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LCA/LCC REPORT

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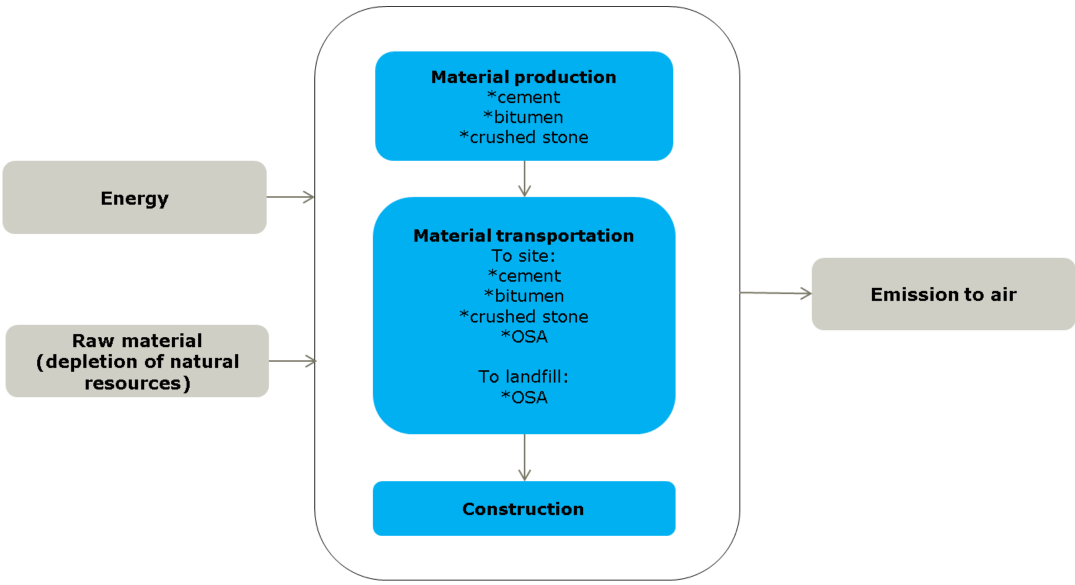

RAMBOLL

LIFE09 ENV/EE/000227

LCA/LCC REPORT

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Description	**LCA and LCC report**

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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) [7]. Coefficients mean that methane effects 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 life time [1]. An incomplete LCA like a Streamlined LCA is possible in case there is shortage of time, money, data or other necessary resources to carry out a complete one. For OSAMAT projects Verification a Streamlined LCA was carried out [14].

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 used abbreviations 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 [2].

1. INTRODUCTION

This LCA/LCC report introduces the results of the verification action carried out in the framework of the OSAMAT project. The purpose of the OSAMAT project was to verify the utilisation potential of oil shale ash in road construction applications. OSAMAT demonstrated the practical implementation of different types of civil-engineering applications in full-scale pilots based on the utilisation of oil shale ash.

The OSAMAT project has been implemented in Estonia in 2010 – 2014. OSAMAT was funded by the EU Life+ programme (LIFE09ENV/EE/000227) and the project beneficiaries Eesti Energia and Nordecon. Ramboll Estonia and Ramboll Finland have acted as subcontractors for the project.

The implementation of OSAMAT was carried out with the help of several 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 the quality control and the follow-up of the pilots were carried out.
2. Materials (Action 2): carried out with the help of geotechnical and chemical laboratory tests in order to ascertain appropriate materials based on oil shale ash (OSA) for the different pilot applications. The test results were compared with the results of the quality control and follow-up procedures. The results of this Action were used in Actions 3 and 4.
3. Applications (Action 3): ascertained that the piloting Action 4 was based on appropriate and efficient plans to produce successful applications with respect to general civil engineering criteria and that the project achieved all the information and data necessary for the verification procedure of Action 5.
4. Piloting (Action 4): demonstrated the practical implementation of civil engineering applications with materials based on oil shale ash. All quality control activities were carried out as part of Action 5.
5. Verification (Action 5): gave the project stakeholders a proof that the methods, materials and applications based on oil shale ash are environmentally safe and technically and economically feasible. Verification action used instructions from Action 3 and data from Actions 2 and 3. Action 1 provided the criteria for the verification of materials and pilot applications. The 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 target groups.
7. Management (Action 7): involved the overall management and co-ordination of the project according to the details of the project plan.

Actions from 1 to 4 all affected and fed information and data for the needs of Action 5 (Verification) and their results were described in detail in the corresponding reports:

- Material Report (Intermediate Reports of Material Actions)
- Applications, Piloting and Verification Actions Narva-Mustajõe 11/2013
- OSAMAT Mass stabilisation work instruction 07/2012
- Simuna-Vaiatu Quality Control 08/2014

Two road construction pilots were implemented in the framework of the OSAMAT project:

- Narva-Mustajõe - where part of the road was constructed with layer stabilisation (base course stabilisation) using EF PF oil shale ash with cement as a binder. Stabilisation with cement and with CYCLON oil shale ash, and complex stabilisation with bitumen and cement were studied. The complex stabilisation alternative is a theoretical study.
- Simuna-Vaiatu - where 0.9 kilometre of road was constructed using mass stabilisation method. Also layer stabilisation and complex stabilisation on top of the mass stabilisation were compared. Mass exchange was studied too, although this is a theoretical study.

In order to obtain sufficient information, it is important to create enough alternatives/scenarios for the comparison purpose. The OSAMAT LCA and LCC calculations go along with the literature information "Environmental Values and Ecoindicators of the Infra Construction" [10] where the real construction data is compared to a theoretical construction. Without this kind of comparisons it is impossible to put the results on a general scale.

The Verification Action was carried out in cooperation with Ramboll Finland, Ramboll Estonia and Eesti Energy. The activities 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 concentrated on the strength and durability properties and environmental tests.

The report starts with Chapter 2, Methodology and Assumptions in order to describe the methodology of different procedures of the Action (LCA, LCC and Follow-up). Chapters 3 and 4 present detailed reports on the results of the two pilots' LCA, LCC, quality control and follow-up investigations. Chapter 7 gives the conclusions and the summary of the verification including the assessment of the project findings, as well as the recommendations based on the former. The report includes various annexes, e.g. the copies of excel sheet for the LCA and LCC calculations.

2. METHODOLOGY AND ASSUMPTION

2.1 Life cycle analysis: 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 this case are specific road structures. The LCA is carried out according to the principles of available standard procedures EN ISO 14040:2006. The model for the LCC is the available standard procedure described in EN ISO-15686-5:2008. The LCA and LCC studies were carried out as simplified versions or as Streamlined LCA and LCC, which is an acceptable procedure when there is a shortage of time, money and resources for completing such studies.

The aim of the LCA study was to determine and compare the potential environmental impacts of different alternatives of constructing a specific road structure. Primary attention in OSAMAT was paid to the depletion of natural resources and the global warming potential. The consumption of energy in 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 was to compare the relevant investment costs of the alternatives and to show that the use of oil shale ash can be cost-effective.

2.1.1 The goal definition and scope of the study

The intended application is a durable road construction where oil shale ash is utilised in different stabilisation applications, thus savings on the use of virgin rock materials are achieved. The main purpose is to demonstrate that the pilot alternatives are the environmentally and financially feasible applications where oil shale ash can be utilised. The target groups benefiting from the results are civil engineering companies, energy sector and municipalities.

The reason to carry out the LCA and LCC study is the necessity to verify that the pilot alternatives are environmentally sound and economically competitive in comparison with the conventional alternatives. The LCA and LCC are executed using the results from the laboratory tests, and quality control and follow-up studies at the pilot construction sites. The product system for the LCI and LCC calculations has been divided into the following processes:

- material production
- material transportation
- construction

Figure 1 presents the product system of the pilots. The figure is a principle presentation of the processes included in the life cycle assessment. The processes that are excluded from the calculations are justified in the next chapter (2.1.2 Assumptions and restrictions).

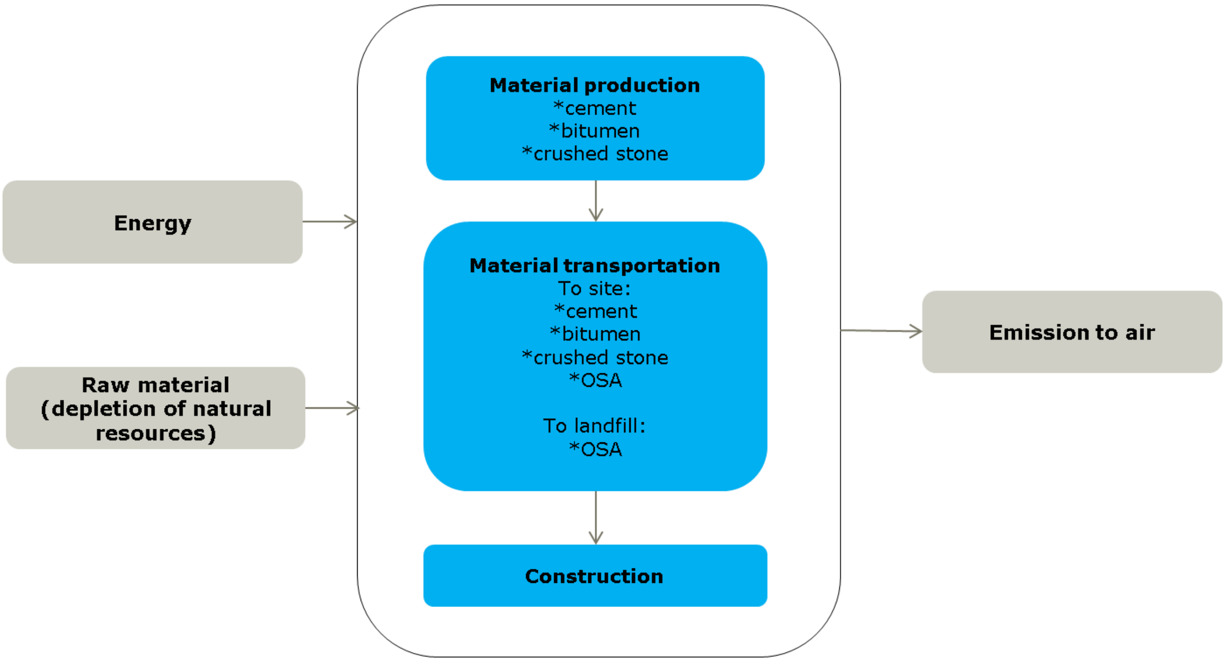

Figure 1. The product system of Narva-Mustajõe and Simuna-Vaiatu pilots.

The following environmental impact categories were chosen for the assessment of the alternatives during the chosen life cycle period: global warming potential and depletion of natural resources. The two categories were chosen because these are the major impacts from the infrastructure construction (mainly because of the energy consumption) and because of the availability of general data about the relevant discharges from the individual processes. Cement is one of the construction materials requiring relatively large amounts of natural resources and energy for its production. In this project, oil shale ash - a by-product from energy production - is used as a substituent for cement in order to demonstrate the possibility to decrease the total global warming potential of stabilisation and use of natural resources.

The Functional Unit (FU) for the LCA and LCC calculations is 1000 meters of a road structure.

The construction phase is the first phase of the life cycle of the road. After construction, the following phase is the usage phase, i.e. the operation and maintenance of the road which are determined by the desired road standard, the desired density of traffic, etc. Usually, there is no final end for the road. Instead, after building the road is used for a long period and during its maintenance the materials used in the road may have to be replaced with new materials (figure 2). In some point, old roads that are given a new routing are often left without being demolished [3].

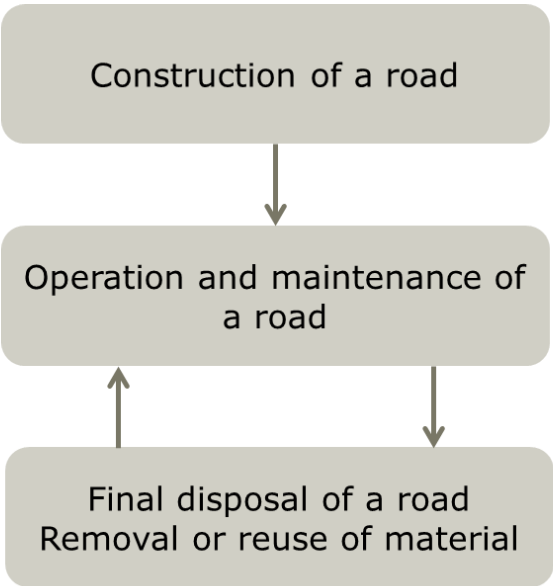

Figure 2. An overview of a life cycle of the road [3].

In the case of both pilots studied in the project and presented in this report, the road already existed and only reconstruction was made to a part of the road.

2.1.2 Assumptions and restrictions

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 about the environmental, technical and economical characteristics of the products. This will be emphasised because of the following assumptions for the studies:

1. Emissions from the production of the oil shale ash are assumed to be zero as the oil shale ash is a secondary product from the energy production when the oil shale is used as a fuel in the power plant. If the oil shale ash is not utilised, it is transported to a landfill and treated as a waste, and the energy producer pays the landfilling costs and the waste taxes. According to the earlier life cycle assessment of oil shale electricity, the environmental load of its production is assumed to be allocated to the main product(s) of the production (e.g. energy) [4]. Also literature sources, such as "Life cycle methods: current use, best practices and development needs" [14] state that there is no allocation need for by-products when the by-product is replacing the use of virgin materials. Other literature reference "Environmental Values and Ecoindicators of the Infra Construction" [10] claims that the material intensity of the recycled materials/by-products is remarkably smaller than the intensities of virgin materials and that the material input can be reduced, for instance, by using recovered materials.
2. When oil shale ash is used in the road construction the amount of transportation to landfill decreases. In the LCA calculations, the diminished transportations to the landfill are taken into account as the distance to the landfill (5 km) is smaller than the distance to the construction site. In addition to the transportation costs, the landfilling costs are taken into consideration in the LCC calculations.
3. Emissions from mining waste (in the case of Narva-Mustajõe) are assumed to include only the crushing of larger mining waste rocks into suitable size for construction use. Similarly as in the case of oil shale ash, mining waste is generated as a by-product of the mining process and crushing of rocks is carried out only to facilitate the use of mining waste. There was no need for calculating transportation to the landfill as either the mining waste is left in-situ where it is quarried or it is utilised in other projects.
4. The design works of the projects are not included in the calculations. The design work is executed in the office as desk work. It is not possible to allocate any energy or space consumption to an individual project of a relatively short duration.
5. The laboratory work for OSAMAT 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.
6. The production of the factories, production plants and landfills (concerning, e.g. productions of fuel, materials, transport vehicles and vehicles for works) are not included as these have not been made for the needs of this or any other individual project.
7. The production of the vehicles or machines used in the transportation and construction has not been included in the product system for the same reason as above.
8. Production and transportation of fuels are not included for the same reason as above.
9. The transportation of OSA to the landfill takes place through hydro transportation, but as there is no data for thus type of transportation, in order to simplify the calculations and to obtain as reliable data as possible, the transportations to the landfill are assumed to happen by truck.

2.1.3 **Available data**

The origin of the data used in the calculations and the basis for the calculations are presented in the following paragraphs and tables.

Table 1. The data of diesel used in the LCA analysis [5], [6].

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

Abiotic material of diesel is calculated on the basis of values from Table 1 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

This numeric value is used for the calculation of depletion of natural resources in processes where diesel fuel is consumed.

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

Table 2. Coefficients used for calculating global warming potential [7].

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 as follows:

[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 for used vehicles are calculated on the basis of the LIPASTO database developed by the Technical Research Centre of Finland [5]. Figures are defined for a typical machine in each working machine category in Finland (in terms of power use and age of fleet). The emissions are calculated as following:

[fuel consumption, l] x [emission factor, g/l].

Energy consumptions in different stages are calculated on the basis of the vehicle energy consumption provided by the LIPASTO database [5], or by the energy consumption figures provided f.eg. by the cement producer/material data. The energy consumptions are calculated with following equations:

[MJ/km] x [total km/FU] = MJ/FU (vehicles)
[MJ/h] x [h/FU] = MJ/FU (vehicles)
[MJ/ton] x [tonnes/FU] = MJ/FU (materials)

Depletions of natural resources in different stages are calculated on the basis of the need on natural aggregates/materials provided by the data sources or by fuel consumption provided by LIPASTO database [5]. The depletions of natural resources are calculated with following equations:
[g/ton] x [ton/FU] = kg/FU (materials)
[kg/l] x [l/FU] = kg/FU (vehicles)
The word 'crushed stone' is used as a synonym for 'crushed rock'.

Table 3. Emission data for used vehicles [5].

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 calculation sheet models in Excel software have been created by Aino Maijala.

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

There is no emission data of methane (CH_4) and nitrous oxide (N_2O) from cement production available. Methane and nitrous oxide are part of the global warming potential calculation. Although the information is lacking, the emissions of CH_4 and N_2O surely are present. The data used for depletion of natural resources in cement production includes the following materials (originating from the environmental report [8]): limestone, limestone fine fraction, clay, gypsum, coal and oil shale ash. The sum of previous material is divided with the sum of clinker and cement production and the resulting number is used for the calculation of depletion of natural resources for cement production (1151 kg/ton). According to environmental report of Kunda cement, the direct energy use is 5,78 GJ/t for clinker and indirect for cement 124,1 kWh/t., which are converted to mega joules and results in 5780 MJ + 44,64 MJ = 5825 MJ / ton [8].

The LCA's and LCC's are calculated according to the following sections:

1. Materials
2. Material transportation
3. Construction

4. Repairing and maintenance the structures (qualitative assessment)
5. Sum of the previous

2.2 Follow-up studies for piloting sites

Technical follow-up studies and their results have been reported in the following reports:

- Applications, Piloting and Verification Actions Narva-Mustajõe Pilot report (03/2013)
- Simuna-Vaiatu quality control 08/2014

The environmental follow-up studies are as follows:

- The leaching tests with diffusion (NEN 7347) or two stage batch tests (DIN-EN-12457-3) and the total content tests by leaching the substances from the material (DIN-EN 13656 or DIN-EN 13657 and by analysing the contents of harmful substances by standard methods (ICP-MS, ICP-AES or AAS).
    - Tests for samples that represent the structure to be constructed
- Analysing (at least) the same components as from the water samples. (These are tested according to the Finnish legislation on the utilisation of recycled materials (Finnish Decree VNa 403/2009) Sb, As, Ba, Cd, Cr, Cu, Hg, Pb, Mo, Ni, Se, Zn, V, SO_4^{2-}, F^-, Cl^-)

2.2.1 Narva-Mustajõe

The environmental procedures were the same before and after the piloting. Appropriate soil and groundwater samples were taken close to the piloting site at spots and distances which could have been affected by the oil shale ash. The spots were determined on the basis of soil and hydrological conditions of the site. Samples were taken also from the pilot construction area at a depth which was directly below the structural course containing oil shale ash material. A longer-term environmental follow-up activities have been carried out once a year, always at the same time of the year (at least for the whole project period).

The condition of vegetation was investigated in June in 2011, 2012 and 2013. The purpose of the investigation was to find out if any vegetation changes have occurred after stabilisation works.

2.2.2 Simuna-Vaiatu

In Simuna-Vaiatu, two oil shale ash qualities and peat mix (made of 5 different peat samples) were tested for environmental properties (leaching test and total contents) to obtain background information. Also mixtures with peat mix and oil shale were tested.

3. LCA

3.1 LCA NARVA-MUSTAJÕE

3.1.1 Structural alternatives

The Narva-Mustajõe pilot was about constructing a part from the existing road with the layer stabilisation method. In total, four different alternative structures were studied in the LCA. Three of the structure alternatives were layer stabilisation alternatives using cement and/or fly ash as binders. Mining waste was used in the layer stabilisation in addition of the old road base course to get a good body for the structure layer. The fourth alternative was a traditional alternative for layer stabilisation, which according to the contractor, is a cold in place complex recycling. The complex recycling is similar to the layer stabilisation but it uses new aggregate, cement and bitumen in stabilisation instead of the old road paving and dry binders. The studied alternatives include:

- Alt 1: layer stabilisation using a binder mixture of cement and oil shale ash (EF PF oil shale ash)
- Alt 2: layer stabilisation using a binder mixture of cement and oil shale ash as a binder (CYCLON oil shale ash)
- Alt 3: layer stabilisation using cement as a binder
- Alt 4: complex recycling using a mixture of cement and bitumen as a binder

In the material tests starting in 2010 also OSA CFB ash was tested. The strength and freeze-thaw results were similar with EF PF ash. Calculations with the selected OSA qualities (EF PF and CYCL) are giving strongly sufficient information also regarding the third OSA quality (OSA CFB).

The processes of different alternatives are presented in Table 4.

Table 4. The process descriptions of different alternatives (italic font describes the work stage that is equal in all alternatives and is not included in the calculations).

	Structure	Materials	Processes for the construction
Alt 1	Old road and mining waste stabilised with OSA EF PF and composite cement	Mining waste, oil shale ash and composite cement	*Grinding of old road*, mixing of osa and cement, spreading of the mining waste and ground road material on the road, wetting the material, spreading the binders, mixing the whole structure and compacting the structure.
Alt 2	Old road and mining waste stabilised with OSA CYCLON and composite cement	Mining waste, oil shale ash and composite cement	*Grinding of old road*, mixing of osa and cement, spreading of the mining waste and ground road material on the road, wetting the material, spreading the binders, mixing the whole structure and compacting the structure.
Alt 3	Old road and mining waste stabilised with composite cement	Mining waste and composite cement	*Grinding of old road*, spreading of the mining waste and ground road material on the road, wetting the material, spreading the binders, mixing the whole structure and compacting the structure.
Alt 4	Cold in place complex recycling	Cement, bitumen, crushed stone	*Grinding of old road*, spreading of crushed stone, wetting the material, spreading the binders, mixing the whole structure and compacting the structure.

The structure alternatives used in the LCA and LCC calculations are presented in Figure 3.

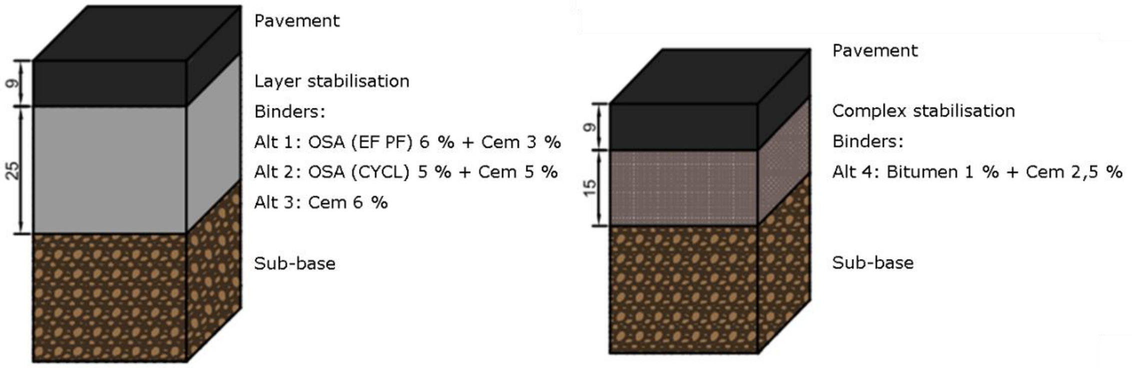

Figure 3. LCA structure alternatives for the Narva-Mustajõe pilot.

3.1.2 Inventory

The processes that are included in the life cycle inventory (LCI) are material production, transportation and construction. The maintenance of the road is studied qualitatively in Chapter 3.1.2.4. All the LCI calculations from each inventory stage are presented in Appendices 1a-e. The inventory is based on the calculation for the road of 9 meter width and width of 9.5 meter layer stabilisation. The length of the road is 1000 m.

3.1.2.1 Material production

The types and amounts of materials used in the alternative structures are presented in Table 5. In Appendix 1b, the calculation sheet is presented.

Table 5. The materials used in the different structural alternatives in Narva-Mustajõe.

	Material	**Amount used [ton/FU]**
Alt 1	Composite cement	139
	Oil shale ash EF PF	278
	Mining waste	3002
	SUM	4877
Alt 2	Composite cement	232
	Oil shale ash CYCLON	232
	Mining waste	3002
	SUM	4923
Alt 3	Composite cement	278
	Mining waste	3002
	SUM	4738
Alt 4	Composite cement	69,5
	Bitumen	27,8
	Crushed stone	6185
	SUM	7740

Table 6 shows that in the material production stage, Alt4 causes the biggest depletion of natural resources as the road is constructed with new crushed rock. The number for natural depletion is 1010 kg/kg for 1 tonne of crushed stone [10] and this result in clearly higher use of natural resources in Alt4. The amounts of materials are high in earth construction when new materials are transported to the site. See further appendix 1a-1e.

Alt3 generates more global warming potential than other alternatives. This is caused by the use of cement.

Table 6. The environmental impacts from the material production stage.

Material production	Use of natural resources [kg/FU]	Global warming potential [kg CO_2 eqv / FU]
Alt 1	160 292	87 749
Alt 2	266 904	145 513
Alt 3	320 209	174 394
Alt 4	6 356 731	62 344

3.1.2.2 Transportation

The vehicles used in transportation, transportation distances and the fuel consumptions are presented in Table 7. Information on distances has been provided by Ramboll Estonia. The negative mark in oil shale ash transportation in the alternatives Alt1 and Alt2 is due to the compensation when OSA is not transported to the landfill in the distance of 5 km. Fuel consumption and emissions to air are calculated as an average of the two-way trip of a loaded and empty vehicle. The fuel consumption [l/km] and emissions to air [g/km] are based on the Lipasto database of traffic emissions [5]. As there was no data for 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.

Table 7. The vehicles used in transportation, transportation distances and fuel consumption per functional unit.

