,0	0,02	0,04	0,7	301	2319	

1d Final results

		Emissions [kg/100 m^2]									Energy consumption [MJ/FU]	Depletion of natural resources [kg/FU]	GWP [CO_2 kg equivalent/FU]
		CO_2	N_2O	CH_4	NOx	CO	HC	VOC	PM	SO_2			
ALT 1	Material production	41 644	0,11	16,58	114	0,2		7,5	6,6	17,0	184 637	244 660	42 138
	Material transportation	2 460	0,10	0,02	18	0,6	0,33	0,3	0,2	0,017	35 288	2 869	2 486
	Mixing and construction	406	0,01	0,02	3,0	1,1	0,30		0,1	0,003	4 415	314	410
		44 511	0,22	16,63	135	1,8	0,63	7,8	6,9	17,0	224 341	247 843	45 034
ALT 2	Material production	21 764	0,06	8,69	59	0,2		4,1	3,5	8,9	98 419	201 504	22 022
	Material transportation	2 154	0,09	0,02	16	0,5	0,30	0,3	0,2	0,01	31 865	2 554	2 178
	Mixing and construction	406	0,01	0,02	3,0	1,1	0,30		0,1	0,003	4 415	314	410
		24 324	0,16	8,74	78	1,8	0,60	4,4	3,8	8,9	134 698	204 372	24 610
ALT 3	Material production	44 908	0,00	0,17	0,3	0,2		0,5	0,2	0,2	276 632	358 925	44 913
	Material transportation	2 161	0,09	0,02	16	0,5	0,32	0,3	0,2	0,01	32 058	2 609	2 185
	Mixing and construction	633	0,02	0,04	5,1	2,0	0,66		0,3	0,004	2 319	301	639
		47 702	0,11	0,22	21	2,7	0,98	0,8	0,6	0,2	311 009	361 835	47 737

Arcada II, Helsinki:

Arcada 2 is located in the Kyläsaari area of Helsinki. The project included the construction of the street Kyläsaarenkuja to a pile slab, the removal of contaminated soils and the existing blasted rock embankment, filling with mass stabilised surplus soils and the construction of a new driveway connection to the Hermanninrantatie road. The area had been filled from the sea in the 1960's. The clay reaches to -15...-25 level from the surface of the sea. The fillings made mainly from blasted rock embankment floated on top of the clay. Their thickness was over 20 meters at largest. Other fillings than the above-mentioned floating embankment were about 2-5 m thick.

Because the thickness of the fillings placed above the clay layers varied a lot, this caused horizontal load and lateral displacement. In order to decrease the load and lateral displacement, the heavy blasted rock fillings were replaced with light weight soil up to level -5. The replacements were made with mass stabilised clay. Also the areas from where contaminated soil had been removed were filled with stabilised clay. At Kyläsaarenkuja, a pile structure was constructed under a concrete slab, which has preventedthe lateral movement. The stabilised clay has decreased the load on the soils below and diminished the horizontal displacements, which consequently has also decreased the horizontal load on the pile structure. The replacement of the blasted rock boulders made the installation of the driven steel piles also much easier. To meet the unit weight requirements set for clay, a pre-treatment method has been developed to decrease its density. The abandoned clay materials are transported from construction sites where utilisation is not possible.

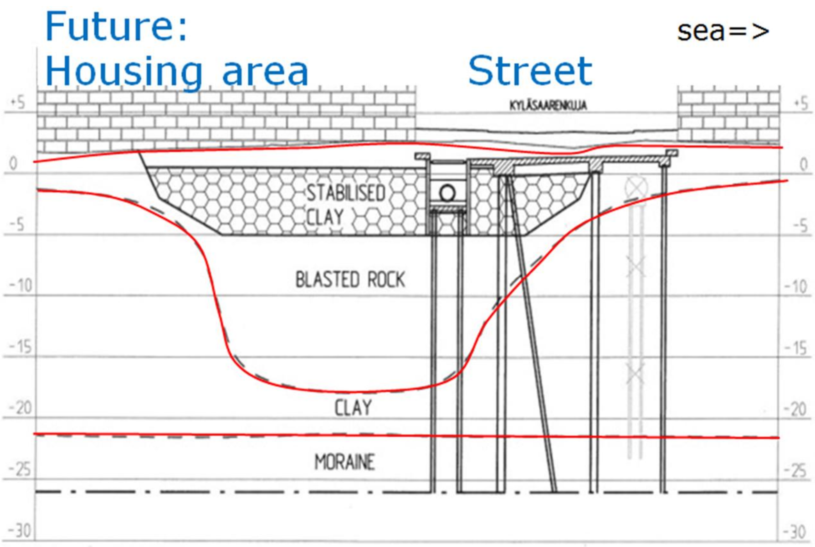

Fig. Phases: digging contaminated blasted rock away => Clay filling to level -5 => Mass stabilisation of the clay => Pile driving (d=400...700 mm / Ruukki) => etc.

