LIFE12 ENV/FI/000592

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ENVIRONMENTAL IMPACT

LCA/LCC/LCIA CALCULATION

LIFE12 ENV/FI/000592 UPACMIC

ENVIRONMENTAL IMPACT

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CONTENT

GLOSSARY OF TERMS

Abiotic material Non-living chemical and physical part of the environment that affect living organisms and the function of ecosystem.

Allocation Sharing of input and output streams of a process or product system between the product system under investigation and one or more other product systems [1].

By-product Secondary product which is produced as side stream from primary production.

Cut-off criteria Specification of the amount of material or energy flow or the level of environmental significance associated with the unit process or product system, to be excluded from the inventory [1].

Functional unit Quantitative performance of a product system used as a reference unit [1].

Environmental aspect The part of an organization's activities, products or services that may interact with the environment [1].

Global warming potential (GWP)
Expresses the relative intensity of the heating effect (radiative forcing) of greenhouse gas emissions over a given time period relative to carbon dioxide unit mass. Its numeric value is expressed as the Global Warming Potential (GWP) coefficient for the most part over a period of 100 years (GWP100) or 20 years (GWP20). For example, the GWP100 factor for methane is 21, which means that the cumulative heating effect of methane emissions over a hundred years is 21 times the effect of carbon dioxide emissions. The heating potential takes into account not only the different thermal transmission characteristics of the gases but also their different residence times in the atmosphere. [4]. This is

estimated using CO_2 equivalent, which is calculated combination of all greenhouse gas emissions which are converted to CO_2 emissions.

Input Product, material or energy flow entering the unit process [1].

Life cycle Successive or interactive stages of the product system from the extraction or production of raw materials from natural resources to final disposal [1].

Life cycle assessment (LCA)
Compiling and evaluating product system life cycle inputs and outputs and potential environmental impacts [1].

Life cycle cost (LCC) Is defined as the cost of an asset or its parts throughout its life cycle while the performance requirements [3].

Life cycle impact assessment (LCIA)
Life cycle assessment phase to understand and evaluate the extent and significance of the potential environmental impacts of a product system throughout the product life cycle [1].

Output Product, material or energy flow leaving the unit process [1].

Product Any good or service [1].

Product system Series of unit processes with elementary streams and product flows that perform one or more specified functions and describe the product life cycle [1].

Unit process The smallest element to take into account in the inventory analysis for which input and output data are defined [1]. Examples of unit processes: material dissemination and sealing.

UPACMIC Utilisation of by-products and alternative construction materials in new mine Construction, LIFE12 ENV/FI/000592

1. INTRODUCTION

Life Cycle Assessment (LCA) is a methodology for assessing environmental impacts of a product, process, or service during its lifetime or over a chosen lifetime period. In the UPACMIC project (Utilisation of by-products and alternative construction materials in new mine Construction, LIFE12 ENV/FI/000592) LCA has been carried out as a simplified version (streamlined LCA). The environmental impact of project pilots is estimated using Life Cycle Impact Assessment (LCIA). The following environmental impact categories have been chosen for the assessment: ***energy consumption, global warming potential*** and ***depletion of natural resources***. Results are mainly represented using following three units: GHG emissions as kg CO_2 eq, used nonrenewal material consumption as kg and energy consumption as MJ.

The goal of LCIA of piloting is to assess the environmental impacts of the piloted structures and to verify that the pilot alternatives are environmentally more viable option compared to the conventional alternative. The three focused pilot structures were tailing basin cover structure's sealing layer, vertical sealing barrier and pre-crushing site covering. Materials what is compared were fibre clay from three different location, surplus soils, natural moraine and aggregates. Fibre clay is produced as a residual material in paper recycling process in paper industry. Fibre clay has been used in landfill sealing layers for some time, but now it has been used in the mining environment for the first time. The conventional alternative for the fibre clay is a cover structure made with virgin moraine. Materials which are used in sealing structure in Kuopio were waste or surplus materials. Moraine, gravel and sand are virgin materials and therefore the emissions from the production and depletion if natural resources have been taken into account in the LCIA. All structure's pilotings are described more detailly in the *B1 Final Technical report on piloting (2022)* .