Alternative	Material	Destination	Total mass [tonnes/FU]	Vehicle	total fuel consumption [l/ FU]
Alt 1	Composite cement	to site	139	tank truck (40t)	292
	Oil shale ash	to site	278	tank truck (40t)	50
	(Oil shale ash)	(to landfill)	278	tank truck (40t)	-29
	Mining waste	to site	3 002	truck (19 t)	7 543
	SUM		**3 763**		**7 855**
Alt 2	Composite cement	to site	232	tank truck (40t)	486
	Oil shale ash	to site	232	tank truck (40t)	41
	(Oil shale ash)	(to landfill)	232	tank truck (40t)	-24
	Mining waste	to site	3 002	truck (19 t)	7 543
	SUM		**3 763**		**8 046**
Alt 3	Composite cement	to site	278	tank truck (40t)	584
	Mining waste	to site	3 002	truck (19 t)	7 543
	Oil shale ash	to landfill	278	tank truck (40t)	29
	SUM		**3 624**		**8 156**
Alt 4	Composite cement	to site	69	tank truck (40t)	146
	Ground road structure	to final storage	1 642	truck (19 t)	536
	Bitumen	to site	28	tank truck (40t)	26
	Crushed stone	to site	6 185	truck (19 t)	15 539
	Oil shale ash	to landfill	278	tank truck (40t)	29
	SUM		**8 268**		**16 276**

The result of the inventory from the transportation stage is shown in Table 8. Alt4 uses more natural resources and has more global warming potential than the other alternatives. In Alt4, the old ground road structure is transported to a temporary storage in the distance of 5 km, and the amount of required natural aggregates for construction is big, resulting in increased transportation kilometres thus influencing the total fuel consumption.

Table 8. The environmental impacts from the material transportation stage.

Transportation	Use of natural resources [kg/FU]	Global warming potential [kg CO_2 eqv / FU]
Alt 1	9 112	19 866
Alt 2	9 334	20 342
Alt 3	9 461	20 614
Alt 4	18 880	41 181

3.1.2.3 Construction

The construction stages and vehicles used in construction and fuel consumptions are presented in Table 9. As the Alt1 and Alt2 apply two different binders and the binders are spread one at a time in layer stabilisation, this results in some higher fuel consumption than in Alt3 where only cement is used. In total, Alt4 consumes more fuel than the other alternatives.

The work stages where the road grader and roller are used are not included in the calculations as they are assumed to be equal in all the alternatives.

Table 9. The vehicles used in construction, capacities and fuel consumption per functional unit.

		Fuel consumption [l/h]	Fuel consumption [l/FU]
Alt 1	**Base coarse stabilisation**		
	*Spreading of mining waste with tractor	16,7	491
	*Spreading of cement with tractor (spreading vessel attached)	18,7	15,0
	*Spreading of OSA with tractor (spreading vessel attached)	18,7	15,0
	SUM		**520**
Alt 2	**Base coarse stabilisation**		
	*Spreading of mining waste with tractor	16,7	491
	*Spreading of cement with tractor (spreading vessel attached)	18,7	15,0
	*Spreading of OSA with tractor (spreading vessel attached)	18,7	15,0
	SUM		**520**
Alt 3	**Base coarse stabilisation**		
	*Spreading of mining waste with tractor	16,7	491
	*Spreading of cement with tractor (spreading vessel attached)	18,7	15,0
	SUM		**505**
Alt 4	Excavating the old ground road structure	31,5	1206
	Spreading of crushed stone	16,7	1093
	*Spreading of cement with tractor (spreading vessel attached)	18,7	15,0
	SUM		**2314**

The results of the inventory from the mixing and construction stage are shown in Table 10. Alt4 depletes more natural resources and results in the biggest GWP value because of excavating the old structure and spreading of crushed stone. There are no significant differences in the environmental impact results between Alt1…Alt3 in the construction stage.

Table 10. The environmental impacts from the construction stage.

Mixing and construction	Use of natural resources [kg/FU]	Global warming potential [kg CO_2 eqv/FU]
Alt 1	740	1 689
Alt 2	740	1 676
Alt 3	723	1 649
Alt 4	2 684	6 111

3.1.2.4 Maintenance and repair, qualitative assessment

The maintenance procedures are the same for all the alternatives, only the timing of maintenance and repairing differs. The repair methods are as follows:

- U-REP: only the worn-off tire track areas of the road surface are paved for a width of about 1 m and
- REP: includes grinding the old pavement layer, transporting it to a storage place and constructing a new layer of 9 cm thick asphalt.

In all the alternatives the U-REP method was assumed to occur 5 times and the REP method 4 times in 40 year of the life cycle. As the repair procedures are equal in all the alternatives, the difference between the alternatives comes mainly from the general overhaul (renewing the structure). In practice, this means the sum from the stages of material production, transportation and construction and therefore the calculation has not been performed.

3.1.3 **Results: Environmental impacts**

3.1.3.1 Global warming potential

The results of calculating the global warming potential (GWP) is shown in Table 11 and Figure 4. Alt3 has the highest GWP which results from the highest use of cement in stabilisation. Alt1 has the lowest value of GWP, although Alt4 has the same magnitude in the GWP result.

Energy consumption itself is not an environmental impact but it produces airborne emissions which have a negative effect on the environment and the impact can be seen in the GWP results. Alt3 has the biggest energy consumption, resulting mainly from the production of cement and the amount of cement. In Figure 4, the global warming potential and energy consumption are presented in the same picture. The energy consumption results are presented in Appendix 1e.

Table 11. Global warming potential in different alternatives.

Narva-Mustajoe Global warming potential [CO_2 kg equivalent/FU]				
Alternative	**Material production**	**Material transportation**	**Mixing and construction**	**Total**
Alt 1	87 749	19 866	1 689	**109 304**
Alt 2	145 513	20 342	1 676	**167 531**
Alt 3	174 394	20 614	1 649	**196 658**
Alt 4	62 344	41 181	6 111	**109 636**

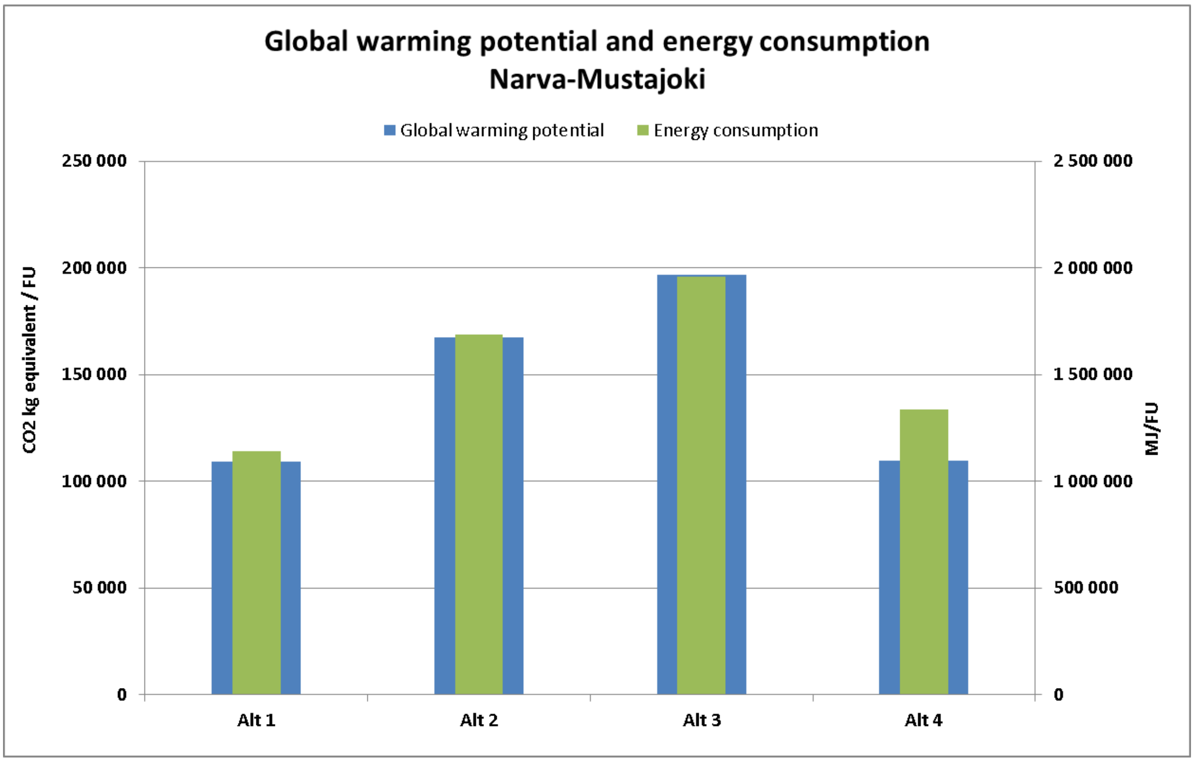

Figure 4. Global warming potential and energy consumption in different alternatives.

3.1.3.2 Depletion of natural resources

The results of calculating depletion of natural resources are shown in Table 12 and Figure 5. Depletion of natural resources is highest in Alt4 as the structure alternative uses new natural aggregate in the construction (no new natural aggregates in other alternatives). Also, the cement production consumes a lot of natural resources when the raw material of cement is quarried and this shows in the results of Alt1-3 where the amount of cement is lowest in Alt1 and highest in Alt3. Material transportation uses natural resources, too, as diesel fuel is consumed in the transportation process and the amount of natural resources per one litre of diesel is 1.16 g/l [6]. As a result, long transportation distances the amount of consumed fuel is high and thus the use of natural resources shows increased values. Depletion of natural resources is lowest in Alt 1 where the cement is partly replaced with the oil shale ash and thus the need of natural resources is lower.

Table 12. Depletion of natural resources in different structure alternatives.

Narva-Mustajoe Depletion of natural resources [kg/FU]				
Alternative	**Material production**	**Material transportation**	**Mixing and construction**	**Total**
Alt 1	160 292	9 112	740	**170 144**
Alt 2	266 904	9 334	740	**276 978**
Alt 3	320 209	9 461	723	**330 393**
Alt 4	6 356 731	18 880	2 684	**6 378 296**

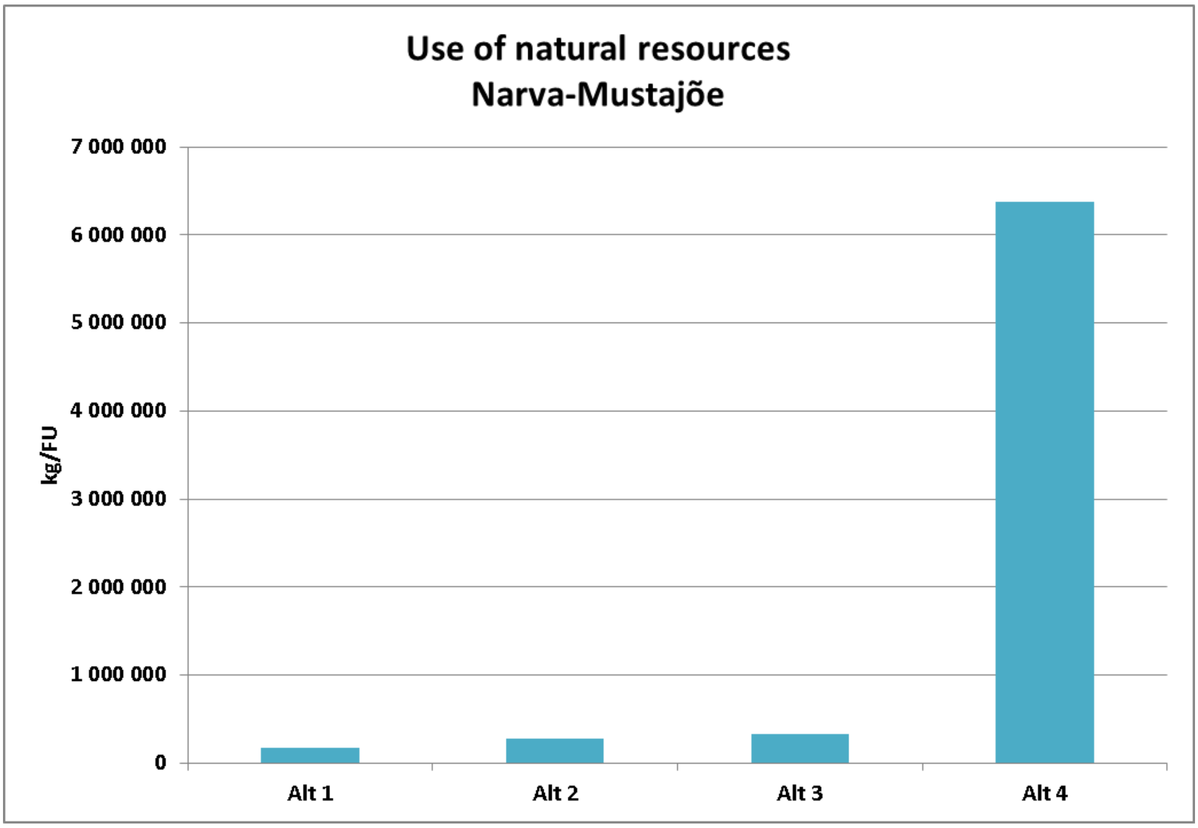

Figure 5. Depletion of natural resources in different structure alternatives.

3.2 LCA SIMUNA-VAIATU

3.2.1 Structural alternatives

In the Simuna-Vaiatu pilot, part of the road Mt no 17192 was constructed with the mass stabilisation method. The length of the reconstructed road is 0.9 km. In total, four different alternative structures were studied in the LCA. All alternatives include the application of various types of stabilisation: mass stabilisation, layer stabilisation or complex stabilisation. The alternatives are (presented also in Figure 6):

- Alt 1: The bottom of the construction is mass stabilised with OSA (EF CFB) and cement and the top of the construction is layer stabilised with OSA (EF CFB)
- Alt 2: The bottom of the construction is mass stabilised with OSA and cement and the top of the construction is complex stabilised with bitumen and cement
- Alt 3: The bottom of the construction is mass stabilised with cement and the top of the construction is complex stabilised with bitumen and cement
- Alt 4: At the bottom of the construction mass exchanged is applied: peat is replaced with natural aggregates and the top of the construction is complex stabilised with bitumen and cement

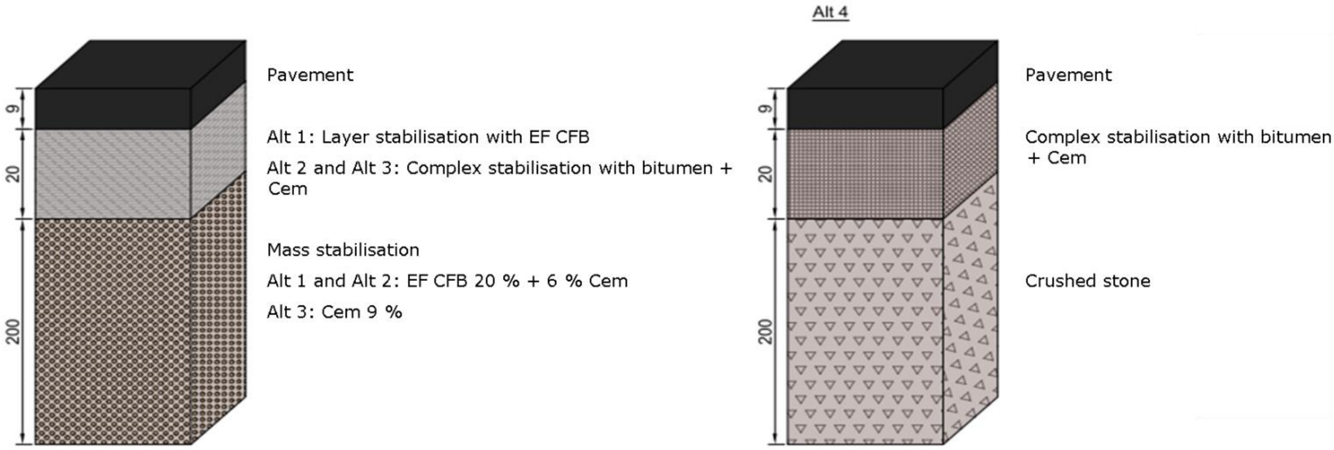

Figure 6. LCA structure alternatives for Simuna-Vaiatu pilot. The figure is out of scale.

The peat in Simuna-Vaiatu had the average water content of 550 % and the average density of 1100 kg/m^3. The water content is not abnormally high for peats but the water amount is so high that it needed a big amount of binder for mass stabilisation.

3.2.2 **Inventory**

The processes that are included in the inventory are material production, transportation and construction. The maintenance of the road is studied qualitatively in Chapter 3.2.2.4. The processes are described also in product systems in Figure 1. All LCI calculations from each inventory stage are presented in Appendices 2a-e.

3.2.2.1 Material production

The types and amounts of materials used in the alternative structures are presented in Table 13.

Table 13. The materials used in the different structural alternatives in Simuna-Vaiatu.

	Materials	Amount used [tonnes/FU]
Alt 1	**Layer stabilisation**	
	OSA EF CFB	323
	Sand for load material	13 248
	Mass stabilisation	
	OSA EF CFB	7 176
	Composite cement	2 153
	SUM	**32 670**
Alt 2	**Complex stabilisation**	
	Bitumen	36
	Composite cement	90
	Sand for load material	13 248
	Mass stabilisation	
	OSA EF CFB	7 176
	Composite cement	2 153
	SUM	**32 473**
Alt 3	**Complex stabilisation**	
	Bitumen	36
	Composite cement	90
	Sand for load material	13 248
	Mass stabilisation	
	Composite cement	3 229
	SUM	**23 061**
Alt 4	Gravel and medium sand	8 280
	Rock material 2 m	40 480
	Complex stabilisation	
	Bitumen	36
	Composite cement	90
	SUM	**48 886**

In Table 14, the inventory results from the material production stage are presented. The alternatives Alt1 and Alt2 are quite equal within the studied impact categories. The use of natural resources is remarkably higher in Alt4 as it is the mass exchange alternative. The global warming potential is highest in Alt3 resulting from the use of cement (9 %) in mass stabilisation. Sensitivity analysis where the use of cement with different amounts was studied and the results are presented in chapter 3.2.3.4.

Table 14. The environmental impacts from the material production stage.

Material production	Use of natural resources [kg/FU]	Global warming potential [kg CO_2 eqv / FU]
Alt 1	15 858 353	1 366 801
Alt 2	16 000 886	1 432 681
Alt 3	17 239 823	2 103 954
Alt 4	49 390 134	155 150

3.2.2.2 Transportation

Types of vehicles used in transportation, transportation distances and fuel consumptions are presented in Table 15. The distances are provided by Ramboll Estonia. The negative mark in oil shale ash transportation in the alternatives Alt1 and Alt2 is due to the compensation when OSA is not transported to the landfill in 5 km distance. Fuel consumptions and emissions to air are calculated as an average of the two-way trip of a loaded and empty vehicle. Fuel consumptions [l/km] and emissions to air [g/km] are based on the Lipasto database of traffic emissions [5]. As there was no data for tank truck available, the data used in the tank truck transportation calculations is based on the data of lorry trailer with the same load capacity of 40 tons.

Table 15. The vehicles used in transportation, transportation distances and fuel consumption per functional unit.

	Material	Destination	Total mass [ton/FU]	Vehicle	Distance [km]	Total fuel consumption [l/FU]
Alt 1	**Layer stabilisation**					
	OSA EF CFB	to site	323	tank truck (40t)	155	1051
	(OSA EF CFB)	(to landfill)	323	tank truck (40t)	-5	-34
	Load material, sand, first 80 cm	to site	13248	truck (19 t)	30	12969
	Load material, sand, 30 cm excavated off	to temporary storage	4968	truck (19 t)	3	486
	Water					
	Mass stabilisation					
	OSA EF CFB	to site	7176	tank truck (40t)	155	23358
	(OSA EF CFB)	(to landfill)	7176	tank truck (40t)	-5	-753
	Composite cement	to site	2153	tank truck (40t)	80	3617
	Water	to site	2896	tank truck (40t)	3	182
	SUM					**40 876**
Alt 2	**Complex stabilisation**					
	Bitumen	to site	36	tank truck (40t)	135	102
	Composite cement	to site	90	tank truck (40t)	70	132
	Load material, sand, first 80 cm	to site	13248	truck (19 t)	30	12969
	Load material, sand, 30 cm excavated off	to temporary storage	4968	truck (19 t)	3	486
	Mass stabilisation					
	OSA EF CFB	to site	7176	tank truck (40t)	155	23358
	(OSA EF CFB)	(to landfill)	7176	tank truck (40t)	-5	-753
	Composite cement	to site	2153	tank truck (40t)	70	3165
	Water	to site	2799	tank truck (40t)	3	176
	SUM					**39 634**
Alt 3	**Complex stabilisation**					
	Bitumen	to site	36	tank truck (40t)	135	102
	Composite cement	to site	89,7	tank truck (40t)	70	132
	Load material, sand, first 80 cm	to site	13248	truck (19 t)	30	12969
	Load material, sand, 30 cm excavated off	to temporary storage	4968	truck (19 t)	3	486
	Mass stabilisation					
	Composite cement	to site	3229	tank truck (40t)	80	5425
	OSA	to landfill	3229	tank truck (40t)	5	339
	Water	to site	969	tank truck (40t)	3	61
	SUM					**19 514**
Alt 4	Peat	off site	20240	truck (19 t)	3	1981
	Gravel and medium sand	to site	8280	truck (19 t)	30	8106
	OSA	to landfill	7176	tank truck (40t)	5	1586
	Complex stabilisation					
	*Bitumen	to site	35,88	tank truck (40t)	135	102
	*Composite cement	to site	89,7	tank truck (40t)	70	132
	*Stone material	to site	40480	truck (19 t)	30	39628
	SUM					**51 535**

The inventory results from the transportation inventory stage are presented in Table 16. In transportation stage, Alt3 depletes the lowest amount of natural resources and it also has the lowest global warming potential. In the Simuna-Vaiatu case, the transportation distance of OSA is high, 155 km to the construction site from the power plant and in Alt3 OSA was not used.

Table 16. The environmental impacts from the material transportation stage.

Transportation	Use of natural resources [kg/FU]	Global warming potential [kg CO_2 eqv / FU]
Alt 1	47 416	102 300
Alt 2	45 945	99 209
Alt 3	22 636	49 132
Alt 4	59 780	130 345

3.2.2.3 Construction

The construction stages and vehicles used in construction and fuel consumptions are presented in Table 17.

Table 17. The construction stages, capacities and fuel consumption per functional unit.

		Fuel consumption [l/h]	Fuel consumption [l/FU]
	Layer stabilisation		
	*Road grader	44	35
	*Spreading of OSA with tractor (spreading vessel attached)	19	15
	*The rotary mixer used in stabilisation work	44	35
	*Road grader	44	35
	Spreading of gravel and medium sand with excavator	31,5	5 100
	Excavating of gravel and medium sand with excavator	31,5	1 913
	Mass stabilisation	30	4 600
	*Mass stabilisation of peat with cement + OSA (binders mixed)'		
	*Roller		
	SUM		**11 735**
Alt 2	**Complex stabilisation**		
	*Bitumen	27,2	22
	*Spreading of cement with tractor (spreading vessel attached)	19	15
	Spreading of gravel and medium sand with excavator	31,5	5 100
	Excavating of gravel and medium sand with excavator	31,5	1 913
	Mass stabilisation	30	4 600
	*Mass stabilisation of peat with cement + OSA (binders mixed)'		
	*Roller		
	SUM		**11 650**
Alt 3	**Complex stabilisation**		
	*Bitumen	27,2	22
	*Spreading of cement with tractor (spreading vessel attached)	19	15
	Spreading of gravel and medium sand with excavator	31,5	5 100
	Excavating of gravel and medium sand with excavator	31,5	1 913
	Mass stabilisation	30	4 600
	*Mass stabilisation of peat with cement		
	*Roller		
	SUM		**11 650**
Alt 4	Excavating the peat layer	31,5	4 057
	Complex stabilisation		
	*Bitumen	27,2	22
	*Spreading of cement with tractor (spreading vessel attached)	19	15
	*Spreading of crushed stone 2 m	31,5	12 751
	SUM		**16 845**

In Table 18, the inventory results from the construction stage are presented. Global warming potential is lowest and of the same magnitude between Alt1…Alt3 and highest in Alt4. The use of natural resources is highest in Alt4.

Table 18. The environmental impacts from the construction stage.

Mixing and construction	Use of natural resources [kg/FU]	Global warming potential [kg CO_2 eqv / FU]
Alt 1	13 612	29 959
Alt 2	13 514	29 736
Alt 3	13 514	29 736
Alt 4	19 541	44 343

3.2.2.4 Maintenance and repair, qualitative assessment

Maintenance procedures are the same for all alternatives, only the timing of maintenance and repairing differs. The repair methods are as follows:

- U-REP: only the worn off tire track areas of the road surface are paved for a width of about 1 m and
- REP: includes grinding the old pavement layer, transporting it to storage and constructing a new layer of 9 cm thick asphalt.

In all alternatives, the U-REP method was assumed to occur 5 times and the REP method 4 times in 40 years of a life cycle. As the repair procedures are equal in all alternatives, the difference between the alternatives results mainly from the general overhaul (renewing the structure). In practice, this means the sum from the stages of material production, transportation and construction and therefore the calculation has not been performed.

3.2.3 **Results: Environmental impacts**

3.2.3.1 Global warming potential

Table 19 shows the results of calculating the global warming potential. Alt4 has the lowest and Alt3 has the highest GWP. The high figures of GWP with mass stabilisation alternatives are due to the use of cement that is also used in the top layer for complex stabilisation. The results for Alt1 and Alt2 are equal and in the same magnitude.