Fig. Arcada II. Mass stabilisation on-going.

Appendix 2 Dog Park calculation sheets

2a Starting point

	Three alternative structures	Materials for the structure	Processes for the construction
Alt 1	Mass stabilisation with cement	Clay and cement	Filling with surplus soil. Mass stabilisation of the surplus soil with cement. Spreading of compaction embankment. Surface layer formation.
Alt 2	Mass stabilisation with fly ash (+deSOx) and cement	Clay, cement and fly ash	Filling with surplus soil. Mass stabilisation of the surplus soil with cement and fly ash. Spreading of compaction embankment. Surface layer formation.
Alt 3	Light weight structure with light expanded clay aggregate	Light expanded clay aggregate	Removal of 1 m of soft soil. Filling with light expanded clay aggregate (1.7 m). Spreading of the embankment (1.0 m). Surface layer formation.

2b Material production

				m^3/m^2				Emissions g/ton									
	Materials	Amount [m^3]	density [t/m^3]	Thickness [m]	Amount [t/m^2]	Amount [t/FU]	Amount [m^2]	CO_2	NOx	PM10	SO_2	CO	VOC	CH_4	N_2O	Energy consumption [MJ/ton]	Depletion of natural resources [kg/ton]
Alt 1	Cement [t]	1080	1,2	0,2	0,29	29		668 000	1828	103	271		113	265	1,8	2897	1429
	Surplus clay	6750	1,5	1,5	2,25	225		No emissions from the clay as it is considered waste and otherwise stored in landfill									
	Geotextile, [m^2]				0,003	0,3	4500										2090
	Compaction embankment	2250	1,9	0,5	0,95	95		1 800	2,10	1,20	1,30	1,10	3,00			34	1010
	Sum					349											
Alt 2	Cement [t]	810	1,2	0,2	0,22	22		668 000	1828	103	271		113	265	1,8	2897	1429
	Surplus clay	6750	1,5	1,5	2,25	225		No emissions from the clay as it is considered waste and otherwise stored in landfill									
	Fly ash [t]	1350	1,2	0,3	0,36	36		No emissions from the fly ash as it is considere waste and otherwise stored in landfill									
	Geotextile, [m^2]				0,003	0,3	4500										2090
	Compaction embankment	2250	1,9	0,5	0,95	95		1 800	2,10	1,20	1,30	1,10	3,00				1010
	Sum					378											
Alt 3	Filling, light weight material	7650	0,344	1,7	0,58	58		353 663								5234	1766
	Embankment	2250	1,9	0,5	0,95	95		1 800	2,10	1,20	1,30	1,10	3,00				1010
	Sum					153											

Total emissions kg/ 100 m^2								Energy consumption [MJ/100 m^2]	Depletion of natural resources [kg/ 100 m^2]	Reference:
CO_2	NOx	PM	SO_2	CO	VOC	CH_4	N_2O			
19238	53	2,97	7,80	0	3,2544	7,632	0,0518	834	41155	[10]
									627	
171	0,2	0,1	0,1	0,1	0,3	0		32,3	95 950	[17]
19409	53	3,1	7,9	0,1	3,5	8	0,05	867	137 732	
14429	39	2,2	5,9	0	2,4408	5,724	0,0389	626	30 866	[10]
									627	
171	0,2	0,1	0,1	0,1	0,3	0		0	95 950	[10]
14600	40	2,3	6,0	0,1	2,7	6	0,039	626	127 443	
20 682								3 061	103 276	[8]
171	0,2	0,1	0,1	0,1	0,3				95 950	[17]
20 853	0,2	0,1	0,1	0,1	0,3	0,0	0,0	3 061	199 226	