The sizes of pilot structures were different so for even comparison has been used the functional unit (FU) 1000 m^2 of the cover structure. For the vertical sealing structure the functional unit is 1 m^2 of wall. All calculations are carried out for functional unit area and results are easy to scale up or down to match to full size structures impacts by simple multiplication.

For Life Cycle Cost (LCC) calculations data of work and transport costs were collected from real billings. Prices includes fuel, worker and machine costs. Functional unit is same as in LCIA comparison. The transportation cost of fibre clays is given as €/tonne. For other materials same 2,2 €/km cost of transportation was used. That was the most common pricing during this project. Secondary materials such as fibre clay were calculated as free and only loading work costs. Other material prices were collected and estimated from real billings what has got during the project.

The materials of growth layer are not included in the assessments because they are equal in all structures. Material testing and quality control during material production is not included because the suitability of the materials must be verified for each material. Maintenance and monitoring work is considered to be same for each structure, so it is leaved out from calculation and comparison.

2. UPACMIC PROJECT ENVIRONMENTAL IMPACT

Life Cycle Assessment (LCA) is a methodology for assessing environmental impacts of a product, process, or service during its lifetime or over a chosen lifetime period. The LCA is a compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system, that can be described as a collection of unit processes which perform one or more defined functions and model the life cycle of the product: e.g. production and manufacturing of construction materials, transportation of materials, preparing the construction site, construction, maintenance and repair.

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

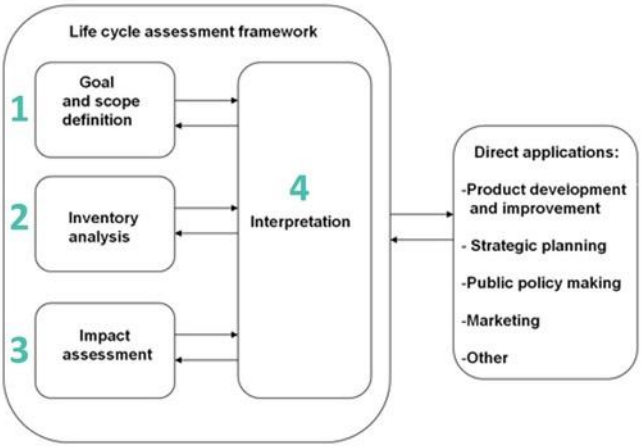

Figure 1. Stages of the life cycle assessment.

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

In the UPACMIC project, LCA methodology is used to assess the environmental impacts of the piloted applications and to compare them with the environmental impacts of a chosen conventional alternative. In the UPACMIC project, LCA was conducted for following pilot structures:

- Fibre clay cover structure piloting in Hitura Mine
- Surplus clay cover structure piloting in Hitura Mine
- Vertical sealing barrier pilot structure in Sorsasalo landfill (in Kuopio)

The LCA methodology is based on the ISO standard (EN ISO 14040:2006). In the UPACMIC project LCA has been carried out as a simplified version (streamlined LCA), where the analysis was limited to the lifecycle phases A1-A3 *product stage* (raw material supply, transport and manufacturing) and A4-5 *construction process* (transport, installation) according to CEN/TC 350 standard EN 15643-5. The analysed structures are permanent and therefore nothing will be done about them after construction. The maintenance and structures monitoring is excluded from LCA comparison.

The environmental impact of project pilots is estimated using Life Cycle Impact Assessment (LCIA). The reason to carry out the LCIA of fibre clay cover structure piloting in Hitura mine is to assess the environmental impacts of the piloted fibre clay cover structures and to verify that the pilot alternatives are environmentally sound compared to the conventional alternative. Fibre clay is produced as a residual material in paper recycling process in paper industry. Fibre clay has been used in landfill sealing layers for some time, but now it has been used in the mining environment for the first time. The conventional alternative for the fibre clay is a cover structure made with virgin moraine. Cover structure piloting in Hitura mine is described in the *B1 Final Technical report on piloting (2022)*.