Energy consumption itself is not an environmental impact but it produces airborne emissions which affect the environment and the impact can be seen in the GWP results (Figure 7). The energy consumption results are presented in Appendix 2e.

Table 19. Global warming potential in different alternatives.

Simuna-Vaiatu Global warming potential [CO_2 kg equivalent/FU]				
Alternative	**Material production**	**Material transportation**	**Mixing and construction**	**Total**
Alt 1	1 366 801	102 300	29 959	**1 499 059**
Alt 2	1 432 681	99 209	29 736	**1 561 626**
Alt 3	2 103 954	49 132	29 736	**2 182 822**
Alt 4	155 150	130 345	44 343	**329 838**

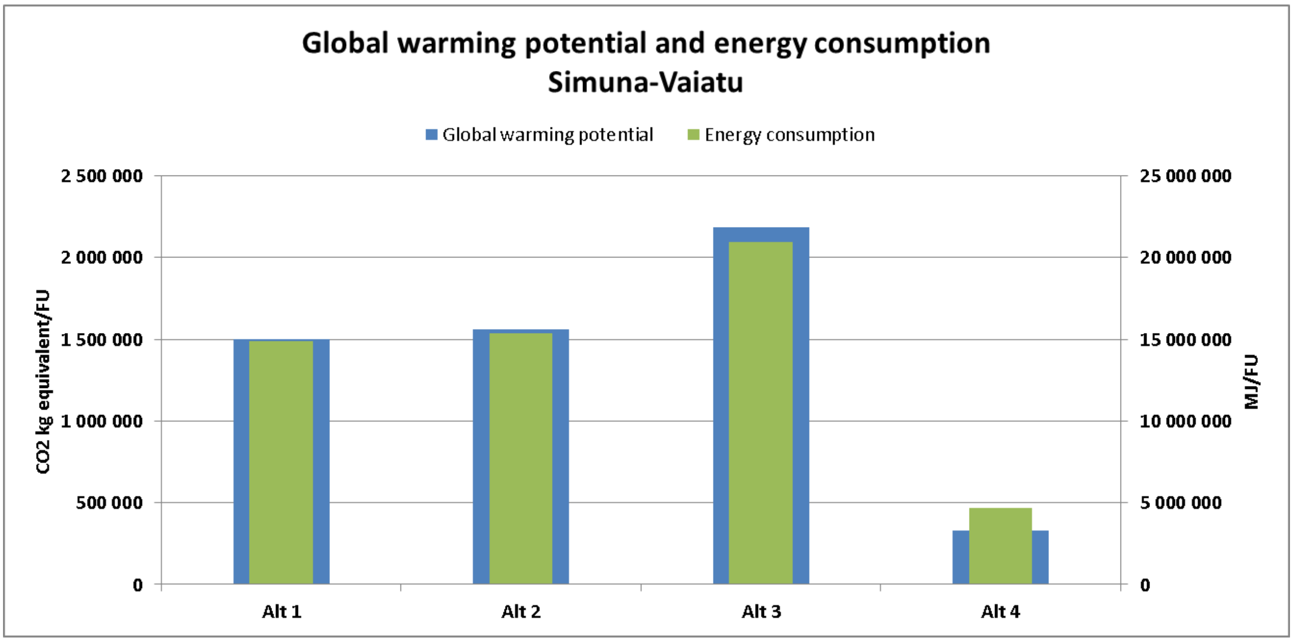

Figure 7. Global warming potential in different alternatives.

3.2.3.2 Depletion of natural resources

Table 20 and Figure 8 show the depletion of natural resources in different alternatives. The mass exchange alternative Alt4 depletes natural resources most. Alternatives Alt1… Alt3 display figures of the same magnitude.

Table 20. Depletion of natural resources in different alternatives.

Simuna-Vaiatu Depletion of natural resources [kg/FU]				
Alternative	**Material production**	**Material transportation**	**Mixing and construction**	**Total**
Alt 1	15 858 353	47 416	13 612	**15 919 381**
Alt 2	16 000 886	45 976	13 514	**16 060 376**
Alt 3	17 239 823	22 636	13 514	**17 275 973**
Alt 4	49 390 134	59 780	19 541	**49 469 455**

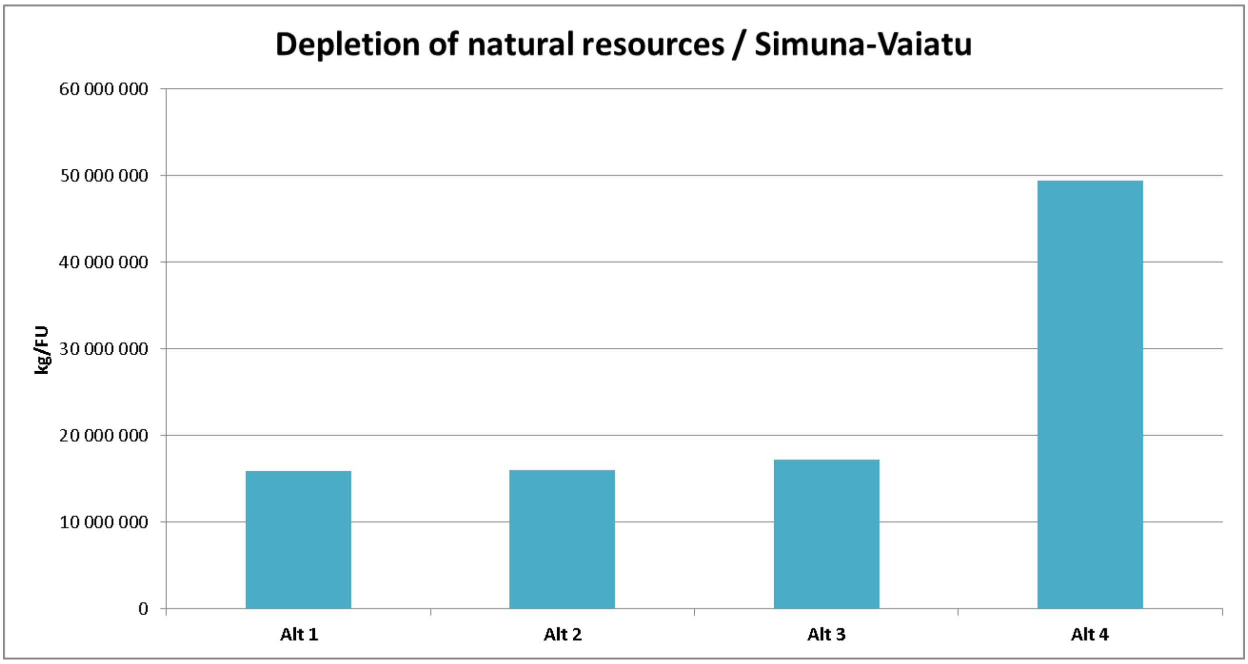

Figure 8. Depletion of natural resources in different alternatives.

3.2.3.3 Sensitivity analysis

In the Simuna-Vaiatu case, also sensitivity analysis was carried out within the LCA studies, as the results were not what had been assumed (the conventional method would have caused bigger environmental load). The clearly higher global warming potential in alternatives Alt1…Alt3 is caused by the long transportation distance of OSA to the site (Alt1 and Alt2) and from the use of cement in mass stabilisation (Alt1…Alt3).

In the sensitivity analysis figures, the first bar presents the original situation and the following bars present the situation when the amount of cement is decreased. Initially, the amount of cement in mass stabilisation in Alt1 and Alt2 is 6 % and in Alt3 9 %.

Figures 9…11 show how radical impact on the final result cement has. As peats' chemistry vary a lot and each case needs anyway its own binder reception for stabilisation, it might be possible that in some construction sites mass stabilisation can be executed by using OSA as the only binder or the amount of cement can be significantly reduced.

As the sensitivity analysis points out, the amount of cement has a very big impact on the results. In some cases it can be possible to mass stabilise using only oil shale ash, depending on the quality and characteristics of the soil/peat to be stabilised and on the strengthening requirements. If the amount of cement is 0 % (Alt1 and Alt2), the energy consumption is lower than in the mass exchange alternative Alt4. When the amount of cement is 0 % in Alt1 and Alt2, the global warming potential is smaller than in Alt4. Even the use of 3 % of cement (Alt3) causes more GWP load than the conventional construction method within this case.

In the sensitivity analysis, no technical strength comparison was made. The stronger the structure needed (depending also on the subgrade conditions), the more materials and fuels are consumed resulting in more expensive structure and more environmental impacts. When stabilisation is an alternative in earth construction the amount of cement can be optimised with the help of by-products (e.g. OSA) which significantly reduces environmental impacts.

This sensitivity analysis is a theoretical study and it could be carried out also with different parameters, e.g. transportation distances. The amount of cement is studied as it significantly depletes natural resources and it generates airborne emissions. It has to be noticed that the sensitivity analysis concerns only the amount of cement in this case and calculations.

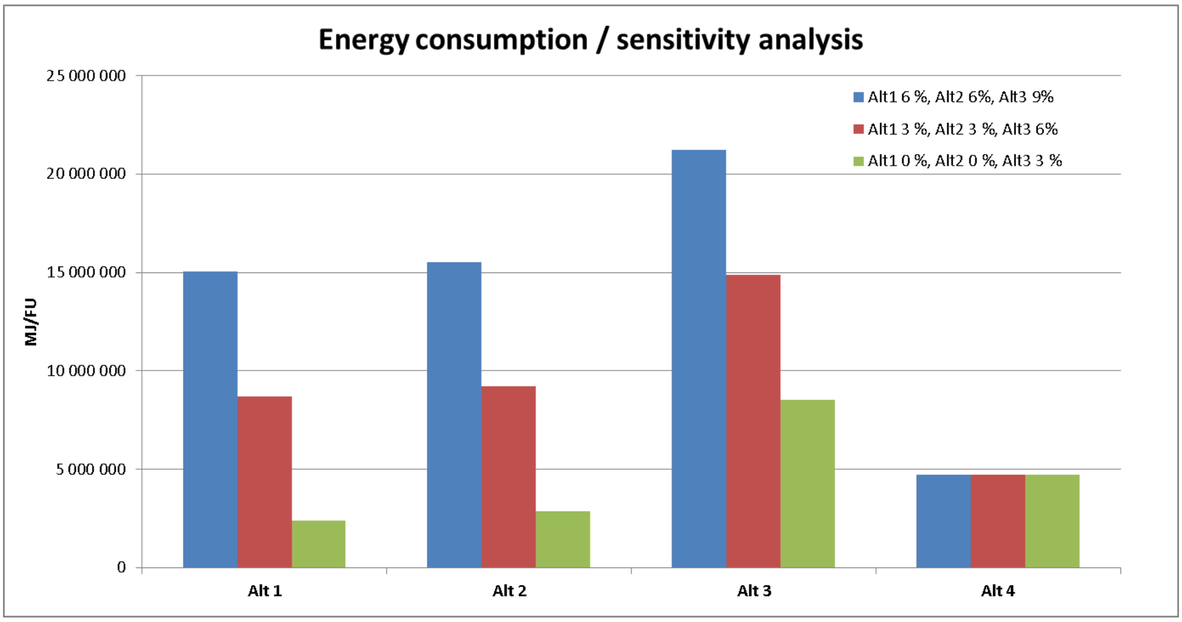

Figure 9. Energy consumption in Simuna-Vaiatu case when the amount of cement is decreased.

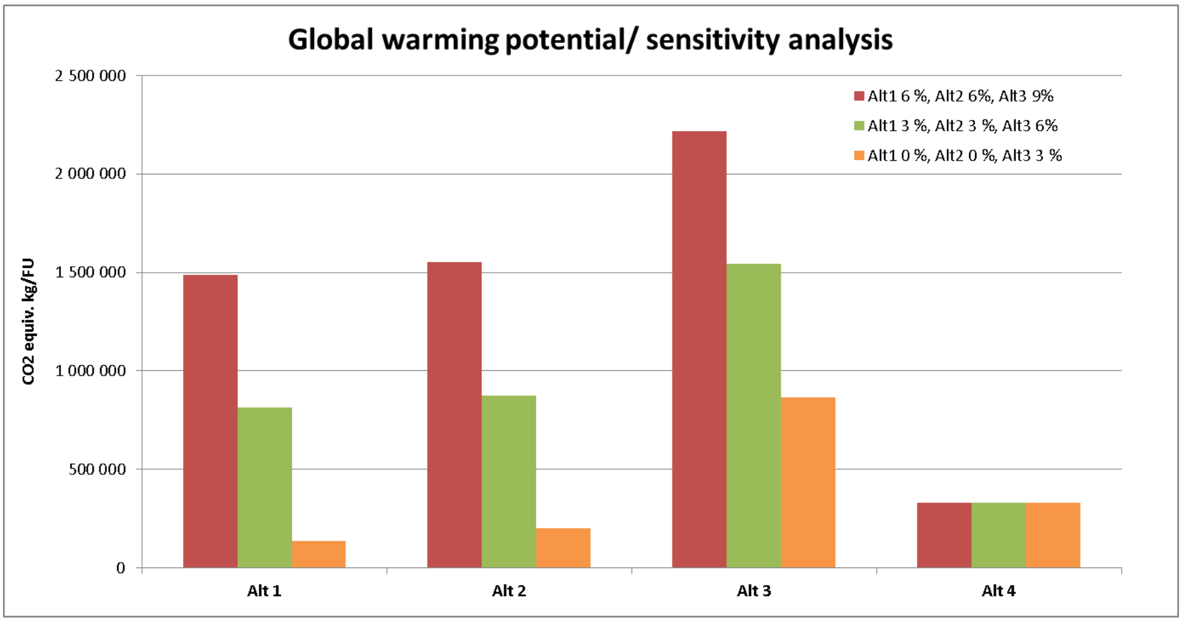

Figure 10. Global warming potential in Simuna-Vaiatu case when the amount of cement is decreased.

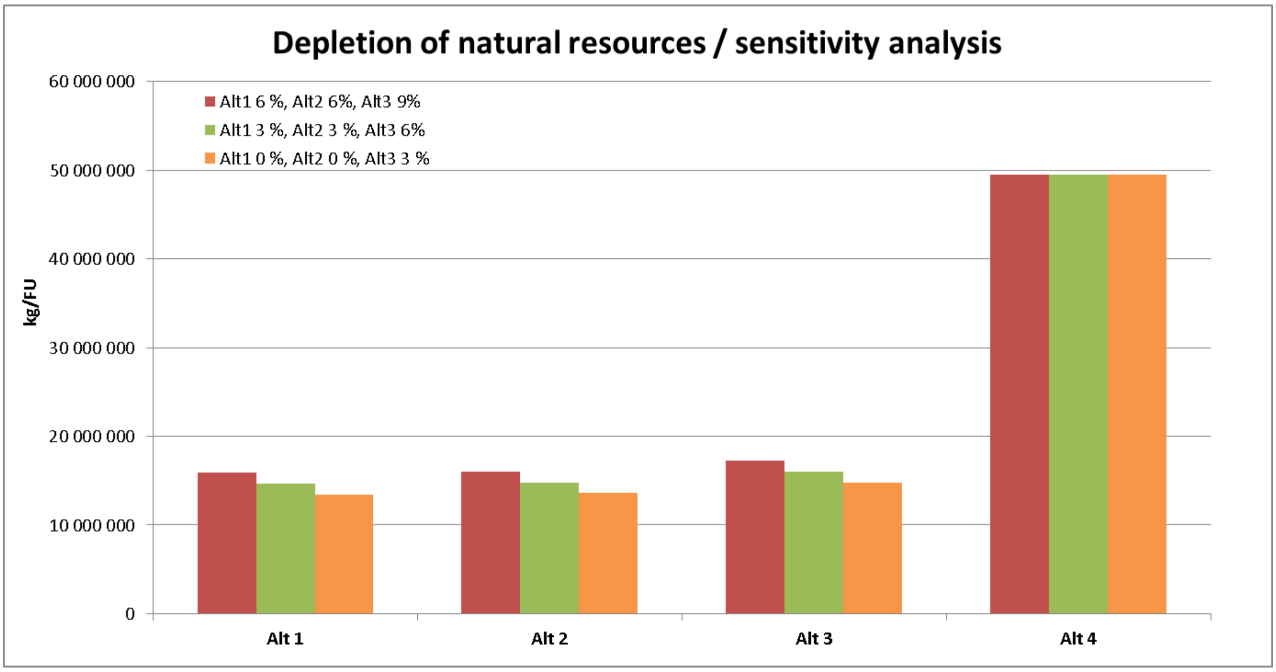

Figure 11. Depletion of natural resources in Simuna-Vaiatu case when the amount of cement is decreased.

4. FOLLOW-UP STUDIES AT PILOTING SITES

4.1 Methods

The methods used for the follow-up studies included geotechnical tests in the field during and after the construction. In the laboratory, the compression strength (in the age of 7, 28 and 90 days), water content and density were studied. After one year from construction, the load bearing rate measurements were made.

The environmental follow-up studies were as follows:

- The leaching tests with diffusion (NEN 7347) or two stage batch tests (DIN-EN-12457-3) and the total content tests by leaching the substances from the material (DIN-EN 13656 or DIN-EN 13657 and by analysing the contents of harmful substances by standard methods (ICP-MS, ICP-AES or AAS).
    - Tests for samples that represent the structure to be constructed
- Analysing (at least) the same components as from the water samples. (These are tested according to the Finnish legislation on the utilisation of recycled materials (Finnish Decree VNa 403/2009) Sb, As, Ba, Cd, Cr, Cu, Hg, Pb, Mo, Ni, Se, Zn, V, SO_4^{2-}, F^-, Cl^-)

4.2 Results

4.2.1 Narva-Mustajõe

The technical follow-up studies showed that the strength values and load bearing measurements gave good results. Bearing capacities in all the test constructions were clearly higher than the target value of

260 MPa. Strength results were also very high. Laboratory tests proved that it is possible to utilise OSA (and mining waste) in order to construct road base courses.

The environmental tests showed that the use of OSA did not involve any additional immediate negative impacts on the environment.

The soil samples were collected in the Narva-Mustajõe section on 30th-31st of October, 2012. The plots where more oil shale ash was used in a binder were selected as sampling places of the first and second construction phases.

The vast majority of sample results had all lower results than background data samples. However, one exception included a sample where sulphate level was significantly higher than in all other the sample results. As this rise of sulphate content was not observed in other samples, this one sample's increase is likely to be an anomaly. Such an anomaly can also be caused if naturally (in Estonian sediment) occurring pyrites were in the sample. For this reason samples were collected from several locations, so that the results of just one sample anomaly could not affect the final conclusions.

The only clearly observed rise in all samples concerned copper content. The copper content of all the samples was still 5-10 times lower than the target value.

A control water sample was collected in the Narva-Mustajõe road section a year after the analysis of the background data sample (26th July 2012) which should in time provide comparable data on the chemical composition of water. The results showed a significant content reduction of hazardous substances (As, Pb, V, Mo and Cr); the only analysed substances that showed an increase in the content were Na, Cl and SO_4.

These results show that the work completed on the site does not substantially increase the content of hazardous substances in water. However, the reason for the reduction of the substances is not due to the implementation of testing method.

About a month after the end of the second construction phase of the Narva-Mustajõe road, new water samples were collected (17th October 2012). Again, the sample results had not changed significantly.

During the visual survey conducted on site in June 2012, water in the ditch was clear and natural looking, and oil shale ash or alkaline pollution effects were not detectable. If alkaline compounds or other hazardous substances leach out for a longer period of time, vegetation and other biota surrounding the ditches can be affected. However, side effects may affect the aquatic biota that can be found in watercourses connected to the ditches (Kulge stream). Given the relatively large dilution effect and the leaching test results, significant impacts on the quality of water and aquatic biota are unlikely.

During the reconstruction of the road, the embankment was renewed and cleaned, roadside ditches were deepened; also, the land around the ditches, around 5-7 meters wide, was cleared and levelled. Bushes were cut down at the cleared area. The topsoil layer of the soil was stripped and later used for replanting the roadsides. Beyond the roadside forest areas, road reconstruction and activities related to it manifested no immediate or significant indirect effects. The work did not harm any natural plant communities or valuable habitats; also there were no known protected species in the affected area or in the neighbourhood.

By the end of June 2012, the land was cleared and levelled; also the bottoms and sides of the ditches were spontaneously re-vegetated. The effects on roadside vegetation were similar to normal, standard technology work. Oil shale ash used in massstabilisation had no detectable impact on the vegetation.

4.2.2 Simuna-Vaiatu

The Simuna-Vaiatu mass stabilisation quality control consisted of XRF analysis, column penetrometer soundings and vane test. According to the field test results, the stabilisation process has been successful and the technical targets have been fulfilled.

In Simuna-Vaiatu, two types of oil shale ash and a peat mix (made of 5 different peat samples) were tested for environmental properties to obtain background information. Also mixtures with peat mix and oil shale were tested. The results were compared to the limit values of the Finnish Decree 403/2009 (decree on utilisation of recycled materials). The solubilities of chromium, fluoride and sulphate were elevated in the binders but low in the stabilised peat samples. For the reasons that need to be discussed, also the solubility of nickel is low in the raw materials but yet little elevated in the stabilised peat samples. All of the elevated solubilites of the stabilised samples exceed the covered structure limit value only a little. Also the environmental targets have been fulfilled.

5. SUMMARY OF ENVIRONMENTAL IMPACTS

According to the life cycle analyses made for the Narva-Mustajõe and Simuna-Vaiatu pilots, by using oil shale ash as a construction material for road construction the environmental load can be decreased. Most clearly the effect can be seen when the stabilisation alternatives are examined – when cement is substituted in the stabilisation structures (in the cases when it is technically feasible and possible) – the environmental loads diminish clearly. The manufacturing of cement consumes a lot of energy and considerably depletes natural resources. Therefore, by replacing part of cement with oil shale ash - which as a by-product of an energy production can be regarded as a "zero impact factor" - all the studied environmental loads are smaller. Also, the technical and environmental follow-up tests showed that OSA can be utilised in a technically and environmentally feasible way.

As the sensitivity analysis shows, the amount of cement used has a very big impact on the final results. Although the results in S-V case were not exactly as expected, the results indicate that OSA can play the role of an environmentally and technically feasible element substituting cement and natural aggregates.

6. LCC

Life-cycle costing (LCC) is based on the standard ISO-15686-5:2008. The assessment is based on the investment calculations of costs of certain product or functional unit during a life-cycle. The purpose of the life-cycle costing should be to quantify life-cycle cost (LCC) into decision making process. This method can be used to assess and evaluate the long term costs of the alternative structure solutions. The general elements of the LCC calculations are provided on the picture below (Figure 12). The results gained from the LCC are highly connected to the basic data received and the defined scope. The information applied in the OSAMAT project is based on the information received from the contractor, Ramboll Estonia and Ramboll Luopioinen own expertize. The costs used here are either capital costs (construction costs) or discounted costs (costs to be realised in the future).

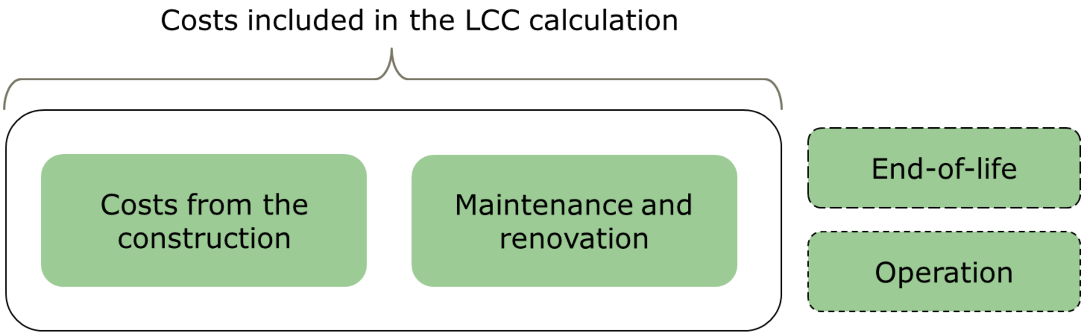

Figure 12. Costs included in the life-cycle costing.

In this calculation, the above mentioned construction costs are the initial costs created during construction. The operation costs are neglected since they are considered insignificant or identical and therefore they do not bring about variation to the calculation. The maintenance costs include repair and structural renovation costs which are discounted into net present values. Certain assumptions needed to be made concerning the long term durability of structures since no monitoring data is available of the long term durability or integrity assessments of structures.

LCC can be used as a tool to show the decision makers the estimated costs of the road construction with discounted cash flows in net present values of total costs. The maintenance costs are paid in-situ, no capital cost incurs here. For each specific year, the incurred costs are discounted into net present value (NPV). The discounted net present costs are then summed up. When considering highway or road construction the following formula of calculating net present value can be applied:

$C_N = I_N + M_N + R_N - D_N$, where

C_N = net present value of total costs

I_N = net present value of investments (Initial construction costs)

M_N = net present value of maintenance costs

R_N = net present value of repair/renovation costs

D_N = net present value of depreciation

The net present value of all cost factors are calculated by discounting each year's costs with the discounting factor c_k, that is calculated from the formula $c_k = 1/(1+i)^n$. The discounted cost flows are then summed up. Then the net present value of total costs is multiplied with the annuity factor c_n to calculate the yearly costs. The annuity cost factor depends on the accepted interest rate level and the time horizon of calculation. The formula for annuity factor is $c_n = i*(1+i)^n/[(1+i)^n-1]$.