2c Material transportation

							Emissions g/km								Energy consumption [MJ/km]	Abiotic material consumption [kg/l]
		Destination	Total mass [ton / FU]	Vehicle	Distance [km]	total fuel consumption [l/FU]	CO_2	NOx	PM	SO_2	CO	VOC + HC	CH_4	N_2O		
Alt 1	Cement	to site	8	tank truck (40t)	170	29	1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16
	Surplus clay	to site	225	Dump truck (19 t)	0,5	4	774,5	5,75	0,063	0,0053	0,195	0,115	0,007	0,033	11,5	1,16
	Geotextile, [m2]		45													
	Fly ash	to landfill	36	tank truck (40t)	25	19	1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16
	Compaction embankment	to site	95	Dump truck (19 t)	20	62	774,5	5,75	0,063	0,0053	0,195	0,115	0,007	0,033	11,5	1,16
	SUM		409			113										
Alt 2	Cement		6	tank truck (40t)	170	21	1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16
	Surplus clay	to site	225	Dump truck (19 t)	0,5	4	774,5	5,75	0,063	0,0053	0,195	0,115	0,007	0,033	11,5	1,16
	Fly ash	to site	36	tank truck (40t)	-15	-11	1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16
	Geotextile, [m2]		45													
	Compaction embankment	to site	95	Dump truck (19 t)	20	84	774,5	5,75	0,063	0,0053	0,195	0,115	0,007	0,033	11,5	1,16
	SUM		407			98										
Alt 3	Filling light weight material	to site	54	Dump truck (19 t)	130	231	774,5	5,75	0,063	0,0053	0,195	0,115	0,007	0,033	11,5	1,16
	Fly ash	to landfill	36	tank truck (40t)	25	19	1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16
	Surplus clay	to landfill	225	Dump truck (19 t)	25	184	774,5	5,75	0,063	0,0053	0,195	0,115	0,007	0,033	11,5	1,16
	Excavated clay	to landfill	160	Dump truck (19 t)	25	131	774,5	5,75	0,063	0,0053	0,195	0,115	0,007	0,033	11,5	1,16
	Embankment	to site	95	Dump truck (19 t)	20	62	774,5	5,75	0,063	0,0053	0,195	0,115	0,007	0,033	11,5	1,16
	SUM		570			626										

Total emissions kg / 100 m^2								Energy consumption [MJ]	Abiotic material consumption [kg/100 m2]	Reference:
CO_2	NOx	PM	SO_2	CO	VOC + HC	CH_4	N_2O			
70	0,5	0,01	0,000	0,01	0,01	0,001	0,002	1,0	33,1	[7]
9	0,1	0,00	0,000	0,00	0,00	0,000	0,00	0,1	4,3	
									0,0	
47	0	0,00	0,00	0,01	0,00	0,00	0,00	0,7	21,9	
155	1,2	0,01	0,001	0,04	0,02	0,001	0,01	2,3	71,9	
281	2	0,0	0,002	0,1	0,03	0,00	0,0	4	131	
53	0,4	0,00	0,000	0,01	0,00	0,0	0,0	0,8	24,8	[7]
9	0,1	0,00	6,2E-05	0,00	0,00	0,000	0,00	0,1	4,3	
-28	-0,2	0,00	-0,0002	-0,01	0,00	-0,0002	-0,001	-0,4	-13,2	
155	1,2	0,01	0,001	0,04	0,02	0,0014	0,01	2,3	97,4	
189	1	0,0	0,001	0,0	0,03	0,00	0,0	3	113	
577	4,3	0,05	0,00	0,1	0,1	0,01	0,0	8,6	267,7	[7]
47	0,347	0,003	0,000	0,009	0,004	0,000	0,001	0,7	21,9	
459	3	0,04	0,00	0,12	0,07	0,00	0,02	6,8	212,9	
326	2,4	0,03	0,002	0,1	0,0	0,00	0,0	4,8	151,4	
155	1,2	0,01	0,001	0,0	0,0	0,001	0,0	2,3	71,9	
1563	12	0,1	0,01	0,4	0,2	0,01	0,1	23	726	