The software used in LCIA calculations is a Microsoft Excel-based calculation tool. In the calculations the emission data for transport vehicles and working machines is based on the LIPASTO unit emissions database by Technical Research Centre of Finland [2].

The origin of the data used in the calculations and the basis for the calculations are presented in the following paragraphs and Tables 1-4.

Table 1. The data of diesel used in the LCIA analysis [2].

Attribute	Value	Unit
Specific weight	0,824	
Caloric value	43,2	MJ/kg
Energy 1 kWh	3,6	MJ/kg
Abiotic raw material	0,032*	kg/MJ
Density	0,824	kg/dm^3

*Value from *MIPS-laskenta* guide [13]

Abiotic material depletion of diesel is calculated on the basis of values from Table 1 as follows:

energy of 1 liter diesel: 43,2 MJ/kg x 0,824 kg/l = 35,63 MJ/l

→abiotic material consumption /1 liter diesel: 0,032 kg/MJ x 35,63 MJ/l = 1,14 kg/l

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

Global warming potential (GWP) is calculated directly using factors that gives CO_2 equivalent (kg or g).

The emissions for used vehicles are calculated on the basis of the LIPASTO database developed by the Technical Research Centre of Finland [2] Where data is 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] = emission g.

Energy consumptions in different stages are calculated on the basis of the vehicle energy consumption provided by the LIPASTO database [2], or by the energy consumption values from material producers data. The energy consumptions are calculated with following equations for functional unit:

[MJ/km] x [total km/FU] = MJ/FU (vehicles)
[MJ/h] x [h/FU] = MJ/FU (vehicles)
[MJ/tonne] x [tonne/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 [2]. The depletions of natural resources are calculated with following equations:

[g/tonne] x [tonne/FU] = kg/FU (materials)
[kg/l] x [l/FU] = kg/FU (vehicles)

Table 2. Emission data for used vehicle in lading, construction and transport from LIPASTO [2].

Drivable machines, diesel	Average power [kW]	Average load factor [-]	CO_2 eq Emissions [g/kWh]	CO_2 eq g/fuel litre	Consumption [g/kWh]	Energy [MJ/kWh]
Bulldozers	112	0,40	821	2674	258	11
Wheel loaders	94	0,33	828	2673	260	11
Excavators, skid steer	104	0,31	829	2672	261	11
Farm tractors	77	0,31	852	2723	263	11
Dumpers	153	0,30	818	2672	257	11

Machine average power in Table 2 is the average maximum power of machinery. However, most of the time machine is under loaded and uses only fraction of its maximum power. So, in same Table 2 is introduced average load factor which is correcting factor for calculating machines real power usage while working.

Table 3. Factors for calculating transport's LCIA from LIPASTO [2].

Machines	**CO_2 eq [g/km]**		**Fuel consumption [l/100km]**		**Energy [MJ/km]**	
	Empty	fully loaded	Empty	fully loaded	Empty	fully loaded
Earth moving lorry	558	761	23,5	32,1	8,4	11
Full trailer combination	796	1205	33,7	51,1	12	18

Factors in Table 3 are for highway driving. There are also available factors for city driving but those are not used in calculation, because construction sites located in sparsely populated area and transporting routs were mostly highways due to long distances.

When machine is worked its energy usage is calculated using LIPASTO's equation:
[MJ/kWh] x [kW] x [average load factor] = MJ/h
CO_2 eq emission is calculated using LIPASTO's equation and multipliers:
[kWh] x [g/kWh] = emission g

Used moraine is excavated and stored on piles. That excavation work is estimated to produce CO_2 eq emission of 1,57 kg/m^3 [10]. If the material density is unknow the used global constant is 1,5 kg/dm^3.

For virgin crushed rock aggregates the international EPD® system data is used based on NCC Mäntsälä quarry – Ohkola information [12]. Used values are collected to following Table 4. There are several sources of data available about different quarries. Ohkola site is selected because it is just like the site in Kuopio which is used as origin of alternative case aggregates and represents it well. Data can vary lot site by site due to varying crushing methods and energy sources.