The LCC-calculations are broadly and actually speaking investment calculations. The traditionally used methods are "net present value", which discounts all the incurred costs to net present values and the "annuity method" which scales all costs as equal annuities for each year of monitoring. Some important aspects of the calculation include:
The definition of the chosen interest rate, the real interest rates have fluctuated between 2 – 5 % in industrialised countries. In this LCC calculation, the 4 % interest rate was used. Badly chosen interest rate leads to over or under estimation of costs in the long run.
The identification of factors that create needs for costs (especially the repair needs based on damage and recognition of the timeframes when renovations are needed for different structures).

For the OSAMAT project, the life cycle cost analysis (LCC) was made for 1 kilometre of road constructed with layer stabilisation technology in the Narva-Mustajõe pilot and mass stabilisation technology in the Simuna-Vaiatu pilot. In both pilots the utilisation of OSA and substitution of cement were studied. Each alternative has a specific cost structure based on materials used, distances transported, construction methods and repaving and structural renovation practices. The following costs are identified in the following chapters:

- Cost of materials
- Cost of transportation
- Cost of construction
- Cost of repaving (2 methods) and structural renovation

Information on work prices and costs were provided by the contractor - Nordecon (via Ramboll Estonia).

In both LCC calculations, no costs of use and operation or costs of road accidents, delays or rush hour were taken into consideration. Since the operation costs of highways are rather small, compared to the total life-cycle costs, they can be left outside the scope of the calculation. The cost calculations do not include planning costs. Some assumptions had to be made to enable the calculation. One difficulty presented was the total price of constructing which needed to be divided into two parts, materials and work. One price was provided for layer stabilisation. However, information on the work part of stabilisation was needed since different stabilisation works must contain some variation. The prices given are based on this pilot site. The chosen recipes and market prices for stabiliser materials define much of the total costs.

6.1 LCC Narva-Mustajõe

The physical dimensions of the road – length, width, height – define how much material is needed. In the Narva-Mustajõe case, the stabilisation height was kept constant in 250 mm, with the exception of Alt4 (cold in place stabilisation) where the height was 150 mm (Figure 16).

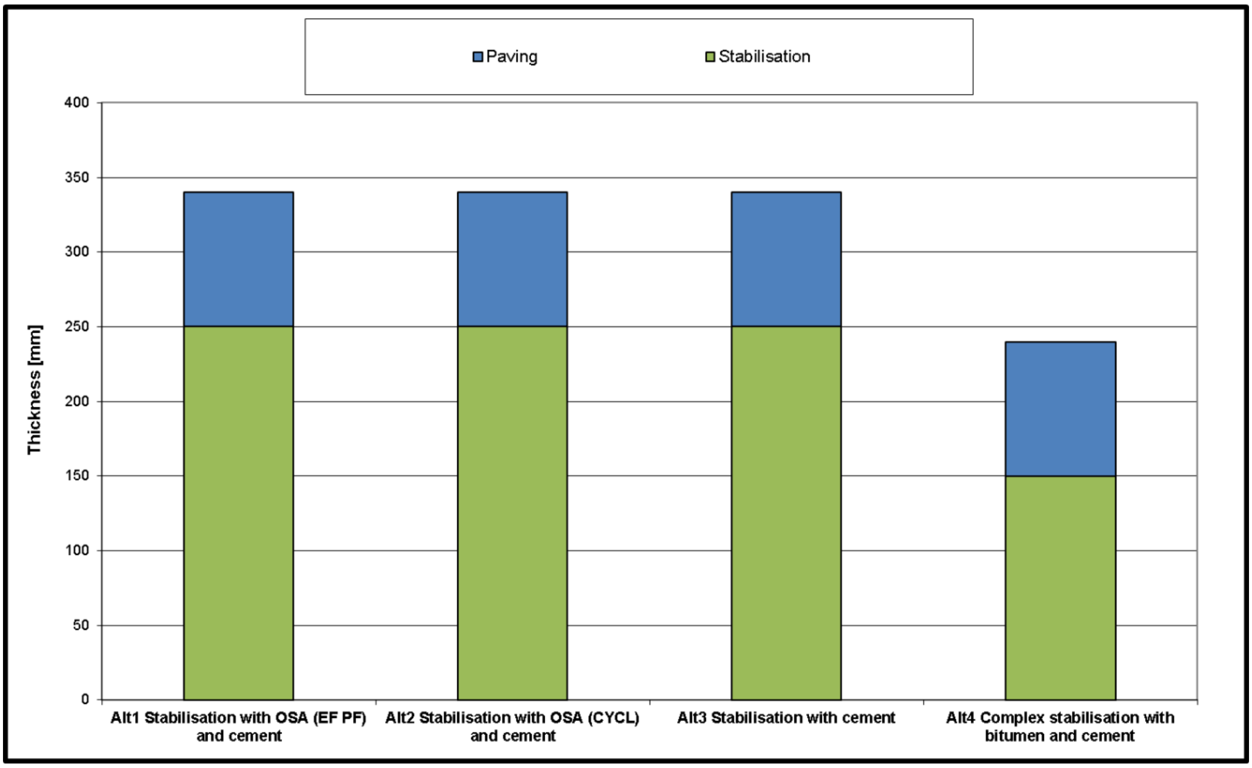

Figure 13. Structure thicknesses in different alternatives.

6.1.1 LCC of road construction with layer stabilisation / Narva-Mustajõe

6.1.1.1 Definition of the Life Cycle Cost period

In the LCC calculation for Narva-Mustajõe pilot, the following financial parameters were used (Table 21).

Table 21. Financial parameters used in LCC-calculation.

Parameter	Unit
The calculation time horizon (n) used in the calculation of the annuity factor the fixed-annual cost	40 years
Internal interest rate, i, (used in discounting NPV, net present values for costs)	4 %
Depreciation (=the value of investment in the end of financial period)	70 %

6.1.1.2 Cost factor for each scenario

The costs of materials and their transportation to the pilot site are presented in Table 22. (The amount of materials used in the calculation is shown in Chapter 3.1.2.1). The following general assumptions were made about the materials and their transportation costs. See the footnotes below.

The transportation prices and distances and material prices were provided by the OSAMAT project. The transportation costs are described in the following:

- Transportation price for cement tank truck transportations is 0,1254 € / (t*km) resulting from the sum of shipping cost 0,08 €/ (t*km) and unloading/loading 0,0454 € / (t*km). In total the transportation costs sums up to 0,1254 € / (t*km). This price is used in all tank truck deliveries (also in Simuna-Vaiatu) as there wasn't detailed information from other materials.

- Mining waste and natural road gravel: the transportation price used in calculation is 0,06 €/(t*km). This price is calculated based on the hourly rate of 32 €/h, average speed of 60 km/h and average capacity of 19 tons. The value obtained is doubled to get the price for two ways.
- The price of water is 0,00 €/m^3 as water is taken from the nearby water system.

Table 22. Material purchase prices, transportation costs and distances provided by the OSAMAT project.

Material	Purchase price (€/t)	Transportation unit cost (€/t/km)	Transportation distances (km)
Mining waste aggregate (MWA)	3,20	0,06	77
Composite cement	87,75	0,1254	100
OSA fly ash	8,00	0,1254	15
Bitumen, BE60M	430,00	0,1254	44
Water	0,00	0,1254	3
Natural road gravel	13,50	0,06	77

6.1.2 Construction stages and costs

The initial construction includes constructing of the following layers:

- base layer with 16 cm thick mining waste aggregate (MWA) for Alt1 – Alt3
- base layer with 15 cm of crushed rock for Alt4
- layer stabilisation with 4 different mixtures of grinded asphalt, composite cement, OSA fly ash, bitumen and water
- constructing a 9 cm pavement layer

The construction costs were provided and they are presented in Table 23. In general, the cost of construction can be divided into the cost of materials and work done. The basic road renovation method here is the layer stabilisation method. For each structure type, the original binder mixture is used and calculated. Therefore, the chosen material recipe has an impact on the material costs side of the application.

In addition to material prices, the costs of constructing needed to sum up for the LCC calculations. The general constructing unit prices used in the LCC calculations are shown in the table below. These prices are the contractors' price, which include the price of material and work.

Table 23. Constructing unit prices used in calculations provided by the contractor.

Work type	Contractor price (including work and materials)
Milling (depth 10 cm) the asphalt concrete (MAC 9 cm) and transporting to storage area (distance 8.5 km), heaping at the storage area	1,20 €/m^2
Milling (depth 10 cm) the asphalt concrete (MAC 9 cm)	0,79 €/m^2

Spreading mine waste aggregate (MWA 16 cm) (Calculation shows that materials account for 2,55 €/m^2 and work is 2,40 €/m^2).	4,95 €/m^2
Layer stabilisation (25 cm), including spreading the materials, adding water, stabilisation and compacting	10,46 €/m^2

6.1.3 Maintenance during the life cycle period

During the 40 years' time horizon, the structure is repaired and renovated many times. There are different repair and renovation methods for different structure material solutions. The chosen repair and structural improvement time horizons are shown in Table 25. There are 3 different scenarios where the following repair methods are used in different intervals. The scenarios are assumptions as there is no experience yet how durable the structure is for real.

- REP (Repaving) method includes grinding of the old road pavement surface and constructing a new one
- U-REP is a method where only the worn off tire track areas of the road surface are paved for the width of about 1 meter). Since the width of the paved area is about 4 meters out of 9,5 meter wide road, 20 % cost of REM is assumed. The calculation is based on the assumption that about 40 % of the width of the road is paved. An additional 50 % reduction to the costs is made since the track ruts are worn off in a parabolic form.
- Structural renovation - this method brings back the original service level of the road structure. In this study, the structural improvement is done with "layer stabilisation 250 mm and with original material recipe". Since the cost of renovation is based on the materials used, making it economical to use alternative binders.

Table 24. Repaving unit prices used in calculations.

Method	**Price / m^2**
REP, re-paving with new asphalt-concrete, AC 32 (5 cm) + AC 12 (4 cm)	17,10
U-REP, re-paving (paving just the tire tracks	1,40
Structural renovation (4 different layer stabilisation choices). Prices include all the materials needed, work done and also paving.	27,00 – 33,00

The paving methods REP and U-REP are used many times for these structures. However, the structural renovation is done once during the 40 year time horizon. The time point of this renovation varies in Scenarios 1 – 3. The time point has an impact on the overall calculation. The calculation contains 3 scenarios where the first has the shortest life-time for structural renovation (Table 26). The third scenario has the longest life-time until structural renovation. The annuity factor for the calculation was chosen to be 40 years. By postponing the renovation time, lower lifecycle costing is achieved.

Different structure solutions and traffic loads create different needs for maintenance and renovation actions. In some cases, computational damage modeling and forecasts could be used to evaluate the renovation time periods. However, if accurate, they could only be valid for some traditional solutions. In these structures, repair costs would follow repair needs derived from the damage assessments and prognosis. For the time being, only the empiric evaluation of the repair and maintenance costs is considered a viable alternative. No generally accepted reliable models have been developed for the damage assessment. Table 26 presents the repair intervals used in this project. As these intervals are based on assumptions, also the sensitivity of the results can be studied by changing the interval years.

Table 25. Repair intervals for different structural solutions.

Scenario 1

Structure solution	Action	Maintenance period (years 1 - 40) year									
		yr. 4	yr. 8	yr. 12	yr. 16	yr. 20	yr. 24	yr. 28	yr. 32	yr. 36	yr. 40
Alt 1	U-REP	x		x		x		x		x	
	REP		x		x		x				x
	Structural Renovation								Scen1		
Alt 2	U-REP	x		x		x			x		x
	REP		x		x		x			x	
	Structural Renovation							Scen1			
Alt 3	U-REP	x		x		x		x		x	
	REP		x		x				x		x
	Structural Renovation						Scen1				
Alt 4	U-REP	x		x			x		x		x
	REP		x		x			x		x	
	Structural Renovation					Scen1					

Scenario 2

Structure solution	Action	Maintenance period (years 1 - 40) year									
		yr. 4	yr. 8	yr. 12	yr. 16	yr. 20	yr. 24	yr. 28	yr. 32	yr. 36	yr. 40
Alt 1	U-REP	x		x		x		x			x
	REP		x		x		x		x		
	Structural Renovation									Scen2	
Alt 2	U-REP	x		x		x		x		x	
	REP		x		x		x				x
	Structural Renovation								Scen2		
Alt 3	U-REP	x		x		x			x		x
	REP		x		x		x			x	
	Structural Renovation							Scen2			
Alt 4	U-REP	x		x		x		x		x	
	REP		x		x				x		x
	Structural Renovation						Scen2				

Scenario 3

Structure solution	Action	Maintenance period (years 1 - 40) year									
		yr. 4	yr. 8	yr. 12	yr. 16	yr. 20	yr. 24	yr. 28	yr. 32	yr. 36	yr. 40
Alt 1	U-REP	x		x		x		x		x	
	REP		x		x		x		x		
	Structural Renovation										Scen3
Alt 2	U-REP	x		x		x		x			x
	REP		x		x		x		x		
	Structural Renovation									Scen3	
Alt 3	U-REP	x		x		x		x		x	
	REP		x		x		x				x
	Structural Renovation								Scen3		
Alt 4	U-REP	x		x		x			x		x
	REP		x		x		x			x	
	Structural Renovation							Scen3			

6.1.4 End of life

Normally, the costs from the end of life stage of the studied product/service are included in the LCC calculation. The studied product in this case is a road and when the use of a road stops the road structure is usually left in place. Even if the structures are excavated out, the used construction materials are utilised in some way and the landfilling is out of the question – also according to EU waste hierarchy. So in this LCC calculation the end of life stage is not taken into account in the LCC calculations.

6.2 End results and summary

The calculation performed provided the following results. These results show how the discounted annual cost per 1 kilometre of road (9.5 m wide) is lower for structures with alternative construction materials postponed structural renovation time horizons. In Scenario 3, the structural renovation time periods are done between 28 – 40 years after construction. In Scenario 1, the structural renovation time periods are done between 20 – 28 years after the construction. The calculation used a total time horizon of 40 years. According to these results it can be seen, that the life cycle costing with alternative construction materials is also lower.

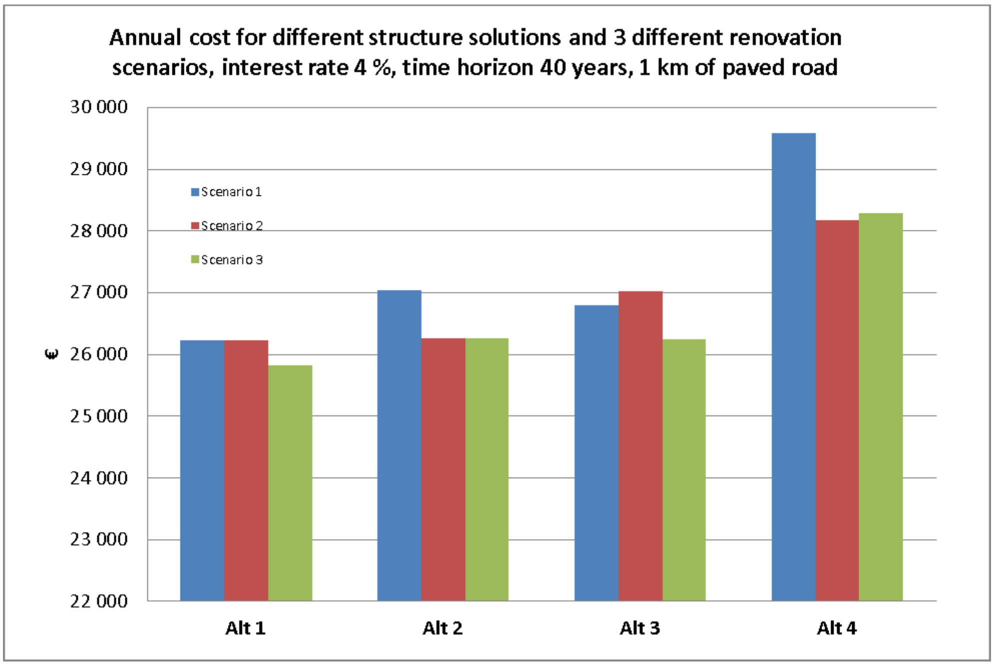

Figure 14. Annual cost (NPV) in euros (€) for structures Alt 1–4 with scenarios 1–3.

In the Figure 14 different annual costs for 1 kilometre of paved road are presented. It needs to be emphasised that the calculations here represent scenario based on assessments. Throughout this report different calculation principles are presented. In the beginning situation cheaper material purchasing costs can be achieved due to use of alternative construction materials. It should be noted that using repaving solution means intensive and heavy costs. Also that reduction in stabilisation work costs might lower the overall costs. According to the results the annual costs of Alt4 is approximately 10 % higher than the costs in Alt1. All the LCC calculation sheets are provided in Appendix 3.

The calculation result includes also the benefit of avoiding the landfilling of OSA. The landfilling fee in Estonia is 50 eur/ton including taxes [13].

6.3 LCC Simuna-Vaiatu

The structure thicknesses and structure materials are presented in Figure 15. The pavement is equal in all alternatives what it comes to material and work costs.

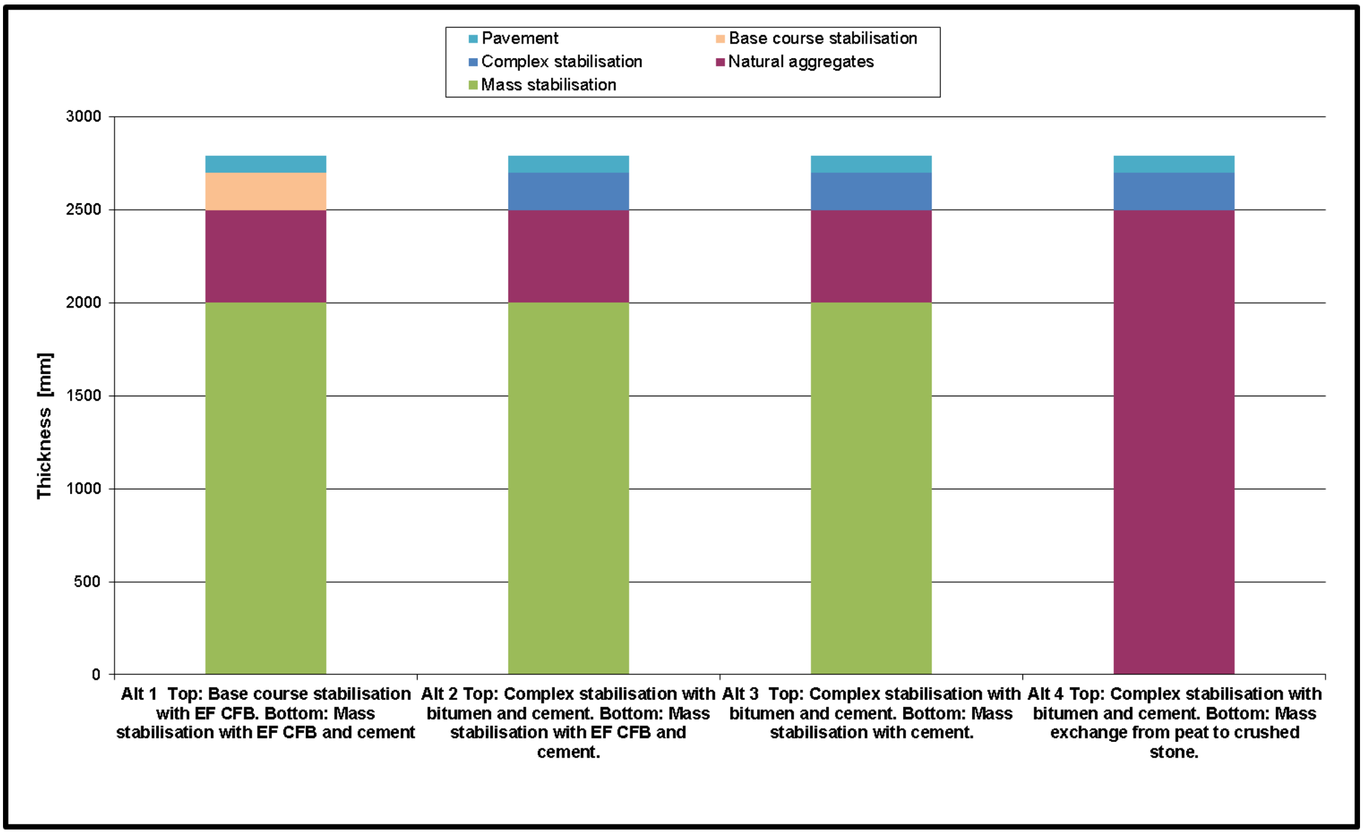

Figure 15. Structure thicknesses in different alternatives.

6.3.1 LCC of road construction with mass stabilisation

The costs of materials and their transportation of the pilot site are presented in the table 26. The transportation price and material prices were provided by the OSAMAT project. The following general assumptions were made about the materials and their transportation costs.

- Transportation price for cement tank truck transportations is 0,1254 € / (t*km) resulting from the sum of shipping cost 0,08 €/ (t*km) and unloading/loading 0,0454 € / (t*km). In total the transportation costs sums up to 0,1254 € / (t*km). This price is used in all tank truck deliveries as there were no detailed information from other materials.
- Natural road gravel: the transportation price used in calculation is 0,06 €/(t*km). This price is calculated based on the hourly rate of 32 €/h, average speed of 60 km/h and average capacity of 19 tons. The value obtained is doubled to get the price for two ways.
- The price of water is 0,00 eur/m^3 as the water is taken from the nearby water system.

Table 26. Material purchase prices, transportation costs and distances provided by the OSAMAT project.

Material	Purchase price (€/t)	Transportation unit cost (€/t/km)	Transportation distances (km)
Composite cement	87,75	0,1254	70
OSA fly ash	8,00	0,1254	155
Bitumen, BE60M	430,00	0,1254	135
Water	0,00	0,1254	3
Natural road gravel	13,50	0,06	30

6.3.2 Construction stages and costs

The initial construction includes constructing the following layers:

- mass stabilisation of the peat layer (2 m) with cement and/or OSA
- top layer 20 cm made with layer stabilisation (with OSA) or complex stabilisation (with bitumen and cement)
- constructing a 9 cm pavement layer

The construction costs are presented in Table 27. The basic road renovation method here is the mass stabilisation method. For each structure type, the original binder mixture is used and calculated. Therefore the chosen material recipe has an impact on the material costs side of the application.

In addition to material prices, the costs of constructing needed to sum up for the LCC calculations. The general constructing unit prices used in the LCC calculations are shown in the table below. These prices are contractors' price, which include the price of material and work.

Table 27. Constructing unit prices used in calculations provided by the contractor.

Work type	Contractor price
Milling (depth 10 cm) the asphalt concrete (MAC 9 cm) and transporting to storage area (distance 8.5 km), heaping at the storage area	1,20 €/m^2
Milling (depth 10 cm) the asphalt concrete (MAC 9 cm)	0,79 €/m^2
Spreading natural aggregates (Based on the information that the price is 16-18 euros/m^3 in Helsinki region. The price is an assumption when Estonian price level is taken into account)	8,00 €/m^3
Layer stabilisation (25 cm), including spreading the materials, adding water, stabilisation and compacting	10,46 €/m^2
Mass stabilisation, including adding water, mixing the binders and peat and compacting	10,00 €/m^3

6.3.3 Maintenance during the life cycle period

During the 40 years' time horizon, the structure is repaired and renovated many times. There are different repair and renovation methods for different structure material solutions. The chosen repair and structural improvement time horizons are shown in the Table 28. There are 3 different scenarios where the following repair methods are used in different intervals. The scenarios are assumptions as there is no experience yet how durable the structure is for real.

- REP (Repaving) method includes grinding of the old road pavement surface and constructing a new one
- U-REP is a method where only the worn off tire track areas of the road surface are paved for the width of about 1 meter). Since the width of the paved area is about 4 meters out of 9,5 meter wide road, 20 % cost of REM is assumed. The calculation is based on the assumption that about 40 % of the width of the road is paved. An additional 50 % reduction to the costs is made since the track ruts are worn off in a parabolic form.
- Structural renovation - this method brings back the original service level of the road structure. In this study, the structural improvement is done with "layer stabilisation 250 mm and with original material recipe". Since the cost of renovation is based on the materials used, making it economical to use alternative binders.

Table 28. Re-paving unit prices used in the LCC calculations.

Method	Price (€/m^2)
REP, re-paving with new asphalt-concrete, AC 32 (5 cm) + AC 12 (4 cm)	17,12
U-REP, re-paving (paving just the tire tracks). Since the width of the paved area is about 4 meters out of 9,5 meter wide road, 20 % cost of REM is assumed.	3,42
Structural renovation (4 different layer stabilisation choices). Prices include all the materials needed, work done and also paving.	25,00 – 46,00

The paving methods REP and U-REP are used many times for these structures. However the structural renovation is done once during the 40 year time horizon. The time point of this renovation varies in Scenarios 1 – 3. Time point has an impact on the overall calculation. The calculation contains 3 scenarios, where the first has the shortest life-time for structural renovation (see Table 29). The third scenario has the longest life-time until structural renovation. The annuity factor for the calculation was chosen to be 40 years. By postponing the renovation time, lower lifecycle costing is achieved.

In Simuna-Vaiatu case the patching starts from year 6, continuing every 10 year. The re-paving takes place beginning from year 10, continuing every 8 year. In year 26, both patching and re-paving takes place, but in the LCC analysis only re-paving is taken into account. The structural renovation starts from year 25 (Scen1). In scenario 3 the longest period taken into account is 35 years until the structural renovation is done for Alt1. Although the complex stabilisation is considered to last 20 years before it has to be renovated, in Simuna-Vaiatu case the renovation is considered to start from year 25, as the traffic amounts in Simuna-Vaiatu are much lower than in Narva-Mustajõe.