2d Construction

			Emissions g/l								Non-renewable material [kg/l]	Energy consumption [MJ/h]	Emissions [kg/100 m^2]							
		Total fuel consumption [l]/FU	CO_2	NOx	PM	SO_2	CO	N_2O	CH_4	HC			CO_2	NOx	PM	SO_2	CO	N_2O	CH_4	HC
Alt 1	Clearing of topsoil	29,1	790	3,8	0,13	0,0051	1,6	0,021	0,045	0,32	1,16	347	24	0,12	0,00	0,00	0,05	0,00	0,00	0,01
	Mass stabilisation	67,5									1,16		90	0,6	0,02	0,001	0,2		0,005	0,1
	Spreading of geotextile [0,004 tth/m2]	5,4	790	5,4	0,22	0,0051	1,9	0,021	0,045	0,52	1,16	355	5	0,031	0,001	0,000	0,011	0,0001	0,0003	0,003
	Spreading of compaction embankment (excavator)	33,3	2607	18	0,7	0,017	6,3	0,071	0,15	1,7	1,16	355	87	0,6	0,02	0,0006	0,2	0,002	0,005	0,057
	SUM	135											206	1,37	0,05	0,001	0,49	0,003	0,01	0,13
Alt 2	Clearing of topsoil	29,1	790	3,8	0,13	0,005	1,6	0,021	0,05	0,3	1,16	347	24	0,12	0,00	0,00	0,05	0,00	0,00	0,01
	Mass stabilisation	67,5									1,16		90	0,6	0,024	0,001	0,2		0,01	0,1
	Spreading of geotextile [0,004 tth/m2]		790	5,4	0,22	0,0051	1,9	0,021	0,045	0,52	1,16	355	5	0,034	0,001	0,000	0,012	0,000	0,000	0,003
	Spreading of compaction embankment (excavator)	33,3	2607	18	0,7	0,017	6,3	0,071	0,15	1,7	1,16	355	87	0,6	0,023	0,001	0,2	0,002	0,01	0,1
	SUM	130											206	1,37	0,05	0,001	0,49	0,003	0,01	0,13
Alt 3	Excavation of clay	81,5	2607	18	0,7	0,017	6,3	0,071	0,15	1,7	1,16	355	212	1	0,1	0,0	0,5	0,0	0,0	0,1
	Spreading of light weight clay (excavator)	41,2	2607	18	0,7	0,017	6,3	0,071	0,15	1,7	1,16	355	107	1	0,03	0,001	0,3	0,003	0,01	0,1
	Rock aggregate (excavator)	74,4	2607	18	0,7	0,017	6,3	0,071	0,15	1,7	1,16	355	194	1	0,05	0,001	0,47	0,01	0,01	0,13
	Compaction of structure (puskutraktori)	64,4	2607	18	0,7	0,017	6,3	0,071	0,15	1,7	1,16	493	168	1	0,05	0,001	0,41	0,005	0,01	0,11
	SUM	262											682	5	0,2	0,004	1,6	0,02	0,04	0,4

Emissions [kg/100 m^2]								Non-renewable material [kg/100 m^2]	Energy consumption [MJ/100 m^2]	Reference:
CO_2	NOx	PM	SO_2	CO	N_2O	CH_4	HC			
24	0,12	0,00	0,00	0,05	0,00	0,00	0,01	33,8	336	
90	0,6	0,02	0,001	0,2		0,005	0,1	78,3	1257	
5	0,031	0,001	0,000	0,011	0,0001	0,0003	0,003	6,3		[6], [7], [16]
87	0,6	0,02	0,0006	0,2	0,002	0,005	0,057	38,7	394	
206	1,37	0,05	0,001	0,49	0,003	0,01	0,13	157	1987	
24	0,12	0,00	0,00	0,05	0,00	0,00	0,01	33,756	337	
90	0,6	0,024	0,001	0,2		0,01	0,1	78,300	1257	
5	0,034	0,001	0,000	0,012	0,000	0,000	0,003	0,000		[6], [7], [16]
87	0,6	0,023	0,001	0,2	0,002	0,01	0,1	38,667	394	
206	1,37	0,05	0,001	0,49	0,003	0,01	0,13	151	1987	
212	1	0,1	0,0	0,5	0,0	0,0	0,1	94,500	917	
107	1	0,03	0,001	0,3	0,003	0,01	0,1	47,783	464	
194	1	0,05	0,001	0,47	0,01	0,01	0,13	86,356	788	[6], [7], [16]
168	1	0,05	0,001	0,41	0,005	0,01	0,11	74,731	948	
682	5	0,2	0,004	1,6	0,02	0,04	0,4	303	3117	

2d Final results

		Emissions [kg/100 m^2]									Energy consumption [MJ/FU]	Depletion of natural resources [kg/FU]	GWP [CO_2 kg equivalent/FU]
		CO_2	N_2O	CH_4	NOx	CO	HC	VOC	PM	SO_2			
ALT 1	Material production	41 644	0,11	16,58	114	0,2		7,5	6,6	17,0	184 637	244 660	42 138
	Material transportation	2 460	0,10	0,02	18	0,6	0,33	0,3	0,2	0,017	35 288	2 869	2 486
	Mixing and construction	406	0,01	0,02	3,0	1,1	0,30		0,1	0,003	4 415	314	410
		44 511	0,22	16,63	135	1,8	0,63	7,8	6,9	17,0	224 341	247 843	45 034
ALT 2	Material production	21 764	0,06	8,69	59	0,2		4,1	3,5	8,9	98 419	201 504	22 022
	Material transportation	2 154	0,09	0,02	16	0,5	0,30	0,3	0,2	0,01	31 865	2 554	2 178
	Mixing and construction	406	0,01	0,02	3,0	1,1	0,30		0,1	0,003	4 415	314	410
		24 324	0,16	8,74	78	1,8	0,60	4,4	3,8	8,9	134 698	204 372	24 610
ALT 3	Material production	44 908	0,00	0,17	0,3	0,2		0,5	0,2	0,2	276 632	358 925	44 913
	Material transportation	2 161	0,09	0,02	16	0,5	0,32	0,3	0,2	0,01	32 058	2 609	2 185
	Mixing and construction	633	0,02	0,04	5,1	2,0	0,66		0,3	0,004	2 319	301	639
		47 702	0,11	0,22	21	2,7	0,98	0,8	0,6	0,2	311 009	361 835	47 737