Table 4. Virgin crushed aggregates data of Mäntsälä where values are per 1000 kg. [12]

Product names	**Global warming potential total kg CO_2 eq**	**Total use of non-renewable primary energy resources [MJ]**
All-in Rock 0-150	2,6	34
Coarse rock 16/32	3,5	46
Rock Fines 0/3	4,3	58

3. LIFE CYCLE COST IN UPACMIC PILOTS

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 2). The results gained from the LCC are highly connected to the basic data received and the defined scope. The information applied in the UPACMIC project is based on the information received from the contractor and Ramboll Luopioinen own expertise. LCC studies is carried out as simplified versions or as streamlined LCC. The costs used here are capital costs (construction work and material costs). Service life of structures are estimated to be identical and the maintenance and renovation costs as well and structures performance is estimated to be same. Those are excluded from UPACMIC LCC calculations and comparison.

Utilization of waste material cut costs of material producer viewpoint, because then there is no landfilling or waste fees. This positive aspect is excluded from LCC calculations but will be crucial to take in account when comparing transportation costs between natural and waste material.

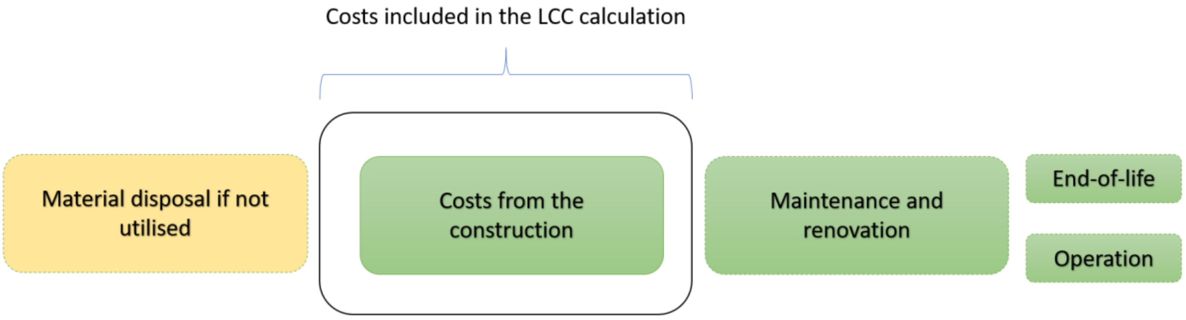

Figure 2: Costs that are included in the life cycle costing.

The purpose of the LCC was to compare the relevant investment costs of the alternatives and to show that the use of surplus soils and secondary materials can be cost-effective.

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

1. Materials
2. Material transportation
3. Construction

LCC’s are calculated from same scenarios than LCIA’s are done.

4. FIBRE CLAY COVER STRUCTURE PILOTING IN HITURA MINE

The goal and scope of the LCIA

The reason to carry out the LCIA of fibre clay cover structure piloting in Hitura mine is to assess the environmental impacts of the piloted fibre clay cover structures and to verify that the pilot alternatives are environmentally sound compared to the conventional alternative. Fibre clay is produced as a residual material in paper recycling process in paper industry. Fibre clay has been used in landfill sealing layers for some time, but now it has been used in the mining environment for the first time. The conventional alternative for the fibre clay is a cover structure made with virgin moraine. Cover structure piloting in Hitura mine is described in the *B1 Final Technical report on piloting (2022)*.

Figure 3. Fibre clay and moraine cover strictures on top of tailings.

The fibre clay is partly biodegradable which need to take account to maintain layer thickness after some time, but degradation clogs the layer and water permeability decrease. Maintain layer thickness was the reason behind different thickness (200 vs 250 m) of material layers between structures. Fibre clay structure is shown in figure 3. Another benefit of using fibre clay is that it doesn’t crack when it dries as natural moraine does. That makes fibre clay sealing layer more durable against weather changes.