Different structure solutions and traffic loads create needs for different maintenance and renovation actions. In some cases computational damage modeling and forecasts, could be used to evaluate the renovation time periods. However, if accurate, they could only be valid for some traditional solutions. In these structures repair costs would follow repair needs derived from damage assessments and prognosis. For the time being, only empiric evaluation of the repair and maintenance costs is considered viable alternative. No generally accepted reliable models are developed for damage assessment.

Table 29. Repair intervals for different structural solutions. The grey colour marks for the interval of U-REP, but only REP is taken into account in the calculations.

Scenario 1													
Structure solution	Action	Maintenance period (years 1-40) year											
		yr 6	yr 10	yr 16	yr 18	yr 25	yr 26	yr 28	yr 30	yr 31	yr 34	yr 35	yr 36
Alt1	U-REP	x		x									x
	REP		x		x		x				x		
	Structural Renovation					Scen 1							
Alt2	U-REP	x		x									x
	REP		x		x		x				x		
	Structural Renovation					Scen 1							
Alt3	U-REP	x		x									x
	REP		x		x		x				x		
	Structural Renovation					Scen 1							
Alt4	U-REP	x		x									x
	REP		x		x		x				x		
	Structural Renovation					Scen 1							

Scenario 2													
Structure solution	Action	Maintenance period (years 1-40) year											
		yr 6	yr 10	yr 16	yr 18	yr 25	yr 26	yr 28	yr 30	yr 31	yr 34	yr 35	yr 36
Alt1	U-REP	x		x									x
	REP		x		x		x				x		
	Structural Renovation								Scen 2				
Alt2	U-REP	x		x									x
	REP		x		x		x				x		
	Structural Renovation							Scen 2					
Alt3	U-REP	x		x									x
	REP		x		x		x				x		
	Structural Renovation							Scen 2					
Alt4	U-REP	x		x									x
	REP		x		x		x				x		
	Structural Renovation							Scen 2					

Scenario 3													
Structure solution	Action	Maintenance period (years 1-40) year											
		yr 6	yr 10	yr 16	yr 18	yr 25	yr 26	yr 28	yr 30	yr 31	yr 34	yr 35	yr 36
Alt1	U-REP	x		x									x
	REP		x		x		x				x		
	Structural Renovation											Scen 3	
Alt2	U-REP	x		x									x
	REP		x		x		x				x		
	Structural Renovation									Scen 3			
Alt3	U-REP	x		x									x
	REP		x		x		x				x		
	Structural Renovation									Scen 3			
Alt4	U-REP	x		x									x
	REP		x		x		x				x		
	Structural Renovation									Scen 3			

6.3.4 **End of life**

Normally the costs from end of life stage of the studied product/service are included in the LCC calculation. As the studied product in this case is a road, and when the use of a road stops, the road structure is usually left in place. Even if the structures are excavated out, the used construction materials are utilised in some way and landfilling is not an option – also according to the EU waste hierarchy. For this reason, the end of life stage is not taken into account in neither the Simuna-Vaiatu or the Narva-Mustajõe LCC calculations.

6.4 End results and summary

The performed calculation provided the following results. In scenario 3, the structural renovation time periods are done between 31-35 years after construction. In Scenario 1, the structural renovation time periods are done 25 years after the construction. The calculation used a total time horizon of 40 years. According to these results, it can be seen that the life cycle costing with Alt1 (mass stabilisation with OSA and cement + layer stabilisation with OSA) and Alt2 (mass stabilisation with OSA and cement + complex stabilisation) is lower.

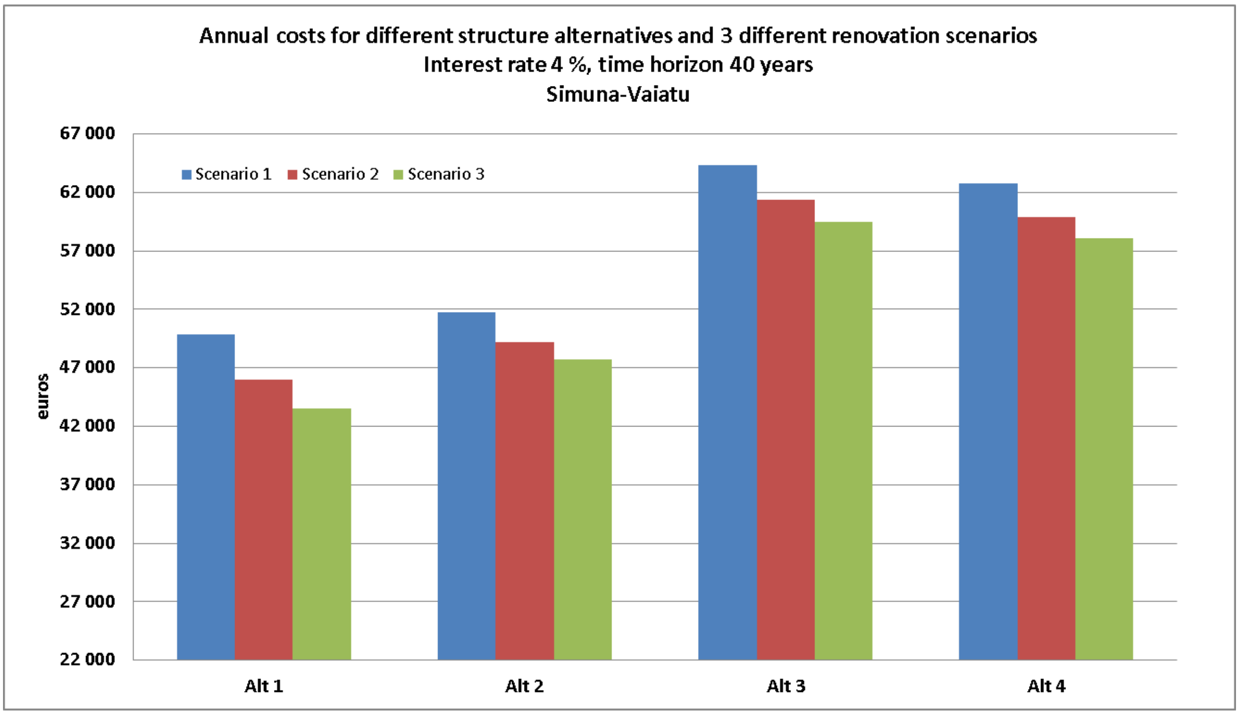

Figure 16. Annual cost (NPV) in euros (€) for structures Alt 1–4 with scenarios 1–3.

In Figure 16, different annual costs for 1 kilometre of paved road are presented. It needs to be emphasised that the calculations here represent a scenario based on assessments. Throughout this report, different calculation principles are presented. In the initial situation, cheaper material purchasing costs can be achieved due to the use of alternative construction materials. It should be noted that using repaving solution means intensive and heavy costs. Also, that the reduction in stabilisation work costs might lower the overall costs.

The calculation result includes also the benefit of avoiding the landfilling of OSA. The landfilling fee in Estonia is 50 €/ton including taxes [13].

6.5 Summary and conclusions of LCC

The LCC calculations show in both pilot cases that the utilisation of OSA and the utilisation of mining waste (Narva-Mustajõe) are financially feasible with the studied repair intervals. The calculations have also showed that the stabilisation applications are the financially feasible construction methods compared to the conventional way of constructing a road. There are a lot of assumptions about the repair intervals that will have an impact on the end result. The material prices, transportation prices and work costs are based on the real figures.

7. SUMMARY AND CONCLUSION OF LCA AND LCC

According to the results achieved in the OSAMAT LCA and LCC analysis, this study indicates that the structure alternatives implemented in the OSAMAT pilots (Narva-Mustajõe and Simuna-Vaiatu) may cause less environmental harm than if stabilisation is carried out using only cement or if the structure is built exclusively with natural aggregates. Even a partial substitution of cement with oil shale ash (OSA) may decrease environmental harm. It has to be pointed out that the LCA was performed as a Streamlined LCA which is not a complete one. This Streamlined LCA was performed according to the budget available in the project. Although the data used for the calculations originates from reliable sources, there are still uncertainties as the results and the conclusions are based only on the studied environmental impacts, depletion of natural resources and global warming potential.

This LCA/LCC report demonstrates that OSA and the implemented methods can be environmentally and financially feasible for civil engineering purposes. The environmental follow-up procedures of the pilot cases have indicated so far that OSA has no negative effects on the environment as the analyses of water and soil samples have shown no harmful leaching or elevated total concentrations of harmful substances / elements.

According to the material tests performed previously and for this LCA/LCC report, OSA can be a very promising substitute for cement and natural aggregates. Utilising OSA is a re-use action according to European Union Waste Hierarchy where the primary objective is to reduce waste and where landfilling is the final alternative if reuse, recycling or energy recovery cannot be made. By utilising OSA in various civil engineering applications, it is possible to reduce CO_2 emissions and by this to address the issue of climate change. Moreover, savings in the use of natural aggregates constitutes a major advantage in Estonia as currently crushed rock and gravel for construction purposes need to be imported from abroad.

The results achieved in the LCA/LCC studies of OSAMAT indicate that the end result of the project has met the expectations – utilising OSA proves to be feasible technically and environmentally.

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Appendix 1 Narva-Mustajoe LCA calculation sheets

1a Starting point

	Structure	Materials	Processes for the construction
Alt 1	Old road and mining waste stabilised with OSA Q1 and composite cement	Mining waste, oil shale ash and composite cement	*Grinding of old road*, mixing of osa and cement, spreading of the mining waste and ground road material on the road, wetting the material, spreading the binders, mixing the whole structure and compacting the structure.
Alt 2	Old road and mining waste stabilised with OSA Q2 and composite cement	Mining waste, oil shale ash and composite cement	*Grinding of old road*, mixing of osa and cement, spreading of the mining waste and ground road material on the road, wetting the material, spreading the binders, mixing the whole structure and compacting the structure.
Alt 3	Old road and mining waste stabilised with composite cement	Mining waste and composite cement	*Grinding of old road*, spreading of the mining waste and ground road material on the road, wetting the material, spreading the binders, mixing the whole structure and compacting the structure.
Alt 4	Cold in place complex recycling	Cement, bitumen, crushed stone	*Grinding of old road*, spreading of crushed stone, wetting the material, spreading the binders, mixing the whole structure and compacting the structure.
	OSA = oil shale ash		
	Q1 = better quality oil shale ash		
	Q2 = lower quality oil shale ash		

	Material	Amount [m^2] / (1 kilometre)	Amount [m^3]	Amount [%]	Amount [ton/FU]	Other information	Reference:
Alt 1	Mining waste aggregate (Aidu) 0–32 mm	9500	1520		3002	16 cm to 25 cm stabilisation, density 1,975	Material report, Ramboll expertise
	Layer stabilisation	9500	2375		4631	Thickness 25 cm, Density 1,95 mining waste + old paving	
	Oil shale fly ash EF BL3, w = 20 %			6	278		
	Composite cement			3	139		
Alt 2	Mining waste aggregate (Aidu) 0–32 mm	9500	1520		3002	16 cm to 25 cm stabilisation, density 1,975	Material report, Ramboll expertise
	Layer stabilisation	9500	2375		4631	Thickness 25 cm, Density 1,95 mining waste + old	
	Oil shale fly ash CYCL			5	232		
	Composite cement			5	232		
Alt 3	Mining waste aggregate (Aidu) 0–32 mm	9500	1520		3002	16 cm to 25 cm stabilisation, density 1,975	Material report, Ramboll expertise
	Layer stabilisation	9500	2375		4631	Thickness 25 cm, Density 1,95 mining waste + old	
	Composite cement			6	278		
Alt 4	Cold in place complex recycling	9500	1425		2779	Thickness 15 cm, body material average density 1950 kg/m3	Material report, Ramboll expertise
	Bitumen			1	28	Density 1900 kg/m3	
	Composite cement			2,5	69		
	Crushed stone	9500	2945		6185	Density 2100 kg/m3, thickness 31 cm (according to the Material Rport the aggregate layer MWA 160/260 mm and MAC 100/100 mm -> the averge is 310 mm.	

1b Material production

	Material	Amount used [tonnes/FU]	Emissions per ton [g/ton]									Energy consumption [MJ/ton]	Use of natural resources [g/ton]
			CO_2	NOx	PM	SO_2	CO	VOC	CH_4	HC	N_2O		
Alt 1	Composite cement	139	623628	1794	263,1	1791						5825	1151000
	Oil shale ash	278	No emissions from the oil shale ash as it is not a product, instead it is a by-product from the burning of the oil shale for energy.										
	Mining waste	3002	365	3,28	0,13	0,18	0,39		0,0002	0,236	0,0074	5,09	125
	SUM	4877											
Alt 2	Composite cement	232	623628	1794	263,1	1791						5825	1151000
	Oil shale ash	232	No emissions from the oil shale ash as it is not a product, instead it is a by-product from the burning of the oil shale for energy.										
	Mining waste	3002	365	3,28	0,13	0,18	0,39		0,0002	0,236	0,0074	5,09	125
	SUM	4923											
Alt 3	Composite cement	278	623628	1794	263,1	1791						5825	1151000
	Mining waste	3002	365	3,28	0,13	0,18	0,39		0,0002	0,236	0,0074	5,09	125
	SUM	4738											
Alt 4	Composite cement	69,5	623628	1794	263,1	1791						5825	1151000
	Bitumen	27,8	255669	1207		993	1057	410	764	68		510	1095010
	Crushed stone	6185	1 800	2,10	1,20	1,30	1,10	0,30	1,1			34	1010000
	SUM	7740											

Emissions total [kg/FU]											Reference:
CO_2	NOx	PM	SO_2	CO	VOC	CH_4	HC	N_2O	Energy consumption [MJ/FU]	Use of natural resources [kg/FU]	
86 645	249	37	249	0	0	0	0		809 261	159 917	[8]
No emissions from the oil shale ash as it is not a product, instead it is a by-product from the burning of the oil shale for energy.											
1 097	10	0,4	0,5	1,2	0,0000	0,001	0,7	0,02	15 278	375	[10]
87 743	**259**	**37**	**249**	**1,2**	**0,7**	**0,001**	**0,7**	**0,02**	**824 539**	**160 292**	
144 409	415	61	415	0	0	0	0	0	1348768	266 528	[8]
No emissions from the oil shale ash as it is not a product, instead it is a by-product from the burning of the oil shale for energy.											
1 097	10	0,4	0,5	1,2	0,0	0,0	0,7	0,02	15 278	375	[10]
145 506	**425**	**61**	**415**	**1,2**	**0,7**	**0,001**	**0,7**	**0,02**	**1 364 046**	**266 904**	
173 291	499	73	498	0	0	0	0		1 618 522	319 834	[8]
1 097	10	0,4	0,5	1,2	0	0,001	0,7	0,02	15 278	375	[10]
174 388	**508**	**73**	**498**	**1**	**1**	**0**	**0,7**	**0,0**	**1 633 799**	**320 209**	
43 323	125	18	124	0	0	0	0	0	404 630	79 959	[8]
7 104	34	0	28	29	11	21	2	0	14 172	30 428	[11]
11 132	13	7	8	7	2	7	0	0	210 273	6 246 345	[10]
61 559	**171**	**26**	**160**	**36**	**13**	**28**	**2**	**0,0**	**629 075**	**6 356 731**	

1c Material transportation

Alternative	Material	Destination	Total mass [tonnes/FU]	Vehicle	Distance [km]	Number of loads	Total km*	fuel consumption** [l/km]	total fuel consumption [l/ FU]
Alt 1	Composite cement	to site	139	tank truck (40t)	100	3,5	695	0,42	292
	Oil shale ash	to site	278	tank truck (40t)	8,5	6,9	118	0,42	50
	(Oil shale ash)	(to landfill)	278	tank truck (40t)	-5	6,9	-69	0,42	-29
	Mining waste	to site	3 002	truck (19 t)	77	158	24 332	0,31	7 543
	SUM		**3 763**				**25 075**		**7 855**
Alt 2	Composite cement	to site	232	tank truck (40t)	100	6	1 158	0,42	486
	Oil shale ash	to site	232	tank truck (40t)	8,5	6	98	0,42	41
	(Oil shale ash)	(to landfill)	232	tank truck (40t)	-5	5,8	-58	0,42	-24
	Mining waste	to site	3 002	truck (19 t)	77	158	24 332	0,31	7 543
	SUM		**3 763**				**25 530**		**8 046**
Alt 3	Composite cement	to site	278	tank truck (40t)	100	7	1 389	0,42	584
	Mining waste	to site	3 002	truck (19 t)	77	158	24 332	0,31	7 543
	Oil shale ash	to landfill	278	tank truck (40t)	5	6,9	69	0,42	29
	SUM		**3 624**				**25 791**		**8 156**
Alt 4	Composite cement	to site	69	tank truck (40t)	100	2	347	0,42	146
	Ground road structure	to final storage	1 642	truck (19 t)	5	86	1 728	0,31	536
	Bitumen	to site	28	tank truck (40t)	44	1	61	0,42	26
	Crushed stone	to site	6 185	truck (19 t)	77	326	50 127	0,31	15 539
	Oil shale ash	to landfill	278	tank truck (40t)	5	6,9	69	0,42	29
	SUM		**8 268**				**52 333**		**16 276**

Emissions [g/km]								Energy consumption [MJ/km]	Depletion of natural resources [kg/l]	Total emissions [kg / FU]								Energy consumption [MJ/FU]	Depletion of natural resources [kg/FU]	Reference:
CO_2	NOx	PM	SO_2	CO	VOC + HC	CH_4	N_2O			CO_2	NOx	PM	SO_2	CO	VOC + HC	CH_4	N_2O			
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	720	5	0,1	0,005	0,1	0,1	0,01	0,02	10 420	338	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	122	1	0,01	0,001	0,02	0,01	0,001	0,004	1 771	58	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	-72	-1	-0,01	-0,0005	-0,01	-0,01	-0,001	-0,002	-1 042	-34	[5], [6]
774,5	5,75	0,063	0,0053	0,195	0,115	0,007	0,033	11,5	1,16	18 845	140	1,5	0,1	4,7	2,8	0,2	0,8	279 818	8 750	
										19 615	**146**	**1,6**	**0,13**	**4,9**	**2,9**	**0,2**	**0,8**	**290 968**	**9 112**	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	1 199	8,9	0,1	0,008	0,2	0,1	0,01	0,04	17 367	564	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	102	0,8	0,007	0,001	0,02	0,01	0,001	0,003	1 476	48	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	-60	-0,4	-0,004	-0,0004	-0,01	-0,01	-0,001	-0,002	-868	-28	[5], [6]
774,5	5,75	0,063	0,0053	0,195	0,115	0,007	0,033	11,5	1,16	18 845	140	1,5	0,1	4,7	2,8	0,17	0,8	279 818	8 750	
										20 087	**149**	**1,6**	**0,14**	**5,0**	**2,9**	**0,2**	**0,8**	**297 793**	**9 334**	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	1 439	11	0,1	0,01	0,3	0,1	0,01	0,04	20 841	677	
774,5	5,75	0,063	0,0053	0,195	0,115	0,007	0,033	11,5	1,16	18 845	140	1,5	0,13	4,7	2,8	0,17	0,8	279 818	8 750	[5], [6]
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	72	1	0,01	0,0005	0,01	0,01	0,001	0,002	1 042	34	
										20 356	**151**	**1,6**	**0,1**	**5,1**	**2,9**	**0,2**	**0,8**	**301 701**	**9 461**	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	360	3	0,026	0,002	0,1	0,03	0,003	0,011	5 210	169	
774,5	5,75	0,063	0,0053	0,195	0,115	0,007	0,033	11,5	1,16	1 338	10	0,1	0,01	0,3	0,2	0,01	0,1	19 872	621	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	63	0	0,005	0,0004	0,01	0,01	0,001	0,002	917	30	[5], [6]
774,5	5,75	0,063	0,0053	0,195	0,115	0,007	0,033	11,5	1,16	38 823	288	3,2	0,26	9,8	5,8	0,4	1,7	576 461	18 026	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	72	1	0,005	0,0005	0,01	0,01	0,001	0,002	1 042	34	
										40 657	**302**	**3,3**	**0,3**	**10,2**	**6,0**	**0,4**	**1,7**	**603 502**	**18 880**	

1d Construction

		Fuel consumption [l/h]	Fuel consumption [l/FU]	Emissions per l [g/l] CO_2	NOx	PM	SO_2	CO	VOC + HC	CH_4	N_2O	Energy consumption [MJ/h]	Depletion of natural resources [kg/l]
Alt 1	**Base coarse stabilisation**												
	*Spreading of mining waste with tractor	16,7	491	2624	19	0,9	0,017	7,3	2,1	0,15	0,071	671	1,16
	*Spreading of cement with tractor (spreading vessel attached)	18,7	15,0	2624	19	0,9	0,017	7,3	2,1	0,15	0,071	671	1,16
	*Spreading of OSA with tractor (spreading vessel attached)	18,7	15,0	2624	19	0,9	0,017	7,3	2,1	0,15	0,071	671	1,16
	SUM		**520**										
Alt 2	**Base coarse stabilisation**												
	*Spreading of mining waste with tractor	16,7	491	2624	19	0,9	0,017	7,3	2,1	0,15	0,071	671	1,16
	*Spreading of cement with tractor (spreading vessel attached)	18,7	15,0	2624	19	0,9	0,017	7,3	2,1	0,15	0,071	671	1,16
	*Spreading of OSA with tractor (spreading vessel attached)	18,7	15,0	2624	19	0,9	0,017	7,3	2,1	0,15	0,071	671	1,16
	SUM		**520**										
Alt 3	**Base coarse stabilisation**												
	*Spreading of mining waste with tractor	16,7	491	2624	19	0,9	0,017	7,3	2,1	0,15	0,071	671	1,16
	*Spreading of cement with tractor (spreading vessel attached)	18,7	15,0	2624	19	0,9	0,017	7,3	2,1	0,15	0,071	671	1,16
	SUM		**505**										
Alt 4	Excavating the old ground road structure	31,5	1206	2607	18,0	0,70	0,02	6,30	1,70	0,15	0,07	1595	1,16
	Spreading of crushed stone	16,7	1093	2624	19	0,9	0,017	7,3	2,1	0,15	0,071	671	1,16
	*Spreading of cement with tractor (spreading vessel attached)	18,7	15,0	2624	19	0,9	0,017	7,3	2,1	0,15	0,071	671	1,16
	SUM		**2314**										

Emissions [kg/FU] CO_2	NOx	PM	SO_2	CO	VOC + HC	CH_4	N_2O	Energy consumption [MJ/FU]	Depletion of natural resources [kg/FU]	Reference:
										[5], [6]
1 287	9,32	0,44	0,01	3,58	1,03	0,07	0,03	19 709	569	
39	0,28	0,01	0,0003	0,11	0,03	0,002	0,001	537	17	
39	0,28	0,01	0,0003	0,11	0,03	0,002	0,001	537	17	
1 672	**12**	**0,55**	**0,01**	**4,6**	**1,3**	**0,10**	**0,05**	**25 017**	**740**	
										[5], [6]
1 287	50	0,02	0,000	0,0001	0,02	0,0003	0,00001	19 709	569	
39	0,3	0,01	0,000	0,1	0,03	0,002	0,001	537	17	
39	0,3	0,01	0,000	0,1	0,03	0,002	0,001	537	17	
1 672	**52**	**0,13**	**0,003**	**0,98**	**0,3**	**0,02**	**0,01**	**25 017**	**740**	
										[5], [6]
1 287	9,3	0,44	0,01	3,58	1,03	0,07	0,03	19 709	569	
39	0,28	0,01	0,0003	0,11	0,03	0,00	0,00	537	17	
1 633	**12**	**0,54**	**0,01**	**4,5**	**1,3**	**0,09**	**0,04**	**24 481**	**723**	
3 145	22	0,84	0,02	7,60	2,05	0,18	0,09	61 083	1 399	[5], [6]
2 868	21	0,98	0,02	7,98	2,30	0,16	0,08	43 913	1 268	
39	0,28	0,01	0,00	0,11	0,03	0,00	0,00	537	17	
6 052	**43**	**1,84**	**0,04**	**16**	**4,4**	**0,35**	**0,16**	**105 533**	**2 684**	

1e Final results

Narva-Mustajoe Life Cycle Analysis		Emissions total [kg/FU]								Energy consumption [MJ/FU]	Depletion of natural resources [kg/FU]	Global warming potential [kg CO_2 eqv/FU]
		CO_2	NOx	PM	SO_2	CO	VOC + HC	CH_4	N_2O			
ALT 1	**Material production**	87 743	259	37	249	1,2	0,71	0,001	0,02	824 539	160 292	87 749
	Material transportation	19 615	146	1,6	0,13	4,9	2,9	0,2	0,8	290 968	9 112	19 866
	Construction	1 672	12	0,55	0,01	4,6	1,3	0,096	0,05	25 017	740	1 689
		109 030	**417**	**39**	**250**	**11**	**4,9**	**0,27**	**0,89**	**1 140 524**	**170 144**	**109 304**
ALT 2	**Material production**	145 506	425	61	415	1,2	0,71	0,001	0,02	1 364 046	266 904	145 513
	Material transportation	20 087	149	1,6	0,14	5,0	2,9	0,2	0,8	297 793	9 334	20 342
	Construction	1 672	52	0,13	0,003	0,98	0,278	0,02	0,01	25 017	740	1 676
		167 265	**627**	**63**	**415**	**7,2**	**3,9**	**0,20**	**0,87**	**1 686 856**	**276 978**	**167 531**
ALT 3	**Material production**	174 388	508	73	498	1,2	0,71	0,001	0,02	1 633 799	320 209	174 394
	Material transportation	20 356	151	1,6	0,1	5,1	2,9	0,18	0,85	301 701	9 461	20 614
	Construction	1 633	12	0,54	0,01	4,5	1,3	0,09	0,04	24 481	723	1 649
		196 377	**671**	**76**	**498**	**11**	**4,9**	**0,28**	**0,91**	**1 959 981**	**330 393**	**196 658**
ALT 4	**Material production**	61 559	171	26	160	36	13	28	0,00	629 075	6 356 731	62 344
	Material transportation	40 657	302	3,3	0,28	10	6,0	0,37	1,7	603 502	18 880	41 181
	Construction	6 052	43	1,8	0,04	16	4,4	0,35	0,16	105 533	2 684	6 111
		108 268	**516**	**31**	**160**	**62**	**24**	**29**	**1,9**	**1 338 110**	**6 378 296**	**109 636**

Appendix 2 Simuna-Vaiatu LCA calculation sheets

2a Starting point

	Alternative strcutures	Materials for the structure	Processes for the construction
Alt 1	First mass stabilisation with OSA (EF CFB) and cement (1-3 m deep peat material) and base course stabilisation on top of it with OSA (EF CFB)	Oil shale ash, composite cement	Removal of the old road layers and top soil to the sides of the road. First mass stabilisation with OSA (EF CFB) and cement and base course stabilisation with OSA (EF CFB) on top of mass stabilisation.
Alt 2	First mass stabilisation with OSA (EF CFB) and cement (1-3 m deep peat material) and then complex stabi on top of it	Oil shale ash, composite cement	Removal of the old road layers and top soil to the sides of the road. First mass stabilisation with OSA (EF CFB) and cement and then complex stabilisation on top of mass stabilisation.
Alt 3	First mass stabilisation with cement (1-3 deep peat material) and then complex stabilisation on top of it	Cement, bitumen	Removal of the old road layers and top soil to the sides of the road. First mass stabilisation with cement and then complex stabilisation on top of mass stabilisation.
Alt 4	Replacing the peat layer with crushed stone, and complex stabilisation on top of it	Crushed stone, bitumen, cement	Removal of the peat layer. Filling with crushed stone. Complex stabilisation on top of crushed stone.