Dog Park, Espoo:

Perkkaa Dog Park pilot application in Espoo is a park which area is ≈4 500 m^2 and it lies in the flood prone zone. The soil of the area was described as soft clay which used to be seabed. The thickness of the clay is ≈11 … 14 m and the area was classified as a very difficult constructing target due to its low load bearing capacity. The purpose of the pilot was to raise the area to prevent flooding. In order to prevent mass exchange, landfilling of the soft soils and replacing them with other materials, it was planned to utilise both the poor quality spoils encountered in the target and the surplus clays obtained from an adjacent construction site – the construction of a street foundation with a mass replacement method.

The redundant clays from the neighbouring street were transported to the pilot site where the materials were stockpiled in the area surrounded with an embankment to prevent the escape of the fluid clay material out from the stabilisation area. The transportation and construction of the embankment took place between January and March 2012. The transportation distance in this case was only 200...500 meters. The transportation distance to the landfill would have been about 25 km had it not been possible to use the redundant masses in the construction process of the Perkkaa Dog Park. Surplus soft clay is a very troublesome and expensive material to dispose at landfill.

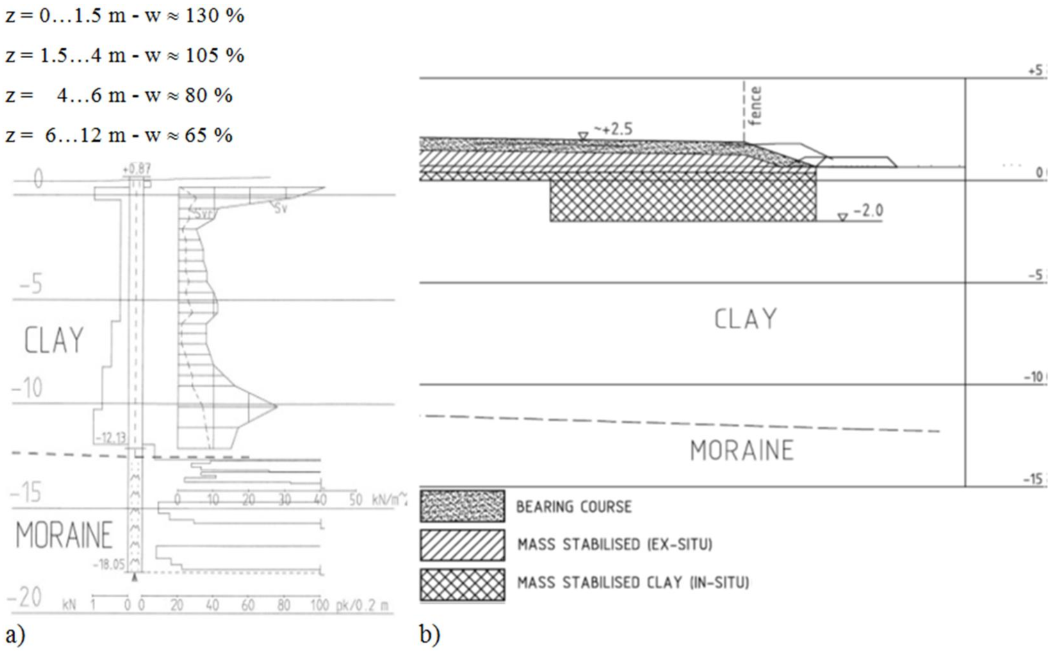

Fig. (a) Properties of subsoil in the Perkkaa Dog Park, Swedish weight sounding and vane test and water content. (b) Cross section of the mass stabilised structure (embankment + subsoil)