The LCIA of fibre clay cover structure piloting in Hitura mine includes four alternative structures. Structure 1 is the conventional alternative, where the cover structure is made of virgin moraine originated from Nivala. Structures 2-4 are made of secondary material of fibre clay originated from three different sites: Mänttä (Structure 2), Oulu (Structure 3) or Äänekoski (Structure 4). Origin of materials is shown in the figure 4.

The total LCIA results of constructed cover layer is compared to alternative case. Alternative fictional case is that pilot site is constructed as in Hitura but the fibre clay producers are closer (50 km each) to the constructing site and source of moraine is further away (37 km).

Table 5. Alternative cover structures compared in the LCIA.

Alternative structure	**Description**
Structure 1	moraine, origin from Nivala
Structure 2	fibre clay, origin from Mänttä (Metsä Tissue)
Structure 3	fibre clay, origin from Oulu (so called “OPA-sakka”)
Structure 4	fibre clay, origin from Äänekoski

Figure 4. Origins of fibre clay and moraine.

Table 6. The materials used in the different pilot structure alternatives.

	Material	**Structural thickness [m]**	**Area [m²]**	**Volume [m³]**	**Volume/FU [m³]**	**Density (wet) [kg/m³]**
Structure 1	Moraine	0,2	116242	23 248	200	2070
Structure 2	Fibre clay	0,25	43766	10 942	250	1157
Structure 3	Fibre clay	0,25	56599	14 150	250	1515
Structure 4	Fibre clay	0,25	48485	12 121	250	1182

In 2019 constructed Pilot structures size were different so for even comparison has used the functional unit (FU) 1000 m^2 of the cover structure. All calculations are carried out for functional unit area and results are easy to scale up or down to match to construction area by simple multiplication. The materials of growth layer are not included in the assessment because they are equal in all structures. Material testing and quality control during material production is not included because the suitability of the materials must be verified for each material. Maintenance and monitoring work is considered to be same for each structure, so it is leaved out from calculation and comparison. The following environmental impact categories have been chosen for the assessment: ***energy consumption, global warming potential*** and ***depletion of natural resources***. Results are mainly represented using following three units: GHG emissions as kg CO_2 eq, used nonrenewal material consumption as kg and energy consumption as MJ.

Material production

Fibre clay is a secondary material from paper industry. Therefore, the environmental impacts related to production of fibre clay have been excluded from the LCIA. The emissions from the production of fibre clay have been allocated to the previous process (the process from which the by-product originates). Only the emissions from loading of fibre clay add emissions and energy usage to material production phase for fibre clay.

The emissions of virgin moraine used in structure alternative 1 include the excavation of moraine and its loading. The CO_2 eq emission moraine excavation is 1,57 kg/m^3 [10]. The loading work hours per loaded m^3 of moraine is 0,012 h/m^3 [11]. For fibre clay that is estimated to be 0,005 h/m^3 because material can be loaded with much higher rate using bigger bucket because fibre clay is lighter than moraine.

Transportation

Moraine is mainly transported by cassette trucks (full trailer combination) and fibre clay is transported by truck combinations. Transportation vehicles payloads are same (40 tonne) so full trailer combinations data values are used in both vehicles. In the calculations LIPASTO data [2] for full trailer combination (Gross vehicle mass 60 t, pay load capacity 40 t) was used, since this option is assumed to be the most descriptive for both transport options. All trucks and working machines are assumed to use same diesel as fuel since it has not been considered essential to study different fuels for every machine or truck. The data used for diesel fuel in the LCIA calculations is based on the LIPASTO data [2] which is shown in Table 1.

Table 7. Transportation distances and driven kilometers.

	Material	Distance to Hitura mine [km]	Driven kilometers/FU [km]
Structure 1 (Nivala)	Moraine	16	166
Structure 2 (Mänttä)	Fibre clay	282	2039
Structure 3 (Oulu)	Fibre clay	167	1581
Structure 4 (Äänekoski)	Fibre clay	176	1300

Construction

The thickness of the piloted cover structure 1 (moraine) was 0,2 m, where the thickness of piloted fibre clay cover structures (alternatives 2-4) was 0,25 m. The fibre clay is partly biodegradable which need to take account to maintain layer thickness after some time, but degradation Glogs the layer and water permeability decreases. Maintaining the layer thickness is the reason behind different thicknesses (200 vs 250 mm) of material layers between structures.