	Material	Amount [m²] / 1 kilometre	Amount [m³]	Amount [%]	Amount [t/1 kilometer]	Other information	Reference:
Alt 1	**Layer stabilisation**	9 200	1 840		3 588	Thickness 20 cm, width 9,2 meters, density 1950 kg/m3	Material report, Ramboll expertise
	*Oil shale fly ash EF CFB			9	323		
	Load material, sand, first 80 cm	9 200	7 360		13 248	Thickness 80 cm, density 1800 kg/m3	
	*sand, excavated 30 cm off	9 200	2 760		4 968	Thickness 80 cm, density 1800 kg/m3	
	*gravel sand 30 cm and medium sand 20 cm, left on place	9 200	4 600		8 280	Thickness 50 cm, density 1800 kg/m3	
	Mass stabilisation	9 200	18 400		35 880	Thickness average 2,0 m, density 1950 kg/m3	
	*Oil shale fly ash EF CFB			20	7 176		
	*Composite cement			6	2 153		
	Water			30	2 896	30 %	
Alt 2	**Complex stabilisation**	9 200	1 840		3 588	Complex stabilisation depth 20 cm, density 1950 kg/m3	Material report, Ramboll expertise
	*Bitumen			1	36		
	*Composite cement			2,5	90		
	Load material, sand, first 80 cm	9 200	7 360		13 248	Thickness 80 cm, density 1800 kg/m3	
	*sand, excavated 30 cm off	9 200	2 760		4 968	Thickness 80 cm, density 1800 kg/m3	
	*gravel sand 30 cm and medium sand 20 cm, left on place	9 200	4 600		8 280	Thickness 50 cm, density 1800 kg/m3	
	Mass stabilisation	9 200	18 400		35 880	Thickness average 2,0 m, density 1950 kg/m3	
	*Oil shale fly ash EF CFB			20	7 176		
	*Composite cement			6	2 153		
	Water			30	2 799	30 %	
Alt 3	**Complex stabilisation**	9 200	1 840		3 588	Thickness 20 cm, body material average density 1950 kg/m3	Material report, Ramboll expertise
	*Bitumen			1	36	Density 1900 kg/m3	
	*Composite cement			2,5	90		
	Load material, sand, first 80 cm	9 200	7 360		13 248	Thickness 80 cm, density 1800 kg/m3	
	*sand, excavated 30 cm off	9 200	2 760		4 968	Thickness 80 cm, density 1800 kg/m3	
	*gravel sand 30 cm and medium sand 20 cm, left on place	9 200	4 600		8 280	Thickness 50 cm, density 1800 kg/m3	
	Mass stabilisation	9 200	18 400		35 880	Thickness average 2,0 m, density 1950 kg/m3	
	*Composite cement			9	3 229		
	Water			30	969	30 %	
Alt 4	Peat layer	9 200	18 400		20 240	Thickness 2 m, density 1100 kg/m3 (average)	Material report, Ramboll expertise
	Complex stabilisation	9 200	1 840		3 588	Thickness 20 cm, body material average density 1950 kg/m3	
	*Bitumen			1	36		
	*Composite cement			2,5	90		
	Water			30	27	30 %	
	Gravel sand 30 cm and medium sand 20 cm	9 200	4 600		8 280	Thickness 50 cm, density 1800 kg/m3	
	Rock material for replacing the peat, 2 m	9 200	18 400		40 480	Thickness 2 m, density 2200 kg/m3	

2b Material production

	Materials	Amount used [tonnes/FU]	Emissions per ton [g/ton]									Energy consumption [MJ/ton]	Use of natural resources [g/ton]
			CO_2	NOx	PM	SO_2	CO	VOC	CH_4	HC	N_2O		
	Layer stabilisation												
	OSA EF CFB	323	No emissions from the oil shale ash as it is not a product, instead it is a by-product from the burning of the oil shale for energy.										
	Sand for load material	13 248	1 800	2,1	1,2	1,3	1,1	0,3	1,1			34	1010000
Alt 1	**Mass stabilisation**												
	OSA EF CFB	7 176	No emissions from the oil shale ash as it is not a product, instead it is a by-product from the burning of the oil shale for energy.										
	Composite cement	2 153	623 628	1794	263,1	1791						5825	1151000
	SUM	**32 670**											
	Complex stabilisation												
	Bitumen	36	255 669	1207		993	1057	410	764	68		510	1095010
	Composite cement	90	623 628	1794	263,1	1791						5825	1151000
	Sand for load material	13 248	1 800	2,1	1,2	1,3	1,1	0,3	1,1			34	1010000
Alt 2	**Mass stabilisation**												
	OSA EF CFB	7 176	No emissions from the oil shale ash as it is not a product, instead it is a by-product from the burning of the oil shale for energy.										
	Composite cement	2 153	623 628	1794	263,1	1791						5825	1151000
	SUM	**32 473**											
	Complex stabilisation												
	Bitumen	36	255 669	1207		993	1057	410	764	68		510	1095010
	Composite cement	90	623 628	1794	263,1	1791						5825	1151000
Alt 3	Sand for load material	13 248	1 800	2,1	1,2	1,3	1,1	0,3	1,1			34	1010000
	Mass stabilisation												
	Composite cement	3 229	623 628	1794	263,1	1791						5825	1151000
	SUM	**23 061**											
	Gravel and medium sand	8 280	1 800	2,1	1,2	1,3	1,1	0,3	1,1			34	1010000
	Rock material 2 m	40 480	1 800	2,1	1,2	1,3	1,1	0,3	1,1			34	1010000
Alt 4	**Complex stabilisation**												
	Bitumen	36	255 669	1207		993	1057	410	764	68		510	1095010
	Composite cement	90	623 628	1794	263,1	1791						5825	1151000
	SUM	**48 886**											

continuing…

Emissions total [kg/FU]											Reference:
CO_2	NOx	PM	SO_2	CO	VOC	CH_4	HC	N_2O	Energy consumption [MJ/FU]	Use of natural resources [kg/FU]	
No emissions from the oil shale ash as it is not a product, instead it is a by-product from the burning of the oil shale for energy.											
23 846	28	16	17	14,6	4,0	14,6			450 432	13 380 480	[8], [10]
No emissions from the oil shale ash as it is not a product, instead it is a by-product from the burning of the oil shale for energy.											
1 342 546	3862	566	3856						12 539 285	2 477 873	
1 366 393	**3 890**	**582**	**3 873**	**15**	**4**	**15**	**0**	**0**	**12 989 717**	**15 858 353**	
9 173	43		36	38	15	27	2,4		18 299	39 289	
55 939	161	24	161						522 470	103 245	
23 846	28	16	17	15	4,0	15			450 432	13 380 480	[8], [10]
No emissions from the oil shale ash as it is not a product, instead it is a by-product from the burning of the oil shale for energy.											
1 342 546	3862	566	3856						12 539 285	2 477 873	
1 431 506	**4 094**	**606**	**4 069**	**52**	**19**	**42**	**2**	**0**	**13 530 486**	**16 000 886**	
9 173	43	0	36	38	15	27	2		18 299	39 289	
55 939	161	24	161						522 470	103 245	
23 846	28	16	17	15	4	15			450 432	13 380 480	[8], [10]
2 013 820	5 793	850	5 783						18 808 927	3 716 809	
2 102 779	**6 025**	**889**	**5 997**	**52**	**19**	**42**	**2**	**0**	**19 800 128**	**17 239 823**	
14 904	17	9,9	11	9,1	2,5	9,1			281 520	8 362 800	
72 864	85	49	53	45	12	45			1 376 320	40 884 800	
											[8], [10], [11]
9 173	43	0	36	38	15	27	2,4		18 299	39 289	
55 939	161	24	161						522 470	103 245	
152 881	**307**	**82**	**260**	**92**	**29**	**81**	**2,4**	**0**	**2 198 609**	**49 390 134**	

2c Material transportation

	Material	Destination	Total mass [ton/FU]	Vehicle	Distance [km]	Number of loads	Total km*	Fuel consumption ** [l/km]	Total fuel consumption [l/FU]
Alt 1	**Layer stabilisation**								
	OSA EF CFB	to site	323	tank truck (40t)	155	8	2503	0,42	1051
	(OSA EF CFB)	(to landfill)	323	tank truck (40t)	-5	8	-81	0,42	-34
	Load material, sand, first 80 cm	to site	13248	truck (19 t)	30	697	41836	0,31	12969
	Load material, sand, 30 cm excavated off	to temporary storage	4968	truck (19 t)	3	261	1569	0,31	486
	Water								
	Mass stabilisation								
	OSA EF CFB	to site	7176	tank truck (40t)	155	179	55614	0,42	23358
	(OSA EF CFB)	(to landfill)	7176	tank truck (40t)	-5	179	-1794	0,42	-753
	Composite cement	to site	2153	tank truck (40t)	80	54	8611	0,42	3617
	Water	to site	2896	tank truck (40t)	3	72	434	0,42	182
	SUM						**108 692**		**40 876**
Alt 2	**Complex stabilisation**								
	Bitumen	to site	36	tank truck (40t)	135	1	242	0,42	102
	Composite cement	to site	90	tank truck (40t)	70	2	314	0,42	132
	Load material, sand, first 80 cm	to site	13248	truck (19 t)	30	697	41836	0,31	12969
	Load material, sand, 30 cm excavated off	to temporary storage	4968	truck (19 t)	3	261	1569	0,31	486
	Mass stabilisation								
	OSA EF CFB	to site	7176	tank truck (40t)	155	179	55614	0,42	23358
	(OSA EF CFB)	(to landfill)	7176	tank truck (40t)	-5	179	-1794	0,42	-753
	Composite cement	to site	2153	tank truck (40t)	70	54	7535	0,42	3165
	Water	to site	2799	tank truck (40t)	3	70	420	0,42	176
	SUM						**105 735**		**39 634**
Alt 3	**Complex stabilisation**								
	Bitumen	to site	36	tank truck (40t)	135	1	242	0,42	102
	Composite cement	to site	89,7	tank truck (40t)	70	2	314	0,42	132
	Load material, sand, first 80 cm	to site	13248	truck (19 t)	30	697	41836	0,31	12969
	Load material, sand, 30 cm excavated off	to temporary storage	4968	truck (19 t)	3	261	1569	0,31	486
	Mass stabilisation								
	Composite cement	to site	3229	tank truck (40t)	80	81	12917	0,42	5425
	OSA	to landfill	3229	tank truck (40t)	5	81	807	0,42	339
	Water	to site	969	tank truck (40t)	3	24	145	0,42	61
	SUM						**57 830**		**19 514**
Alt 4	Peat	off site	20240	truck (19 t)	3	1065	6392	0,31	1981
	Gravel and medium sand	to site	8280	truck (19 t)	30	436	26147	0,31	8106
	OSA	to landfill	7176	tank truck (40t)	5	378	3777	0,42	1586
	Complex stabilisation								
	*Bitumen	to site	35,88	tank truck (40t)	135	1	242	0,42	102
	*Composite cement	to site	89,7	tank truck (40t)	70	2	314	0,42	132
	*Stone material	to site	40480	truck (19 t)	30	2131	127832	0,31	39628
	SUM						**164 704**		**51 535**

Emissions [g/km]								Energy consumption [MJ/km]	Depletion of natural resources [kg/l]	Total emissions [kg / FU]								Energy consumption [MJ/FU]	Depletion of natural resources [kg/FU]	Reference:
CO_2	NOx	PM	SO_2	CO	VOC + HC	CH_4	N_2O			CO_2	NOx	PM	SO_2	CO	VOC + HC	CH_4	N_2O			
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	2 593	19	0,19	0,02	0,53	0,23	0,02	0,08	37 539	1 219	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	-84	-0,62	-0,006	-0,0006	-0,02	-0,007	-0,0007	-0,002	-1 211	-39	
774,5	5,8	0,063	0,0053	0,195	0,115	0,007	0,033	11,5	1,16	32 402	241	2,6	0,2	8,2	4,8	0,3	1,4	481 112	15 044	
774,5	5,8	0,063	0,0053	0,195	0,115	0,007	0,033	11,5	1,16	1 215	9,0	0,1	0,01	0,3	0,2	0,01	0,1	18 042	564	
																				[5]
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	57 616	428	4,1	0,39	12	5,0	0,50	1,7	834 210	27 095	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	-1 859	-13,8	-0,13	-0,01	-0,38	-0,16	-0,02	-0,05	-26 910	-874	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	8 921	66	0,6	0,06	1,8	0,78	0,08	0,26	129 168	4 195	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	450	3,3	0,03	0,003	0,09	0,04	0,004	0,01	6 515	212	
										101 255	**752**	**7,6**	**0,69**	**22**	**11**	**0,89**	**3,4**	**1 478 465**	**47 416**	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	251	1,9	0,02	0,002	0,05	0,02	0,002	0,01	3 633	118	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	325	2,4	0,02	0,002	0,07	0,03	0,003	0,01	4 709	153	
774,5	5,8	0,063	0,0053	0,195	0,115	0,007	0,033	11,5	1,16	32 402	241	2,6	0,22	8,2	4,8	0,3	1,4	481 112	15 044	
774,5	5,8	0,063	0,0053	0,195	0,115	0,007	0,033	11,5	1,16	1 215	9,0	0,10	0,01	0,31	0,18	0,01	0,05	18 042	564	[5]
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	57 616	428	4,1	0,39	12	5,0	0,50	1,7	834 210	27 095	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	-1 859	-14	-0,13	-0,01	-0,38	-0,16	-0,02	-0,05	-26 910	-874	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	7 806	58	0,56	0,05	1,6	0,68	0,07	0,23	113 022	3 671	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	435	3,2	0,03	0,003	0,09	0,04	0,004	0,01	6 297	205	
										98 192	**730**	**7,3**	**0,67**	**22**	**11**	**0,86**	**3,3**	**1 434 114**	**45 976**	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	251	1,9	0,02	0,002	0,05	0,02	0,002	0,007	3 633	118	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	325	2,4	0,02	0,002	0,07	0,03	0,003	0,010	4 709	153	
774,5	5,75	0,063	0,0053	0,195	0,115	0,007	0,033	11,5	1,16	32 402	241	2,6	0,22	8,2	4,8	0,29	1,4	481 112	15 044	
774,5	5,8	0,063	0,0053	0,195	0,115	0,007	0,033	11,5	1,16	1 215	9	0,1	0,0	0,3	0,2	0,0	0,1	18 042	564	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	13 382	99	0,96	0,09	2,71	1,16	0,12	0,39	193 752	6 293	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	836	6,2	0,06	0,006	0,17	0,07	0,007	0,02	12 110	393	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	151	1,1	0,01	0,001	0,03	0,01	0,001	0,004	2 180	71	
										48 562	**361**	**3,8**	**0,3**	**11**	**6,3**	**0,4**	**1,9**	**715 537**	**22 636**	
774,5	5,8	0,063	0,0053	0,195	0,115	0,007	0,033	11,5	1,16	4 950	37	0,4	0,0	1,2	0,7	0,0	0,2	73 503	2 298	
774,5	5,8	0,063	0,0053	0,195	0,115	0,007	0,033	11,5	1,16	20 251	150	1,6	0,1	5,1	3,0	0,2	0,9	300 695	9 403	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	11,5	1,16	3 913	29	0,28	0,03	0,79	0,34	0,03	0,12	43 434	1 840	
																				[5]
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	251	1,9	0,018	0,002	0,051	0,022	0,002	0,007	3 633	118	
1036	7,7	0,074	0,0071	0,21	0,09	0,009	0,0305	15	1,16	325	2,4	0,023	0,002	0,066	0,028	0,003	0,010	4 709	153	
774,5	5,8	0,063	0,0053	0,195	0,115	0,007	0,033	11,5	1,16	99 006	735	8,1	0,7	24,9	14,7	0,9	4,2	1 470 063	45 968	
										128 696	**955**	**10**	**0,9**	**32**	**19**	**1,2**	**5,4**	**1 896 037**	**59 780**	

2d Construction

		Fuel consumption [l/h]	Capacity [m²/h]	Capacity [h/m³]	Volume [m³/h]	[l/m³]	m³/FU	Time [h/FU]	Fuel consumption [l/FU]
Alt 1	**Layer stabilisation**								
	*Road grader	44	11875					0,8	35
	*Spreading of OSA with tractor (spreading vessel attached)	19	11500					0,8	15
	*The rotary mixer used in stabilisation work	44	11875					0,8	35
	*Road grader	44	11875					0,8	35
	Spreading of gravel and medium sand with excavator	31,5		0,022	45	0,693	7 360	162	5 100
	Excavating of gravel and medium sand with excavator	31,5		0,022	45	0,693	2 760	61	1 913
	Mass stabilisation	30			120		18 400	153	4 600
	*Mass stabilisation of peat with cement + OSA (binders mixed)'								
	*Roller								
	SUM								**11 735**
Alt 2	**Complex stabilisation**								
	*Bitumen	27,2	11500					0,8	22
	*Spreading of cement with tractor (spreading vessel attached)	19	11500					0,8	15
	Spreading of gravel and medium sand with excavator	31,5		0,022	45	0,693	7 360	162	5 100
	Excavating of gravel and medium sand with excavator	31,5		0,022	45	0,693	2 760	61	1 913
	Mass stabilisation	30			120		18 400	153	4 600
	*Mass stabilisation of peat with cement + OSA (binders mixed)'								
	*Roller								
	SUM								**11 650**
Alt 3	**Complex stabilisation**								
	*Bitumen	27,2	11500					0,8	22
	*Spreading of cement with tractor (spreading vessel attached)	19	11500					0,8	15
	Spreading of gravel and medium sand with excavator	31,5		0,022	45	0,693	7 360	162	5 100
	Excavating of gravel and medium sand with excavator	31,5		0,022	45	0,693	2 760	61	1 913
	Mass stabilisation	30			120		18 400	153	4 600
	*Mass stabilisation of peat with cement								
	*Roller								
	SUM								**11 650**
Alt 4	Excavating the peat layer	31,5		0,007	77	0,22	18 400	129	4 057
	Complex stabilisation								
	*Bitumen	27,2	11500					0,8	22
	*Spreading of cement with tractor (spreading vessel attached)	19	11500					0,8	15
	*Spreading of crushed stone 2 m	31,5	11500	0,022	45	0,693	18 400	405	12 751
	SUM								**16 845**

Emissions per l [g/l]										Emissions [kg/FU]								Energy consumption [MJ/FU]	Depletion of natural resources [kg/FU]	Reference:
CO_2	NOx	PM	SO_2	CO	VOC + HC	CH_4	N_2O	Energy consumption [MJ/h]	Depletion of natural resources [kg/l]	CO_2	NOx	PM	SO_2	CO	VOC + HC	CH_4	N_2O			
2 607	25	1,2	0,017	7,6	2,6	0,15	0,07	1639	1,16	92	0,89	0,04	0,001	0,27	0,09	0,01	0,003	1 311	41	
2 624	19	0,9	0,017	7,3	2,1	0,15	0,071	671	1,16	40	0,29	0,01	0,0003	0,11	0,03	0,002	0,001	537	18	
2 607	25	1,2	0,017	5,4	2,6	0,15	0,072	1639	1,16	92	0,89	0,04	0,001	0,19	0,09	0,01	0,003	1 311	41	
2 607	25	1,2	0,017	7,6	2,6	0,15	0,07	1639	1,16	92	0,89	0,04	0,001	0,27	0,09	0,01	0,003	1 311	41	
2 607	18	0,7	0,017	6,3	1,7	0,15	0,071	1144	1,16	13 297	92	3,6	0,09	32	8,7	0,77	0,36	185 236	5 917	[5], [12]
2 607	18	0,7	0,017	6,3	1,7	0,15	0,071	1144	1,16	4 986	34	1,3	0,03	12	3,3	0,29	0,14	69 464	2 219	
									1,16	11 070	76	3,0	0,07	27	7,2	0,64	0,30	154 135	5 336	
										29 670	**206**	**8,0**	**0,19**	**72**	**19**	**1,7**	**0,81**	**413 306**	**13 612**	
2 607	17	0,7	0,017	6,5	1,7	0,15	0,072	979	1,16	57	0,37	0,02	0,00	0,14	0,04	0,00	0,00	783	25	
2 624	19	0,9	0,017	7,3	2,1	0,15	0,071	671	1,16	40	0,29	0,01	0,00	0,11	0,03	0,00	0,00	537	18	
2 607	18	0,7	0,017	6,3	1,7	0,15	0,071	1144	1,16	13 297	92	3,6	0,09	32,13	8,67	0,77	0,36	185 236	5 917	
2 607	18	0,7	0,017	6,3	1,7	0,15	0,071	1144	1,16	4 986	34	1,3	0,03	12	3,3	0,29	0,14	69 464	2 219	[5], [12]
									1,16	11 070	76	3,0	0,07	27	7,2	0,64	0,30	154 135	5 336	
										29 450	**203**	**7,9**	**0,19**	**71**	**19**	**1,7**	**0,80**	**410 156**	**13 514**	
2 607	17	0,7	0,017	6,5	1,7	0,15	0,072	979	1,16	57	0,37	0,02	0,0004	0,14	0,04	0,003	0,002	783	25	
2 624	19	0,9	0,017	7,3	2,1	0,15	0,071	671	1,16	40	0,29	0,01	0,0003	0,11	0,03	0,002	0,001	537	18	
2 607	18	0,7	0,017	6,3	1,7	0,15	0,071	1144	1,16	13 297	92	3,6	0,09	32	8,7	0,77	0,36	185 236	5 917	
2 607	18	0,7	0,017	6,3	1,7	0,15	0,071	1144	1,16	4 986	34	1,3	0,03	12	3,3	0,29	0,14	69 464	2 219	[5], [12]
									1,16	11 070	76	3,0	0,07	27	7,2	0,64	0,30	154 135	5 336	
										29 450	**203**	**8**	**0,19**	**71**	**19**	**1,7**	**0,80**	**410 156**	**13 514**	
2 607	18	0,7	0,017	6,3	1,7	0,15	0,071	1144	1,16	10 577	73	2,8	0,07	26	6,9	0,61	0,29	147 347	4706	
2 607	17	0,7	0,017	6,5	1,7	0,15	0,072	979	1,16	57	0,37	0,02	0,00	0,14	0,04	0,00	0,00	783	25	
2 624	19	0,9	0,017	7,3	2,1	0,15	0,071	671	1,16	40	0,29	0,01	0,00	0,11	0,03	0,00	0,00	537	18	[5], [12]
2 607	18	0,7	0,017	6,3	1,7	0,15	0,071	1144	1,16	33 242	229,52	8,93	0,22	80,33	21,68	1,91	0,91	463 091	14791	
										43 916	**303**	**12**	**0,29**	**106**	**29**	**2,5**	**1,2**	**611 758**	**19 541**	

2d Final results

Simuna-Vaiatu Life Cycle Analysis		Emissions total [kg/FU]								Energy consumption [MJ/FU]	Use of natural resources [kg/FU]	Global warming potential [kg CO_2 eqv / FU]
		CO_2	NOx	PM	SO_2	CO	VOC + HC	CH_4	N_2O			
ALT 1	**Material production**	1 366 393	3 890	582	3 873	15	4,0	15	0	12 989 717	15 858 353	1 366 801
	Material transportation	101 255	752	7,6	0,69	22	11	0,89	3,4	1 478 465	47 416	102 300
	Construction	29 670	206	8,0	0,19	72	19	1,7	0,81	413 306	13 612	29 959
		1 497 317	**4 848**	**598**	**3 874**	**109**	**34**	**17**	**4,2**	**14 881 488**	**15 919 381**	**1 499 059**
ALT 2	**Material production**	1 431 506	4 094	606	4 069	52	21	42	0	13 530 486	16 000 886	1 432 681
	Material transportation	98 192	730	7,3	0,67	22	11	0,86	3,3	1 434 114	45 976	99 209
	Construction	29 450	203	7,9	0,19	71	19	1,7	0,80	410 156	13 514	29 736
		1 559 147	**5 027**	**621**	**4 070**	**145**	**51**	**45**	**4,1**	**15 374 756**	**16 060 376**	**1 561 626**
ALT 3	**Material production**	2 102 779	6 025	889	5 997	52	21	42	0	19 800 128	17 239 823	2 103 954
	Material transportation	48 562	361	3,8	0,33	11	6	0,43	1,9	715 537	22 636	49 132
	Construction	29 450	203	8	0,19	71	19	1,7	0,80	410 156	13 514	29 736
		2 180 790	**6 589**	**901**	**5 998**	**135**	**47**	**44**	**2,7**	**20 925 821**	**17 275 973**	**2 182 822**
ALT 4	**Material production**	152 881	307	82	260	92	32	81	0	2 198 609	49 390 134	155 150
	Material transportation	128 696	955	10	0,87	32	19	1,2	5,4	1 896 037	59 780	130 345
	Construction	43 916	303	12	0,29	106	29	2,5	1,2	611 758	19 541	44 343
		325 493	**1 565**	**104**	**261**	**230**	**79**	**85**	**6,6**	**4 706 404**	**49 469 455**	**329 838**