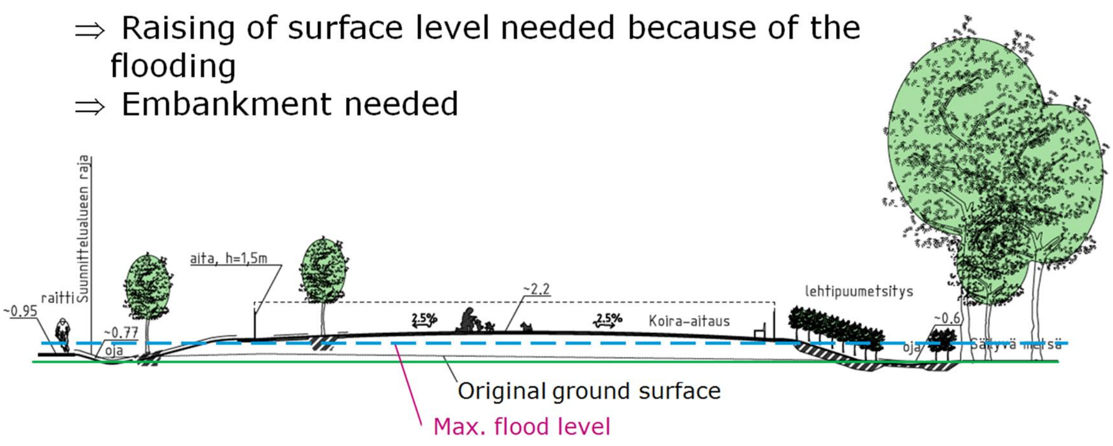

Fig. Cross section of the Dog Park.

Appendix 3 Jätkäsaari (West Harbour) calculation sheets

3a Starting point

	Alternative structures	Materials for the structure	Processes for the construction
Alt 1	Mass stabilisation with cement	Sediments and cement, filling material, non-cohesive soils	Dredging from the sea. Dredged sediments to the basins (made from local materials). Stabilisation of sediments with cement. Transportation of stabilised sediments to Hyväntoivonpuisto.
Alt 2	Mass stabilisation with fly ash and cement	Sediments, cement and fly ash, filling material, non-cohesive soils	Dredging from the sea. Dredged sediments to the basins (made from local materials). Stabilisation of sediments with cement and fly ash. Transportation of stabilised sediments to Hyväntoivonpuisto.
Alt 3	Non-cohesive soils / mass exchange?	Sediments, rock aggregate, non-cohesive soils	Dredged sediments to basins made from local material).Sediments to landfill of contaminated soils (either lightly stabilised or as such). Non-cohesive soils from Jätkäsaari to Hyväntoivonpuisto.

3b Material production

	Materials	Amount [m3]	Amount used [ton/m3]	Amount [t]	Emissions [g/ton]									Energy consumption [MJ/ton]	Depletion of natural resources [kg/ton]
					CO_2	NOx	PM	SO_2	CO	VOC	CH_4	HC	N_2O		
Alt 1	Cement [40...80 kg/m3, average 65 kg/m3]		0,065	1727	668 000	1828	103	271		113	265		1,8	2897	1429
	Sum														
Alt 2	Cement [40 kg/m3]		0,04	1063	668 000	1828	103	271		113	265		1,8	2897	1429
	Fly ash [200 kg/m3]		0,2	5314	No emissions from fly ash as it is considered as a waste that would be otherwise stored in a landfill.										
	Sum														
Alt 3	Cement [35 kg/m3]		0,035	930	668 000	1828	103	271		113	265		1,8	2897	1429
	Non-cohesive soil, park				No emissions from non-cohesive soils as it is taken from the construction site and recycled to park filling										
	Sum														

Emissions [kg/m3]									Energy consumption [MJ/m3]	Depletion of natural resources [kg/m3]	Reference
CO_2	NOx	PM	SO_2	CO	VOC	CH_4	HC	N_2O			
43	0,119	0,007	0,018	0,000	0,007	0,017	0,000	0,0001	188,31	93	[10]
43	0,119	0,007	0,018	0,000	0,007	0,017	0,000	0,0001	188	93	
27	0,07	0,00	0,01	0,00	0,00	0,01	0,00	0,0001	115,88	57	[10]
									0,00		
27	0,07	0,004	0,01	0,000	0,005	0,01	0,000	0,0001	116	57	
23	0,064	0,004	0,009	0,000	0,004	0,009	0,000	0,0001	101	50	[10]
											[17]
23	0,06	0,00	0,01	0,000	0,00	0,01	0,00	0,0001	101	50	