The construction stages and vehicles used in the construction process were supposed to be similar for all alternative structures (Table 8). The construction of the cover structure started with spreading the material (moraine / fibre clay) roughly with a bulldozer and after that the spreading was finalized with skid steer excavator. After spreading, the compacting was done with a skid steer excavator by running over the structure 3 times. In calculations it was assumed that the width of tracs of excavator are 800 mm, which means that 1 600 mm is compacted at a time. It was also assumed that the average speed of excavator was 5 km/h. For one FU unit (1000 m^2) that means that excavator drives 1,875 km and it takes 22,5 min. Average loading factor of excavator is estimated to be 0,5 during the compaction task, because the excavator has to continuously move and turn.

The first compaction overrun is harder than the others, because excavator sinks more into the uncompressed clay.

Table 8. The construction stages and used working machines.

Stage	**Working machine**
Coarse spreading of the material	Bulldozer
Spreading of the material	Excavators, skid steer
Compacting	Excavators, skid steer

Results

The climate impacts of the fibre clay cover structure alternatives are presented in Table 9.

Table 9. Results of the GHG emission per FU of fibre clay cover structure piloting in Hitura mine.

	Materials [kg CO_2 eq]	**Transportation** [kg CO_2 eq]	**Construction** [kg CO_2 eq]	**Total emissions** [kg CO_2 eq]	**Total emissions per tonne of material** [kgCO_2 eq/tonne]
Structure 1 Moraine (Nivala)	375	332	293	1000	2,41
Structure 2 Fibre clay (Mänttä)	32,0	4 082	362	4 4	15,47
Structure 3 Fibre clay (Oulu)	32,0	3 166	362	3 559	9,40
Structure 4 Fibre clay (Äänekoski)	32,0	2 603	362	2 997	10,14

Energy consumption is estimated from calculated diesel fuel usage by power usage using Lipasto databank's values. This approach is selected because there is no real fuel consumption data from transportation and construction.

Table 10. Results of the energy consumption per FU of fibre clay cover structure in Hitura mine.

	Materials [MJ]	**Transportation** [MJ]	**Construction** [MJ]	**Total energy consumption** [MJ]	**Total consumption per tonne of material** [MJ/tonne]
Structure 1 Moraine (Nivala)	2 514	5 004	3 951	11 469	27,70
Structure 2 Fibre clay (Mänttä)	1 310	61 616	4 884	67 811	234,44
Structure 3 Fibre clay (Oulu)	1 310	47 780	4 884	53 974	142,51
Structure 4 Fibre clay (Äänekoski)	1 310	39 286	4 884	45 481	153,91

Depletion of natural resources includes only fuel consumption of machinery with fibre clay. The depletion of natural moraine sources was taken into account, using direct calculation mass to mass. Moraine consumption is about 414 tonne per FU which is about 200 times higher. In Table 11 is presented inside brackets the fuel consumptions part of depletion of natural resources of moraine loading and total amount without moraine to illustrate how much moraines affect to depletion of natural resources.

Table 11. Results of the depletion of natural resources per FU of cover structure in Hitura mine.

	Materials [kg]	**Transportation** [kg]	**Construction** [kg]	**Total** [kg]	**Total per tonne of material** [kg/tonne]
Structure 1 Moraine (Nivala)	414 027 (27)	160	127	414 314 (314)	1000,76 (0,76)
Structure 2 Fibre clay (Mänttä)	14	1 972	157	2 143	7,41
Structure 3 Fibre clay (Oulu)	14	1 529	157	1 700	4,49
Structure 4 Fibre clay (Äänekoski)	14	1 257	157	1 428	4,83

Summary

The transportation causes most of the emission, so the fibre clay structures have the highest emissions (Table 9 and Figure 5). However, if the transport distance would be the same for all alternatives, would the emissions of fibre clay structures be smaller than moraine.