Appendix 3 Narva-Mustajoe LCC calculation sheets

3a Material amounts and measurements

Structures that are included in the calculations:	Alt1 Layer stabilisation with OSA Q1 and cement	Alt2 Layer stabilisation with binder OSA Q2 and cement	Alt3 Layer stabilisation with cement	Alt4 Complex stabilisation (with bitumen and cement)
Pavement				
Mass	Height 9 cm, width 900 cm			
Pavement thickness [mm]	90	90	90	90
Surface area				
* surface area [m^2] of the stabilisation	9500	9500	9500	9500
* surface area [m^2] pavement	9000	9000	9000	9000
Other structure layers	**Stabilised layer 25 cm: binder (OSA EF BL3 OBT 6 % + cement 3 %) + crushed asphalt 9 cm + mining waste 16 cm**	**Stabilised layer 25 cm: binder (OSA CYCL 5 % + cement 5 %)+ crushed asphalt 9 cm + mining waste 16 cm**	**Stabilised layer 25 cm: binder (cement 6 %)+ crushed asphalt 9 cm + mining waste 16 cm**	**Stabilised layer 15 cm: binder (bitumen 1 % + cement 2,5 %) + crushed rock 15 cm**
Thickness of the mining waste (m)	**0,16**	**0,16**	**0,16**	
Thickness of the crushed aggregate (m)				**0,31**
The amount of mining waste MWA (Aidu 77km) / crushed aggregate (77 km) needed amount (m3rtr) in the structure (per 1 road-km)	**1520**	**1520**	**1520**	
The amount of needed crushed aggregate (m3rtr) in the structure, (per 1 tiekm)				**2945**
The amount of needed crushed aggregate (previous mass in the structure) tons (per 1 tiekm)				**6185**
Wet density of stabilised aggregate [kg/m^3]	1975	1975	1975	1975
Water content of stabilised aggregate [%]	4,5	4,5	4,5	4,5
Dry density of stabilised aggregate [kg/m^3]	1886	1886	1886	1886
Stabiloitavaa runkoainetta_tyoyksilla [m^3/km]	2375	2375	2375	1425
Total dry mass of stabilised aggregate [t/km]	4479	4479	4479	2687
Total mass of stabilised aggregate [t/km]	**4631**	**4631**	**4631**	**2779**
OSA amount in binder mixture [%]	6,0	5,0	0	0
OSA, dry [t/km]	269	224	0	0
OSA, dry [t/km]	278	232		
Bitumen (%)	0	0	0	1
Bitumen (t/km)	0	0	0	27
Bitumen (t/km)	0	0	0	28
Cement amount in binder mixture [%]	3,0	5,0	6,0	2,5
Cement, dry [t/km]	134	224	269	67
Cement, dry [t/km]	139	232	278	69
Target water content of the binder mixture [%]	30	30	30	30
Extra water for mixing [m^3/km]	17	17	17	10
Total mass of the binder mixture (t/km)	420	465	285	104

3b Calculated material costs

		Alt1 Layer stabilisation with OSA Q1 and cement		Alt2 Layer stabilisation with binder OSA Q2 and cement		Alt3 Layer stabilisation with cement		Alt4 Complex stabilisation (with bitumen and cement)	
Crushed rock	Total need [t/road-km]	0		0		0		6 185	
	Unit price [€/t]	13,50		13,50		13,50		13,50	
	Price in the crushing plant [€]	**0**		**0**		**0**		**83 491**	
	Transportation distance [km]	77		77		77		77	
	Transportation cost [€/t-km]	**0,06**		**0,06**		**0,06**		**0,06**	
	Transportations [€/t-km]	**0**		**0**		**0**		**28 572**	
	Transportations on site [€/road-km]		**0**		**0**		**0**		**112 063**
Mining waste	Estimated need [t]	3 002		3 002		3 002		0	
	*unit price [€/t]	**3,20**		**3,20**		**3,20**		**3,20**	
	*price [€]	**9 606**		**9 606**		**9 606**		**0**	
	*transportation distance [km]	***77***		***77***		***77***		***77***	
	*transportation cost [€/t-km]	**0,06**		**0,06**		**0,06**		**0,06**	
	*transportations [€]	**13 869**		**13 869**		**13 869**		**0**	
	Transportations on site [€/road-km]	23 476	**23 476**	23 476	**23 476**	23 476	**23 476**	0	**0**
Binder components	**Cement [t/road-km]**	139		232		278		69	
	*unit price [€/t]	87,75		87,75		87,75		87,75	
	*price [€]	**12 197**		**20 358**		**24 395**		**6 055**	
	*transportation distance [km]	100		100		100		100	
	*transportation cost [€/t-km]	0,1254		0,1254		0,1254		0,1254	
	*transportations [€]	**1 743**		**2 909**		**3 486**		**865**	
	***costs in mixing site [€/road-km]**		**13 940**		**23 267**		**27 881**		**6 920**
	OSA [t/road-km]	278		232		0		0	
	*unit price [€/t]	8,00		8,00		8,00		8,00	
	*price [€]	**2 224**		**1 856**		**0**		**0**	
	*transportation distance [km]	8,5		8,5		8,5		8,5	
	*transportation cost [€/t-km]	0,1254		0,1254		0,1254		0,1254	
	*transportations[€]	**296**		**247**		**0**		**0**	
	***costs in mixing site [€/road-km]**		**2 520**		**2 103**		**0**		**0**

The benefit obtained from avoiding the landfilling	**OSA [t/road-km]**	278		232		0		0	
	*unit price [€/t]	50,00		50,00		50,00		50,00	
	*price [€]	**-13 900**		**-11 600**		**0**		**0**	
	*transportation distance [km]	5,0		5,0		5,0		5,0	
	*transportation cost [€/t-km]	0,1254		0,1254		0,1254		0,1254	
	*transportations [€]	**-174**		**-145**		**0**		**0**	
	***costs in mixing site [€/road-km]**		**-14 074**		**-11 745**		**0**		**0**
Bitumen	**Bitumen [t/road-km]**	0		0		0		27	
	*unit price [€/t]	430,00		430,00		430,00		430,00	
	*price [€]	**0**		**0**		**0**		**11 556**	
	*transportation distance [km]	44		44		44		44	
	*transportation cost [€/t-km]	0,1254		0,1254		0,1254		0,1254	
	*transportations [€]	**0**		**0**		**0**		**148**	
	***costs in mixing site [€/road-km]**		**0**		**0**		**0**		**11 704**
Water	**water [m3/road-km]**	67		67		67		67	
	*unit price [€/t]	0,00		0,00		0,00		0,00	
	*price [€]	**0**		**0**		**0**		**0**	
	*transportation distance [km]	3		3		3		3	
	*transportation cost [€/t-km]	0,13		0,13		0,13		0,13	
	*transportations [€]	**25**		**25**		**25**		**25**	
	***costs in mixing site [€/road-km]**		25		25		25		**25**
Landfilling costs from general overhaul	**Total mass [t/road-km]**	0		0		0		0	
No landfilling in any of the alternatives	*unit price [€/t]	50,00		50,00		50,00		50,00	
	*price [€]	**0**		**0**		**0**		**0**	
	*transportation distance [km]	5,0		5,0		5,0		5,0	
	*transportation cost [€/t-km]	0,13		0,13		0,13		0,13	
	*transportations [€]	**0**		**0**		**0**		**0**	
	***costs in mixing site [€/road-km]**		**0**		**0**		**0**		**0**
	Material costs on site [€/tie-km] in initial stage	**39 961**		**48 871**		**51 381**		**130 712**	
		Alt1 Layer stabilisation with OSA Q1 and cement		**Alt2 Layer stabilisation with binder OSA Q2 and cement**		**Alt3 Layer stabilisation with cement**		**Alt4 Complex stabilisation (with bitumen and cement)**	
	Road length [m] = FU	1 000		1 000		1 000		1 000	
	Material costs on site [€/tie-km] and landfilling of OSA taken into account	**25 887**		**37 126**		**51 381**		**130 712**	
		Alt1 Layer stabilisation with OSA Q1 and cement		**Alt2 Layer stabilisation with binder OSA Q2 and cement**		**Alt3 Layer stabilisation with cement**		**Alt4 Complex stabilisation (with bitumen and cement)**	
	Road length [m] = FU	1 000		1 000		1 000		1 000	

3c Calculated work costs

Structures included in the calculation:		Alt1 Layer stabilisation with OSA Q1 and cement		Alt2 Layer stabilisation with binder OSA Q2 and cement		Alt3 Layer stabilisation with cement		Alt4 Complex stabilisation (with bitumen and cement)	
Paving (new)		AC 12 surf 4 cm + AC 32 base 5 cm; width 9,00 m							
AC 12, 4 cm, bitumen 5,6 %	Unit price [€/m²]	*9,03*		*9,03*		*9,03*		*9,03*	
AC 32, 5 cm, bitumen 4,0 %	Unit price [€/m²]	*8,09*		*8,09*		*8,09*		*8,09*	
	Surface area to be paved [m²]	9 000		9 000		9 000		9 000	
	New pavement [€]		**154 080**		**154 080**		**154 080**		**154 080**
	Pavement [€/tie-m]	*154,08*		*154,08*		*154,08*		*154,08*	
	Length of FU [m]	1 000		1 000		1 000		1 000	
Work stages	structure; m3-rtr/FU	2 375		2 375		2 375		1 425	
	structure-theor-aggeregate_m2;/	9 500		9 500		9 500		9 500	
	structure-theor-surf_m2;/FU	9 000		9 000		9 000		9 000	
Milling of the pavement and transport to the storage (distance 8,5 km), and pile dumping	unit price; €/m2-rtr	0	0	0	0	0	0	1,2	10 800
Milling of the pavement	unit price; €/m2-rtr	0,79	7 110	0,79	7 110	0,79	7 110		
Spreading of the mining waste	unit price; €/m3-rtr	2,40	22 800	2,4	22 800	2,4	22 800		
Spreading of the crushed rock	unit price; €/m3-rtr							2,40	22 800
Stabilisation (including the spreading of the binders, mixing, wetting, compacting)	unit price; €/m3-rtr	26	61 750	22	52 250	16	38 000	33	47 500
Adding the water	unit price; €/m3-rtr		0	0	0	0	0	0	0
			91 660		**82 160**		**67 910**		**81 100**
	Costs [€/road-km]	**245 740**		**236 240**		**221 990**		**235 180**	
		Alt1 Layer stabilisation with OSA Q1 and cement		**Alt2 Layer stabilisation with binder OSA Q2 and cement**		**Alt3 Layer stabilisation with cement**		**Alt4 Complex stabilisation (with bitumen and cement)**	
General overhaul									
NEW pavement (REM)									
AC 12, 4 cm, bitumen 5,6 %	Unit price [€/m²]	*9,03*		*9,03*		*9,03*		*9,03*	
AC 32, 5 cm, bitumen 4,0 %	Unit price [€/m²]	*8,09*		*8,09*		*8,09*		*8,09*	
Milling of the surface and transportation to the storage (distance 8,5 km)	Unit price [€/m²]	*1,20*		*1,20*		*1,20*		*1,20*	
	Surface area to be paved [m²]	9 000		9 000		9 000		9 000	
	New pavement [€]		**164 880**		**164 880**		**164 880**		**164 880**
	Pavement [€/tie-m]	*164,88*		*164,88*		*164,88*		*164,88*	
	Length of the FU [m]	1 000		1 000		1 000		1 000	
Stabilisation									
Work stages	structure-theor-m3; m3-rtr/FU	2 375		2 375		2 375		1 425	
	structure-theor-m2-pavement	9 000		9 000		9 000		9 000	
	unit price; €/m3-rtr		0		0		0		0
Stabilisation	unit price; €/m3-rtr	26	61 750	22	52 250	16	38 000	33	47 500
Milling of the surface and immeadiate use in the old structure	unit price; €/m3-rtr	0,79	7 110	0,79	7 110	0,79	7 110	0,79	7 110
Adding water	unit price; €/m3-rtr		0	0	0	0	0	0	0
			68 860		**59 360**		**45 110**		**54 610**
	Costs [€/road-km]	**233 740**		**224 240**		**209 990**		**219 490**	

3d Maintenance scenarios

Structure alternative			Alt1 Layer stabilisation with OSA Q1 and cement	Alt2 Layer stabilisation with binder OSA Q2 and cement	Alt3 Layer stabilisation with cement	Alt4 Complex stabilisation (with bitumen and cement)
Paving			AC	AC	AC	AC
Patching (UREM) (assumption 50 % * 40 % of the REM price)		Maintenance cycles (a)	8	8	8	8
			30 816	**30 816**	**30 816**	**30 816**
Re-paving (as REM)		Maintenance cycles (a)	8	8	8	8
			154 080	**154 080**	**154 080**	**154 080**
Need of general overhaul	Scenario 1	Action cycles (a)	32	28	24	20
		Action	Milling of the old surface and mixing it into lowe ash stabilised layer into 200-300 mm depth. New stabilisation (ash + cement) and paving.	Milling of the old surface and mixing it into lowe ash stabilised layer into 200-300 mm depth. New stabilisation (ash + cement) and paving.	Milling of the old surface and mixing it into lowe ash stabilised layer into 200-300 mm depth. New stabilisation (cement) and paving.	Milling of the old surface and mixing it into lowe ash stabilised layer into 200-300 mm depth. New stabilisation (ash + cement) and paving.
		€/FU	**259 627**	**261 366**	**261 371**	**350 202**
	Scenario 2	Action cycles (a)	36	32	28	24
		Action	Milling of the old surface and mixing it into lowe ash stabilised layer into 200-300 mm depth. New stabilisation (ash + cement) and paving.	Milling of the old surface and mixing it into lowe ash stabilised layer into 200-300 mm depth. New stabilisation (ash + cement) and paving.	Milling of the old surface and mixing it into lowe ash stabilised layer into 200-300 mm depth. New stabilisation (cement) and paving.	Milling of the old surface and mixing it into lowe ash stabilised layer into 200-300 mm depth. New stabilisation (ash + cement) and paving.
		€/FU	**259 627**	**261 366**	**261 371**	**350 202**
	Scenario 3	Action cycles (a)	40	36	32	28
		Action	Milling of the old surface and mixing it into lowe ash stabilised layer into 200-300 mm depth. New stabilisation (ash + cement) and paving.	Milling of the old surface and mixing it into lowe ash stabilised layer into 200-300 mm depth. New stabilisation (ash + cement) and paving.	Milling of the old surface and mixing it into lowe ash stabilised layer into 200-300 mm depth. New stabilisation (cement) and paving.	Milling of the old surface and mixing it into lowe ash stabilised layer into 200-300 mm depth. New stabilisation (ash + cement) and paving.
		€/FU	**259 627**	**261 366**	**261 371**	**350 202**

3e Current values of maintenance scenarios

Current value of the actions / scenario 1										
Year	Alternative / actions				**Year**	D(ir)	**Alternative / actions**			
	Alt1	**Alt2**	**Alt3**	**Alt4**			**Alt1**	**Alt2**	**Alt3**	**Alt4**
0	0	0	0	0	0	1,000				
1	0	0	0	0	1	0,962				
2	0	0	0	0	2	0,925				
3	0	0	0	0	3	0,889				
4	26 342	26 342	26 342	26 342	4	0,855	30 816	30 816	30 816	30 816
5	0	0	0	0	5	0,822				
6	0	0	0	0	6	0,790				
7	0	0	0	0	7	0,760				
8	112 585	112 585	112 585	112 585	8	0,731	154 080	154 080	154 080	154 080
9	0	0	0	0	9	0,703				
10	0	0	0	0	10	0,676				
11	0	0	0	0	11	0,650				
12	19 248	19 248	19 248	19 248	12	0,625	30 816	30 816	30 816	30 816
13	0	0	0	0	13	0,601				
14	0	0	0	0	14	0,577				
15	0	0	0	0	15	0,555				
16	82 265	82 265	82 265	82 265	16	0,534	154 080	154 080	154 080	154 080
17	0	0	0	0	17	0,513				
18	0	0	0	0	18	0,494				
19	0	0	0	0	19	0,475				
20	14 064	14 064	14 064	159 828	20	0,456	30 816	30 816	30 816	350 202
21	0	0	0	0	21	0,439				
22	0	0	0	0	22	0,422				
23	0	0	0	0	23	0,406				
24	60 110	60 110	101 967	12 022	24	0,390	154 080	154 080	261 371	30 816
25	0	0	0	0	25	0,375				
26	0	0	0	0	26	0,361				
27	0	0	0	0	27	0,347				
28	10 276	87 160	10 276	51 382	28	0,333	30 816	261 366	30 816	154 080
29	0	0	0	0	29	0,321				
30	0	0	0	0	30	0,308				
31	0	0	0	0	31	0,296				
32	74 009	8 784	43 922	8 784	32	0,285	259 627	30 816	154 080	30 816
33	0	0	0	0	33	0,274				
34	0	0	0	0	34	0,264				
35	0	0	0	0	35	0,253				
36	7 509	37 544	7 509	37 544	36	0,244	30 816	154 080	30 816	154 080
37	0	0	0	0	37	0,234				
38	0	0	0	0	38	0,225				
39	0	0	0	0	39	0,217				
40	32 093	6 419	32 093	6 419	40	0,208	154 080	30 816	154 080	30 816
41	0	0	0	0	41					
Current value	**438 500**	**454 520**	**450 269**	**516 418**						

Current value of actions / scenario 2

Year	Alternative / actions				Year	D(ir)	Alternative / actions			
	Alt1	Alt2	Alt3	Alt4			Alt1	Alt2	Alt3	Alt4
0	0	0	0	0	0	1,000				
1	0	0	0	0	1	0,962				
2	0	0	0	0	2	0,925				
3	0	0	0	0	3	0,889				
4	26 342	26 342	26 342	26 342	4	0,855	30 816	30 816	30 816	30 816
5	0	0	0	0	5	0,822				
6	0	0	0	0	6	0,790				
7	0	0	0	0	7	0,760				
8	112 585	112 585	112 585	112 585	8	0,731	154 080	154 080	154 080	154 080
9	0	0	0	0	9	0,703				
10	0	0	0	0	10	0,676				
11	0	0	0	0	11	0,650				
12	19 248	19 248	19 248	19 248	12	0,625	30 816	30 816	30 816	30 816
13	0	0	0	0	13	0,601				
14	0	0	0	0	14	0,577				
15	0	0	0	0	15	0,555				
16	82 265	82 265	82 265	82 265	16	0,534	154 080	154 080	154 080	154 080
17	0	0	0	0	17	0,513				
18	0	0	0	0	18	0,494				
19	0	0	0	0	19	0,475				
20	14 064	14 064	14 064	14 064	20	0,456	30 816	30 816	30 816	30 816
21	0	0	0	0	21	0,439				
22	0	0	0	0	22	0,422				
23	0	0	0	0	23	0,406				
24	60 110	60 110	60 110	136 622	24	0,390	154 080	154 080	154 080	350 202
25	0	0	0	0	25	0,375				
26	0	0	0	0	26	0,361				
27	0	0	0	0	27	0,347				
28	10 276	10 276	87 161	10 276	28	0,333	30 816	30 816	261 371	30 816
29	0	0	0	0	29	0,321				
30	0	0	0	0	30	0,308				
31	0	0	0	0	31	0,296				
32	43 922	74 504	8 784	43 922	32	0,285	154 080	261 366	30 816	154 080
33	0	0	0	0	33	0,274				
34	0	0	0	0	34	0,264				
35	0	0	0	0	35	0,253				
36	63 263	7 509	37 544	7 509	36	0,244	259 627	30 816	154 080	30 816
37	0	0	0	0	37	0,234				
38	0	0	0	0	38	0,225				
39	0	0	0	0	39	0,217				
40	6 419	32 093	6 419	32 093	40	0,208	30 816	154 080	30 816	154 080
41	0	0	0	0	41					
Nykyarvo	**438 492**	**438 995**	**454 521**	**484 924**						

Current value of actions / scenario 3										
Year	**Alternative / actions**				**Year**	D(ir)	**Alternative / actions**			
	Alt1	**Alt2**	**Alt3**	**Alt4**			**Alt1**	**Alt2**	**Alt3**	**Alt4**
0	0	0	0	0	0	1,000				
1	0	0	0	0	1	0,962				
2	0	0	0	0	2	0,925				
3	0	0	0	0	3	0,889				
4	26 342	26 342	26 342	26 342	4	0,855	30 816	30 816	30 816	30 816
5	0	0	0	0	5	0,822				
6	0	0	0	0	6	0,790				
7	0	0	0	0	7	0,760				
8	112 585	112 585	112 585	112 585	8	0,731	154 080	154 080	154 080	154 080
9	0	0	0	0	9	0,703				
10	0	0	0	0	10	0,676				
11	0	0	0	0	11	0,650				
12	19 248	19 248	19 248	19 248	12	0,625	30 816	30 816	30 816	30 816
13	0	0	0	0	13	0,601				
14	0	0	0	0	14	0,577				
15	0	0	0	0	15	0,555				
16	82 265	82 265	82 265	82 265	16	0,534	154 080	154 080	154 080	154 080
17	0	0	0	0	17	0,513				
18	0	0	0	0	18	0,494				
19	0	0	0	0	19	0,475				
20	14 064	14 064	14 064	14 064	20	0,456	30 816	30 816	30 816	30 816
21	0	0	0	0	21	0,439				
22	0	0	0	0	22	0,422				
23	0	0	0	0	23	0,406				
24	60 110	60 110	60 110	60 110	24	0,390	154 080	154 080	154 080	154 080
25	0	0	0	0	25	0,375				
26	0	0	0	0	26	0,361				
27	0	0	0	0	27	0,347				
28	10 276	10 276	10 276	116 785	28	0,333	30 816	30 816	30 816	350 202
29	0	0	0	0	29	0,321				
30	0	0	0	0	30	0,308				
31	0	0	0	0	31	0,296				
32	43 922	43 922	74 506	8 784	32	0,285	154 080	154 080	261 371	30 816
33	0	0	0	0	33	0,274				
34	0	0	0	0	34	0,264				
35	0	0	0	0	35	0,253				
36	7 509	63 687	7 509	37 544	36	0,244	30 816	261 366	30 816	154 080
37	0	0	0	0	37	0,234				
38	0	0	0	0	38	0,225				
39	0	0	0	0	39	0,217				
40	54 077	6 419	32 093	6 419	40	0,208	259 627	30 816	154 080	30 816
41	0	0	0	0	41					
Current value	**430 397**	**438 916**	**438 997**	**484 145**						

3f LCC calculation final results

Construction and maintenance scenario 1

		Alt1	**Alt2**	**Alt3**	**Alt4**
Construction costs, year 0	R_N	**271 627**	**273 366**	**273 371**	**365 892**
Current value of maintenance costs	KP_N	438 500	454 520	450 269	516 418
Current value of depriciation value	$-J_N$	190 139	191 356	191 360	256 125
Current value of the costs	K_N	519 988	536 529	532 281	626 186
Annual cost	$c*K_N$	26 272	27 107	26 893	31 637

annuity factor = c **$[i*(1+i)^n]/[(1+i)^n-1]$**	0,051	0,051	0,051	0,051

Construction and maintenance scenario 2

		Alt1	**Alt2**	**Alt3**	**Alt4**
Construction costs, year 0	R_N	**271 627**	**273 366**	**273 371**	**365 892**
Current value of maintenance costs	KP_N	438 492	438 995	454 521	484 924
Current value of depriciation value	$-J_N$	190 139	191 356	191 360	256 125
Current value of the costs	K_N	519 980	521 005	536 533	594 692
Annual cost	$c*K_N$	26 271	26 323	27 108	30 046

annuity factor = c **$[i*(1+i)^n]/[(1+i)^n-1]$**	0,051	0,051	0,051	0,051

Construction and maintenance scenario 1

		Alt1	Alt2	Alt3	Alt4
Construction costs, year 0	R_N	**271 627**	**273 366**	**273 371**	**365 892**
Current value of maintenance costs	KP_N	430 397	438 916	438 997	484 145
Current value of depriciation value	$-J_N$	190 139	191 356	191 360	256 125
Current value of the costs	K_N	511 885	520 926	521 008	593 912
Annual cost	$c*K_N$	25 862	26 319	26 323	30 007

annuity factor = c **$[i*(1+i)^n]/[(1+i)^n-1]$**	0,051	0,051	0,051	0,051

Interest 4 %				
Present value	**Alt 1**	**Alt 2**	**Alt 3**	**Alt 4**
Scenario 1	519 988	536 529	532 281	626 186
Scenario 2	519 980	521 005	536 533	594 692
Scenario 3	511 885	520 926	521 008	593 912
Annual cost	**Alt 1**	**Alt 2**	**Alt 3**	**Alt 4**
Scenario 1	26 272	27 107	26 893	31 637
Scenario 2	26 271	26 323	27 108	30 046
Scenario 3	25 862	26 319	26 323	30 007