3c Material transportation

			total mass [tonnes/m3]	Total mass [t] (when stabilised area 26 570 m3)	vehicle	Distance [km]	Number of loads	total km*	fuel consumption** [l/km]	total fuel consumption [l]	Fuel consumption /FU
Alt 1	Cement	to site	0,065	1 727	tank truck (40t)	175	43	15 112	0,42	6 347	0,397
	Fly ash	to landfill	0,200	5 314	tank truck (40t)	25	133	6 643	0,42	2 790	0,174
	Mass stabilized sediment	to park	1,5	39 855	Dump Truck (19t)	0,5	2098	2 098	0,31	650	0,041
	SUM										
Alt 2	Cement	to site	0,04	1 063	tank truck (40t)	175	27	9 300	0,42	3 906	0,244
	Fly ash	to site	0,2	5 314	tank truck (40t)	-21	133	-5 580	0,42	-2 343	-0,146
	Mass stabilized sediment	to park	1,5	39 855	Dump Truck (19t)	0,5	2098	2 098	0,31	650	0,041
	SUM										
Alt 3	Fly ash	to landfill	1,90	5 314	tank truck (40t)	25	133	6 643	0,42	2 790	0,174
	Cement	to site	0,035	930	tank truck (40t)	175	23	8 137	0,42	3 418	0,214
	Mass stabilized sediment	to landfill	1,5	39 855	Dump Truck (19t)	25	2098	104 882	0,31	32 513	2,032
	Non-cohesive soil, park	to park	1,9	50 483	Dump Truck (19t)	20	2657	106 280	0,31	32 947	2,059
	SUM										

Total emissions (on the basis of kg/km emissions)								Energy consumption [MJ]	Non-renewable material [kg/diesel]	Total emissions kg/m3 stabilised mass, volume 26570 m3								Depletion of natural resources [kg/m3]	Energy consumption [MJ/m3]	Reference:
CO2	NOx	PM	SO2	CO	VOC + HC	CH4	N2O			CO2	NOx	PM	SO2	CO	VOC + HC	CH4	N2O			
15 656	116	1	1	3	1	0	0	226675	7362	0,6	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,3	8,5	[6], [7]
6 882	51	0,49	0,47	1,39	0,60	0,06	0,20	99638	3236	0,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,1	3,8	
1 625	12	0	0	0	0	0	0	24123	754	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,9	
24162	180	2	1,6	5	2	0,2	1	350436	11353	1	0,0	0,0001	0,0001	0,0002	0,0001	0,0000	0,0000	0,43	13,2	
9634	72	1	1	2	1	0	0	139493	4531	0,363	0,003	0,000	0,000	0,000	0,000	0,000	0,000	0,2	5,3	[6], [7]
-5781	-43	0	0	-1	-1	0	0	-83696	-2718	-0,218	-0,002	0,000	0,000	0,000	0,000	0,000	0,000	-0,1	-3,2	
1625	12	0	0	0	0	0	0	24123	754	0,061	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,0	0,9	
5478	41	0	0	1	1	0	0	79920	2567	0	0,002	0,000	0,000	0,000	0,000	0,000	0,000	0,10	3,0	
6882	51	0	0	1	1	0	0	99638	3236	0	0,002	0,000	0,000	0,000	0,000	0,000	0,000	0,1	3,8	[6], [7]
8430	63	1	1	2	1	0	0	122056	3964	0	0,002	0,000	0,000	0,000	0,000	0,000	0,000	0,1	4,6	
81231	603	7	1	20	12	1	3	1206138	37715	3	0,0227	0,0002	0,0000	0,0008	0,0005	0,0000	0,0001	1,4	45,4	
82314	611	7	1	21	12	1	4	1222220	38218	3	0,023	0,000	0,000	0,001	0,000	0,000	0,000	1,4	46,0	
178856	1328	14	2	44	26	2	7	2650052	83134	7	0,050	0,001	0,000	0,002	0,001	0,000	0,000	3,13	99,7	

3d Construction

								Emissions g/l (DATA from LIPASTO)									
		Capacity [m3/h]	Fuel consumption [l/m3]	Fuel consumption [l/h]	Working hours [h]	Total consumption [l]	Consumption [l/FU]	CO_2	NOx	PM	SO_2	CO	N_2O	CH_4	HC	Non-renewable material [kg/l/diesel]	Energy consumption [MJ/h]
Alt 1	Spreading of stabilized mass to the park	70	0,450	31,5	379,6	11959	0,450	2607	18	0,7	0,017	6,3	0,071	0,15	1,7	1,160	355
	SUM																
Alt 2	Spreading of stabilized mass to the park	70	0,450	31,5	379,6	11959	0,450	2607	18	0,7	0,017	6,3	0,071	0,15	1,7	1,160	355
	SUM																
Alt 3	Spreading of the non-cohesive soil to park	45	0,700	31,5	590,4	18604	0,7	2607	18	0,7	0,017	6,3	0,072	0,15	1,7	1,160	355
	SUM																