Appendix 4 Simuna-Vaiatu LCC calculation sheets

4a Material amounts and measurements

Structures that are included in the calculations:	Alt 1 Top: Base course stabilisation with OSA (EF CFB). Bottom: Mass stabilisation with OSA (EF CFB) and cement	Alt 2 Top: Complex stabilisation with bitumen and cement. Bottom: Mass stabilisation with OSA (EF CFB) and cement.	Alt 3 Top: Complex stabilisation with bitumen and cement. Bottom: Mass stabilisation with cement.	Alt 4 Top: Complex stabilisation with bitumen and cement. Bottom: Mass exchange from peat to crushed stone.
Pavement				
Mass	Height 9 cm, width 900 cm			
Thickness of the pavement [mm]	90	90	90	90
Surface area				
* surface area [m^2] pavement	9000	9000	9000	9000
* surface area [m^2] base course stabilisation	9200		9200	9200
* surface area [m2] mass stabilisation	9200	9200	9200	
*surface area [m2] complex stabilisation		9200	9200	9200
*surface are [m2] of other structures	9200	9200	9200	9200
Other structural layers	**Base course stabilisation 20 cm with EF CFB 9 % / Mass stabilisation 2 m with EF CFB % + cement 6 %**	**Complex stabilisation with bitumen 1 % and cement 2,5 % / Mass stabilisation 2 m with EF CFB 20 % + cement 6 %**	**Complex stabilisation with bitumen 1 % and cement 2,5 % / Mass stabilisation 2 m with cement 9 %**	**Complex stabilisation with bitumen 1 % and cement 2,5 % / Crushed rock 2 m**
thickness of the natural aggregates (sand/crushed rock) (m)	**0,8**	**0,8**	**0,8**	**2,5**
The amount of needed sand aggregates (m3rtr) in the structure, (per 1 road km), density 1,8 ton/m3	**14720**	**14720**	**14720**	**4600**
The amount of needed crushed rock aggregater (m3rtr) in the structure, (per 1 road km), density 2,2 ton/m3				**18400**
The amount of needed natural aggregates (previous mass in the structure) tons, (per 1 road km)	**26496**	**26496**	**26496**	**48760**
The wet density of the aggregate to be layer stabilised [kg/m^3]	1950			
The wet density of the aggregate to be mass stabilised [kg/m^3]	1100	1100	1100	
The wet density of the aggregate to be complex stabilised [kg/m^3]		1950	1950	1950
The water content of the aggregate to be layer stabilised [%]	4,5			
The water content of the aggregate to be mass stabilised [%]	550	550	550	
The water content of the aggregate to be complex stabilised [%]		4,5	4,5	4,5
The dry density of the aggregate to be layer stabilised [kg/m^3]	1866			
The dry density of the aggregate to be mass stabilised [kg/m^3]	169,2	169,2	169,2	
The dry density of the aggregate to be complex stabilised [kg/m^3]		1866	1866	1866
The dry density of the aggregate to be stabilised [kg/m^3]	1950	0	0	
Stabiloitavaa runkoainetta_tyoyksilla [m^3/km]	20240	20240	20240	1840
Total mass of stabilised aggregate [t/km]	**41194**	**41194**	**41194**	**3433**
OSA in base course stabilisation [%]	9,0	0	0	0
OSA in base course stabilisation, dry [t/km]	323	0	0	0
OSA in mass stabilisation [%]	20	20	0	0
OSA in mass stabilisation, dry [t/km]	7176	7176	0	0
Bitumen (%)	0	1	1	1
Bitumen (t/km)	0	36	36	36
Cement in base course stabilisation [%]	0,0	0	0	0
Cement in base course stabilisation, dry [t/km]	0	0	0	0
Cement in mass stabilisation [%]	6	6	9	0
Cement in mass stabilisation, dry [t/km]	2153	2153	3229	0
Cement in complex stabilisation [%]		2,5	2,5	2,5
Cement in complex stabilisation, dry [t/km]		90	90	90
Target water content of the binder mixture [%]	30	30	30	30
Extra water for mixing [m^3/km]	2896	2799	969	27
Total mass of the binder mixture [t/km]	9652	9455	3355	126
Total mass of OSA [t/km]	7499	7176	0	0
Total mass of cement [t/km]	2153	2243	3319	90
Total mass of bitumen [t/km]	0	36	36	36

4b Calculated material costs

		Alt 1 Top: Base course stabilisation with OSA (EF CFB). Bottom: Mass stabilisation with OSA (EF CFB) and cement		Alt 2 Top: Complex stabilisation with bitumen and cement. Bottom: Mass stabilisation with OSA (EF CFB) and cement.		Alt 3 Top: Complex stabilisation with bitumen and cement. Bottom: Mass stabilisation with cement.		Alt 4 Top: Complex stabilisation with bitumen and cement. Bottom: Mass exchange from peat to crushed stone.	
Crushed rock sand	Total need [t/road-km]	26 496		26 496		26 496		48 760	
	Unit price [€/t]	13,50		13,50		13,50		13,50	
	Price in the crushing plant [€]	**357 696**		**357 696**		**357 696**		**658 260**	
	Transportation distance [km]	30		30		30		30	
	Transportation cost [€/t-km]	**0,06**		**0,06**		**0,06**		**0,06**	
	Transportations [€/t-km]	**47 693**		**47 693**		**47 693**		**87 768**	
	Cost on site [€/tie-km]		**405 389**		**405 389**		**405 389**		**746 028**
Crushed rock sand to the temporary storage (part of the loading embankment is excavated out). This price is only for the transportation to the temporary storage. The price of crushes rock/sand already taken into account in the previous rows.	Total need [t/road-km]	4 968		4 968		4 968		0	
	Unit price [€/t]	0,00		0,00		0,00		0,00	
	Price in the crushing plant [€]	**0**		**0**		**0**		**0**	
	Transportation distance [km]	3		3		3			
	Transportation cost [€/t-km]	**0,06**		**0,06**		**0,06**			
	Transportations [€/t-km]	**894**		**894**		**894**		**0**	
	Cost on site [€/tie-km]	894	**894**	894	**894**	894	**894**	0	**0**
Binder components	**Cement [t/tie-km]**	2 153		2 243		3 319		90	
	*unit price [€/t]	87,75		87,75		87,75		87,75	
	*price [€]	**188 926**		**196 823**		**291 242**		**7 898**	
	*transportation distance[km]	55		55		55		55	
	*transportation price [€/t-km]	0,1254		0,1254		0,1254		0,1254	
	*transportations [€]	**14 849**		**15 470**		**22 891**		**621**	
	***Costs on site [€/road-km]**		**203 775**		**212 293**		**314 133**		**8 518**
	OSA [t/tie-km]	7 499		7 176		0		0	
	*unit price [€/t]	16,39		16,39		16,39		16,39	
	*price [€]	**122 909**		**117 615**		**0**		**0**	
	*transportation distance[km]	155,0		155,0		155,0		155,0	
	*transportation price [€/t-km]	0,1254		0,1254		0,1254		0,1254	
	*transportations [€]	**145 758**		**139 480**		**0**		**0**	
	***Costs on site [€/road-km]**		**268 667**		**257 095**		**0**		**0**
Benefit from avoiding the land filling of OSA	**OSA [t/road km]**	7 499		7 176		0		0	
	*unit price [€/t]	50,00		50,00		50,00		50,00	
	*price [€]	**-374 950**		**-358 800**		**0**		**0**	
	*transportation distance[km]	5,0		5,0		5,0		5,0	
	*transportation price [€/t-km]	0,13		0,13		0,13		0,13	
	*transportations [€]	**-4 702**		**-4 499**		**0**		**0**	
	***Costs on site [€/road-km]**		**-379 652**		**-363 299**		**0**		**0**
Bitumen	**Bitumen [t/road-km]**	0		36		36		36	
	*unit price [€/t]	430,00		430,00		430,00		430,00	
	*price [€]	**0**		**15 480**		**15 480**		**15 480**	
	*transportation distance[km]	0		135		135		135	
	*transportation price [€/t-km]	1,30		1,30		1,30		1,30	
	*transportations [€]	**0**		**6 318**		**6 318**		**6 318**	
	***Costs on site [€/road-km]**		**0**		**21 798**		**21 798**		**21 798**
Water	**Water [m^3/road km]**	2 896		2 799		969		27	
	*unit price [€/t]	0,00		0,00		0,00		0,00	
	*price [€]	**0**		**0**		**0**		**0**	
	*transportation distance[km]	3		3		3		3	
	*transportation price [€/t-km]	0,13		0,13		0,13		0,13	
	*transportations [€]	**1 089**		**1 053**		**364**		**10**	
	***Costs on site [€/road-km]**		1 089		1 053		364		**10**
Landfilling cost from the renovation	**Mass of total material [t/tie-km]**	0		0		0		0	
No landfilling in any of the alternatives	*unit price [€/t]	50,00		50,00		50,00		50,00	
	*price [€]	**0**		**0**		**0**		**0**	
	*transportation distance[km]	5,0		5,0		5,0		5,0	
	*transportation price [€/t-km]	0,13		0,13		0,13		0,13	
	*transportations [€]	**0**		**0**		**0**		**0**	
	***Costs on site [€/road-km]**		**0**		**0**		**0**		**0**
	Material costs on site [€/road km] in initial stage	**500 162**		**535 222**		**742 579**		**776 354**	

4c Calculated work costs

Structures included in the calculation:		Alt 1 Top: Base course stabilisation with OSA (EF CFB). Bottom: Mass stabilisation with OSA (EF CFB) and cement		Alt 2 Top: Complex stabilisation with bitumen and cement. Bottom: Mass stabilisation with OSA (EF CFB) and cement.		Alt 3 Top: Complex stabilisation with bitumen and cement. Bottom: Mass stabilisation with cement.		Alt 4 Top: Complex stabilisation with bitumen and cement. Bottom: Mass exchange from peat to crushed stone.	
Pavement (new pavement)		AC 12 surf 4 cm + AC 32 base 5 cm; vast. lev. 9,00 m ja 9,00 m							
AC 12, 4 cm, bitumen 5,6 %	Unit price [€/m^2]	9,03		9,03		9,03		9,03	
AC 32, 5 cm, bitumen 4,0 %	Unit price [€/m^2]	8,09		8,09		8,09		8,09	
	Surface area to be paved [m^2]	9 000		9 000		9 000		9 000	
	New pavement [€]		**154 080**		**154 080**		**154 080**		**154 080**
	Pavement [€/tie-m]	154,08		154,08		154,08		154,08	
	Length of FU [m]	1 000		1 000		1 000		1 000	
Work stages	structure; m3-rtr/FU	20 240		20 240		20 240		1 840	
	structure-theor-aggeregate_m2;/	9 200		9 200		9 200		9 200	
	structure-theor-surf_m2;/FU	9 000		9 000		9 000		9 000	
Milling of the pavement	unit price; €/m2-rtr	0,79	7 110	0,79	7 110	0,79	7 110	0,79	7 110
			7 110		**7 110**		**7 110**		**7 110**
	Costs [€/FU]	**161 190**		**161 190**		**161 190**		**161 190**	
		Alt 1 Top: Base course stabilisation with OSA (EF CFB). Bottom: Mass stabilisation with OSA (EF CFB) and cement		Alt 2 Top: Complex stabilisation with bitumen and cement. Bottom: Mass stabilisation with OSA (EF CFB) and cement.		Alt 3 Top: Complex stabilisation with bitumen and cement. Bottom: Mass stabilisation with cement.		Alt 4 Top: Complex stabilisation with bitumen and cement. Bottom: Mass exchange from peat to crushed stone.	
NEW Pavement (REM)									
AC 12, 4 cm, bitumen 5,6 %	Unit price [€/m^2]	*9,03*		*9,03*		*9,03*		*9,03*	
AC 32, 5 cm, bitumen 4,0 %	Unit price [€/m^2]	*8,09*		*8,09*		*8,09*		*8,09*	
Milling of the pavement	Unit price [€/m^2]	*1,20*		*1,20*		*1,20*		*1,20*	
	Surface area to be paved [m^2]	9 000		9 000		9 000		9 000	
	New pavement [€]		**164 880**		**164 880**		**164 880**		**164 880**
	Pavement [€/tie-m]	*164,88*		*164,88*		*164,88*		*164,88*	
	Length of the FU [m]	1 000		1 000		1 000		1 000	
Layer / complex stabilisation									
Work stages	structure-m^3; m^3-rtr/FU	1 840		1 840		1 840		1 840	
	structure-m^2-pavement	9 000		9 000		9 000		9 000	
	unit price; €/m^3-rtr		0		0		0		0
Stabilisation	unit price; €/m^3-rtr	26	47 840	33	60 720	33	60 720	33	60 720
Milling of the pavement and immediate use in the old structure	unit price; €/m^3-rtr	0,79	7 110	0,79	7 110	0,79	7 110	0,79	7 110
Mass stabilisation									
Work stages	structure-m^3; m^3-rtr/FU	18 400		18 400		18 400			
	structure-m^2-pavement	9 200		9 200		9 200			
	unit price; €/m^3-rtr								
	unit price; €/m^3-rtr	10	184000	10	184000	10	184000		
Spreading the crushed rock									
	structure-m^3; m^3-rtr/FU	7 360		7 360		7 360		23 000	
	structure-m^2-pavement	9 200		9 200		9 200		9 200	
	unit price; €/m^3-rtr	8		8		8		8	
	unit price; €/m^3-rtr		58880		58880		58880		184000
Excavating part of the loading embankment	structure-m^3; m^3-rtr/FU	2 760		2760		2760			
	structure-m^2-pavement	9 200		9200		9200			
	unit price; €/m^3-rtr	8		8		8			
	unit price; €/m^3-rtr		22080		22080		22080		
Adding of water	unit price; €/m^3-rtr		0	0	0	0	0	0	0
			484 790		**497 670**		**497 670**		**416 710**
	Costs [€/FU]	**649 670**		**662 550**		**662 550**		**581 590**	

4d Maintenance scenarios

Structure alternative			Alt 1 Top: Base course stabilisation with OSA (EF CFB). Bottom: Mass stabilisation with OSA (EF CFB) and cement	Alt 2 Top: Complex stabilisation with bitumen and cement. Bottom: Mass stabilisation with OSA (EF CFB) and cement.	Alt 3 Top: Complex stabilisation with bitumen and cement. Bottom: Mass stabilisation with cement.	Alt 4 Top: Complex stabilisation with bitumen and cement. Bottom: Mass exchange from peat to crushed stone.
Pavement			AC	AC	AC	AC
Patching (UREM) (assumption 50 % * 40 % of the REM price)	Maintenance intervalles (a)		6	6	6	6
			30 816	30 816	30 816	30 816
Re-newing the pavement (REM)	Cycles for maintenance (a)		10	10	10	10
			154 080	154 080	154 080	154 080
Need for renovation	*Scenario 1*	Action cycles / a	25	25	25	25
		Action	Re-newing the structure. New pavement.	Re-newing the structure. New pavement.	Re-newing the structure. New pavement.	Re-newing the structure. New pavement.
		€/FU	1 149 832	1 197 772	1 405 129	1 357 944
	Scenario 2	Action cycles / a	30	28	28	28
		Action	Re-newing the structure. New pavement.	Re-newing the structure. New pavement.	Re-newing the structure. New pavement.	Re-newing the structure. New pavement.
		€/FU	1 149 832	1 197 772	1 405 129	1 357 944
	Scenario 3	Action cycles / a	35	31	31	31
		Action	Re-newing the structure. New pavement.	Re-newing the structure. New pavement.	Re-newing the structure. New pavement.	Re-newing the structure. New pavement.
		€/FU	1 149 832	1 197 772	1 405 129	1 357 944

4e Current values of maintenance scenarios

Current value of the actions / scenario 1										
Year	**Alternatives / actions**				**Year**	D(ir)	**Alternatives / actions**			
	Alt1	**Alt2**	**Alt3**	**Alt4**			**Alt1**	**Alt2**	**Alt3**	**Alt4**
0	0	0	0	0	0	1,000				
1	0	0	0	0	1	0,962				
2	0	0	0	0	2	0,925				
3	0	0	0	0	3	0,889				
4	0	0	0	0	4	0,855				
5	0	0	0	0	5	0,822				
6	24 354	24 354	24 354	24 354	6	0,790	30 816	30 816	30 816	30 816
7	0	0	0	0	7	0,760				
8	0	0	0	0	8	0,731				
9	0	0	0	0	9	0,703				
10	104 091	104 091	104 091	104 091	10	0,676	154 080	154 080	154 080	154 080
11	0	0	0	0	11	0,650				
12	0	0	0	0	12	0,625				
13	0	0	0	0	13	0,601				
14	0	0	0	0	14	0,577				
15	0	0	0	0	15	0,555				
16	16 453	16 453	16 453	16 453	16	0,534	30 816	30 816	30 816	30 816
17	0	0	0	0	17	0,513				
18	76 058	76 058	76 058	76 058	18	0,494	154 080	154 080	154 080	154 080
19	0	0	0	0	19	0,475				
20	0	0	0	0	20	0,456				
21	0	0	0	0	21	0,439				
22	0	0	0	0	22	0,422				
23	0	0	0	0	23	0,406				
24	0	0	0	0	24	0,390				
25	431 321	449 305	527 087	509 388	25	0,375	1 149 832	1 197 772	1 405 129	1 357 944
26	55 575	55 575	55 575	55 575	26	0,361	154 080	154 080	154 080	154 080
27	0	0	0	0	27	0,347				
28	0	0	0	0	28	0,333				
29	0	0	0	0	29	0,321				
30	0	0	0	0	30	0,308				
31	0	0	0	0	31	0,296				
32	0	0	0	0	32	0,285				
33	0	0	0	0	33	0,274				
34	40 608	40 608	40 608	40 608	34	0,264	154 080	154 080	154 080	154 080
35	0	0	0	0	35	0,253				
36	7 509	7 509	7 509	7 509	36	0,244	30 816	30 816	30 816	30 816
37	0	0	0	0	37	0,234				
38	0	0	0	0	38	0,225				
39	0	0	0	0	39	0,217				
40	0	0	0	0	40	0,208				
41	0	0	0	0	41					
Current value	**755 970**	**773 953**	**851 736**	**834 036**						

Current value of the actions, scenario 2				
Year	**Alternatives / actions**			
	Alt1	**Alt2**	**Alt3**	**Alt4**
0	0	0	0	0
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	24 354	24 354	24 354	24 354
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	104 091	104 091	104 091	104 091
11	0	0	0	0
12	0	0	0	0
13	0	0	0	0
14	0	0	0	0
15	0	0	0	0
16	16 453	16 453	16 453	16 453
17	0	0	0	0
18	76 058	76 058	76 058	76 058
19	0	0	0	0
20	0	0	0	0
21	0	0	0	0
22	0	0	0	0
23	0	0	0	0
24	0	0	0	0
25	0	0	0	0
26	55 575	55 575	55 575	55 575
27	0	0	0	0
28	0	399 430	468 579	452 844
29	0	0	0	0
30	354 515	0	0	0
31	0	0	0	0
32	0	0	0	0
33	0	0	0	0
34	40 608	40 608	40 608	40 608
35	0	0	0	0
36	7 509	7 509	7 509	7 509
37	0	0	0	0
38	0	0	0	0
39	0	0	0	0
40	0	0	0	0
41	0	0	0	0
Current value	**679 163**	**724 078**	**793 227**	**777 492**

Year	**D(ir)**	**Alternatives / actions**			
		Alt1	**Alt2**	**Alt3**	**Alt4**
0	1,000				
1	0,962				
2	0,925				
3	0,889				
4	0,855				
5	0,822				
6	0,790	30 816	30 816	30 816	30 816
7	0,760				
8	0,731				
9	0,703				
10	0,676	154 080	154 080	154 080	154 080
11	0,650				
12	0,625				
13	0,601				
14	0,577				
15	0,555				
16	0,534	30 816	30 816	30 816	30 816
17	0,513				
18	0,494	154 080	154 080	154 080	154 080
19	0,475				
20	0,456				
21	0,439				
22	0,422				
23	0,406				
24	0,390				
25	0,375				
26	0,361	154 080	154 080	154 080	154 080
27	0,347				
28	0,333		1 197 772	1 405 129	1 357 944
29	0,321				
30	0,308	1 149 832			
31	0,296				
32	0,285				
33	0,274				
34	0,264	154 080	154 080	154 080	154 080
35	0,253				
36	0,244	30 816	30 816	30 816	30 816
37	0,234				
38	0,225				
39	0,217				
40	0,208				
41					

Current value of the actions, scenario 3

Year	Alternatives / actions			
	Alt1	**Alt2**	**Alt3**	**Alt4**
0	0	0	0	0
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	24 354	24 354	24 354	24 354
7	0	0	0	0
8	0	0	0	0
9	0	0	0	0
10	104 091	104 091	104 091	104 091
11	0	0	0	0
12	0	0	0	0
13	0	0	0	0
14	0	0	0	0
15	0	0	0	0
16	16 453	16 453	16 453	16 453
17	0	0	0	0
18	76 058	76 058	76 058	76 058
19	0	0	0	0
20	14 064	14 064	14 064	14 064
21	0	0	0	0
22	0	0	0	0
23	0	0	0	0
24	0	0	0	0
25	0	0	0	0
26	55 575	55 575	55 575	55 575
27	0	0	0	0
28	0	0	0	0
29	0	0	0	0
30	0	0	0	0
31	0	355 092	416 565	402 577
32	0	0	0	0
33	0	0	0	0
34	40 608	40 608	40 608	40 608
35	291 385	0	0	0
36	7 509	7 509	7 509	7 509
37	0	0	0	0
38	0	0	0	0
39	0	0	0	0
40	0	0	0	0
41	0	0	0	0
Current value	**630 098**	**693 804**	**755 277**	**741 289**

Year	D(ir)	Alternatives / actions			
		Alt1	**Alt2**	**Alt3**	**Alt4**
0	1,000				
1	0,962				
2	0,925				
3	0,889				
4	0,855				
5	0,822				
6	0,790	30 816	30 816	30 816	30 816
7	0,760				
8	0,731				
9	0,703				
10	0,676	154 080	154 080	154 080	154 080
11	0,650				
12	0,625				
13	0,601				
14	0,577				
15	0,555				
16	0,534	30 816	30 816	30 816	30 816
17	0,513				
18	0,494	154 080	154 080	154 080	154 080
19	0,475				
20	0,456	30 816	30 816	30 816	30 816
21	0,439				
22	0,422				
23	0,406				
24	0,390				
25	0,375				
26	0,361	154 080	154 080	154 080	154 080
27	0,347				
28	0,333				
29	0,321				
30	0,308				
31	0,296		1 197 772	1 405 129	1 357 944
32	0,285				
33	0,274				
34	0,264	154 080	154 080	154 080	154 080
35	0,253	1 149 832			
36	0,244	30 816	30 816	30 816	30 816
37	0,234				
38	0,225				
39	0,217				
40	0,208				
41					

4f LCC calculation final results

Construction and maintenance scenario 1

		Alt1	Alt2	Alt3	Alt4
Construction costs, year 0	R_N	**770 180**	**834 473**	**1 405 129**	**1 357 944**
Current value of maintenance costs	KP_N	755 970	773 953	851 736	834 036
Current value of depreciation value	$-J_N$	539 126	584 131	983 590	950 561
Current value of the costs	K_N	987 024	1 024 295	1 273 275	1 241 419
Annual cost	$c*K_N$	49 868	51 751	64 330	62 721
Differences vs. Alt1 (annual costs)	%				

annuity factor = c **$[i*(1+i)^n]/[(1+i)^n-1]$**	0,051	0,051	0,051	0,051

Construction and maintenance scenario 2

		Alt1	Alt2	Alt3	Alt4
Construction costs, year 0	R_N	**770 180**	**834 473**	**1 405 129**	**1 357 944**
Current value of maintenance costs	KP_N	679 163	724 078	793 227	777 492
Current value of depreciation value	$-J_N$	539 126	584 131	983 590	950 561
Current value of the costs	K_N	910 217	974 420	1 214 766	1 184 876
Annual cost	$c*K_N$	45 987	49 231	61 374	59 864
Differences vs. Alt1 (annual costs)	%				

annuity factor = c **$[i*(1+i)^n]/[(1+i)^n-1]$**	0,051	0,051	0,051	0,051

Construction and maintenance scenario 3

		Alt1	Alt2	Alt3	Alt4
Construction costs, year 0	R_N	**770 180**	**834 473**	**1 405 129**	**1 357 944**
Current value of maintenance costs	KP_N	630 098	693 804	755 277	741 289
Current value of depreciation value	$-J_N$	539 126	584 131	983 590	950 561
Current value of the costs	K_N	861 152	944 146	1 176 816	1 148 672
Annual cost	$c*K_N$	43 508	47 702	59 457	58 035
Differences vs. Alt1 (annual costs)	%				

annuity factor = c **$[i*(1+i)^n]/[(1+i)^n-1]$**	0,051	0,051	0,051	0,051

Interest 4 %				
Current value	**Alt 1**	**Alt 2**	**Alt 3**	**Alt 4**
Scenario 1	987 024	1 024 295	1 273 275	1 241 419
Scenario 2	910 217	974 420	1 214 766	1 184 876
Scenario 3	861 152	944 146	1 176 816	1 148 672
Annual cost	**Alt 1**	**Alt 2**	**Alt 3**	**Alt 4**
Scenario 1	49 868	51 751	64 330	62 721
Scenario 2	45 987	49 231	61 374	59 864
Scenario 3	43 508	47 702	59 457	58 035