Emissions [kg/m3]								Non-renewable material [kg/m3/structure/diesel]	Non-renewable material [kg/m3/structure/diesel]	Energy consumption [MJ/m3]	Reference:
CO_2	NOx	PM	SO_2	CO	N_2O	CH_4	HC				
1,2	0,0081	0,0003	0,0000	0,0028	0,0000	0,0001	0,0008	0,5221	0,5221	5,1	[7]
1,2	0,008	0,000	0,000	0,003	0,0000	0,0001	0,001	0,5221	0,5221	5	
1,2	0,0081	0,0003	0,0000	0,0028	0,0000	0,0001	0,0008	0,5221	0,522	5,1	[7]
1,2	0,0081	0,0003	0,0000	0,0028	0,0000	0,0001	0,0008	0,522	0,522	5	
1,8	0,013	0,000	0,000	0,004	0,0001	0,000	0,001	0,8122	0,8122	7,9	[7]
1,8	0,013	0,000	0,000	0,004	0,0001	0,000	0,001	0,8122	0,8122	8	

3d Final results

		Emissions [kg/FU]									Energy consumption [MJ/FU]	Depletion of natural resources [kg/FU]	GWP [CO_2 kg equivalent/FU]
		CO_2	N_2O	CH_4	NOx	CO	HC	VOC	PM	SO_2			
ALT 1	Material production	43	0,0001	0,02	0,119	0,0000	0,000	0,007	0,007	0,018	188	93	44
	Material transportation	1	0,000	0,000	0,007	0,000	0,0001	0,0001	0,0001	5,85E-05	13	0,4	0,9
	Mixing and construction	1	0,0000	0,0001	0,0081	0,0028	0,0008		0,0003	0,0000	5,1	0,52	1,2
		46	0,0002	0,017	0,134	0,003	0,001	0,007	0,007	0,018	207	94	46
ALT 2	Material production	27	0,00007	0,01	0,073	0,0000	0,00	0,005	0,004	0,011	116	57	27
	Material transportation	0	0,0000	0,0000	0,0015	0,0000	0,0000	0,0000	0,0000	0,0000	3,0	0,1	0,2
	Mixing and construction	1	0,0000	0,0001	0,0081	0,0028	0,0008		0,00032	0,00001	5,1	0,52	1,2
		28	0,0001	0,011	0,083	0,003	0,001	0,005	0,004	0,011	124	58	28
ALT 3	Material production	23	0,00	0,01	0,064	0,000	0,000	0,004	0,0036	0,00949	101	50	24
	Material transportation	7	0,000	0,0001	0,050	0,002	0,001	0,0010	0,0005	0,00008	100	3	7
	Mixing and construction	3	0,0001	0,0002	0,020	0,007	0,002		0,0008	0,00002	12,5	1,29	2,9
		33	0,000	0,010	0,134	0,009	0,003	0,005	0,005	0,010	214	54	33

Jätkäsaari (West Harbour), Helsinki:

The treatment site is located in Jätkäsaari (West Harbour) where the dredged sediments are disposed in basins, mixed with binders with the mass stabilisation method and transported to utilisation sites. The volume of these basins is about 90 000 m^3. So far, these basins have been used three times during the years 2011…2015. The most applied binder has been cement. Its high price and carbon footprint have encouraged to use alternative binders. Other binder materials used include fly ash, end product of desulphurization from coal combustion, and fly ash from combustion of Estonian oil shale. The technical and environmental properties of stabilised sediments have been studied in the laboratory and in situ thoroughly. Some of the utilisation sites have been completed, some are still under construction and some will be constructed starting from 2015.

Fig. Mass stabilisation phase II, autumn 2012. Basin number 1 right (near ready-mixed concrete plant) and no. 2…4 to left.

Fig. Mass stabilisation basins in West harbour.

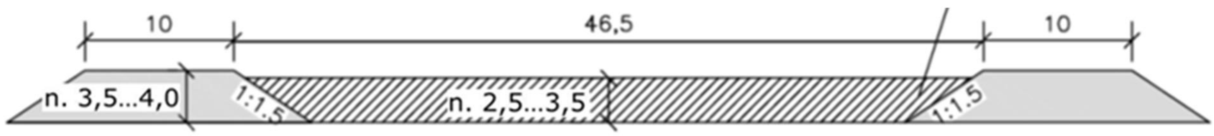

Fig. Cross section of the mass stablilisation basin surrounded with blasted rock embankments.

Fig. Sediment before stabilisation in the basin and stabilisation work ongoing (left). Mass stabilised hardened sediment in a stack. West Harbour, phase I.