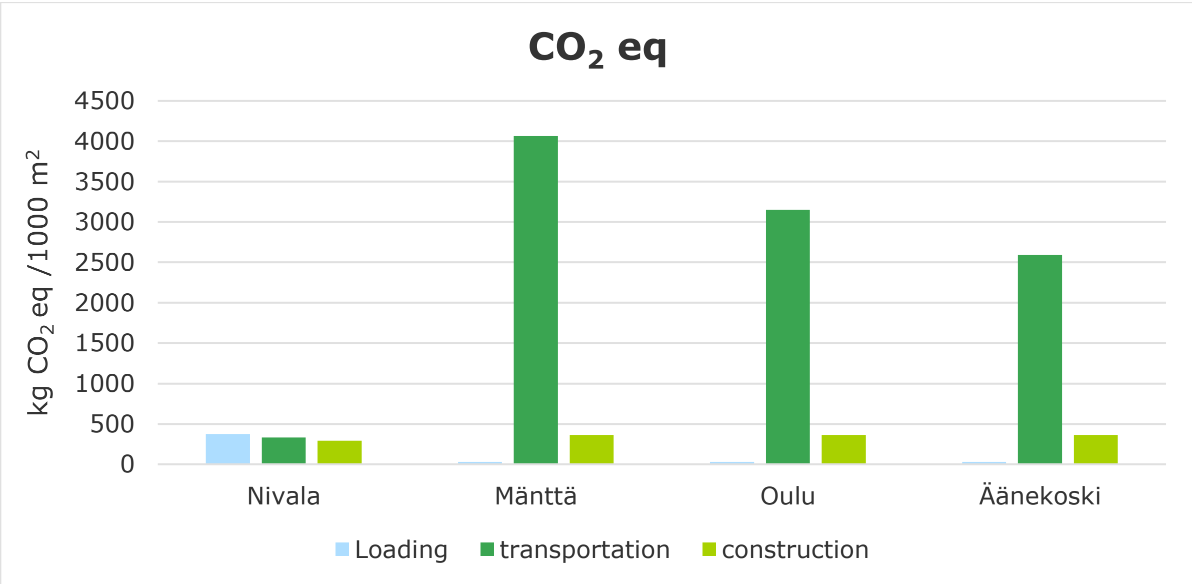

Figure 5. Results of the GHG emission per FU of of fibre clay and moraine cover structure piloting.

As the figure 5 indicates that utilization of fibre clay from Mänttä has app. 4,5 times greater emissions compared to moraine from Nivala and from Oulu and Äänekoski app. 3 times greater. The advantage of using fibre clay is basically zero production emissions, because it is a by-product from industrial production. Therefore, it is good to consider the transport distance while utilizing by-products, because transportation can cause much higher emissions as in this case.

4.1 Life Cycle Cost of fibre clay structures

For LCC calculations data of work and transport costs were collected from real billings. Prices includes fuel, worker and machine costs. Functional unit is again 1000 m^2. The transportation cost of fibre clay is given as €/tonne which is different in Mänttä and Oulu. For Äänekoski there was no transportation cost available, so it was estimated to be same as Oulu's because distance difference was only 9 km. For other road transportations a constant factor 2,2 €/km was used, this was the most common price during this project. Secondary materials such as fibre clay were calculated as free and only loading costed.

Table 12. Work costs of used machinery.

Working machine	**€/h**
Wheel loader	65
Bulldozer	90
Excavator, skid steer	75

Transportation costs were calculated for functional unit with 2 methods. First is total km/FU x €/km =€/FU and second is mass/FU x €/tonne = €/FU. Used values are in Table 13.

Table 13. Transportation costs.

	€/km	**€/tonne**
Moraine	2,2	
Fiber clay Mänttä		16,4
Fiber clay Oulu		13,9
Fiber clay Äänekoski		13,9

Only moraine was bought with the price of 5,05 €/tonne, fibre clays were free. Loading work costs on producing facility was calculated based on hours per functional unit.

For easier comparison costs were first calculated per functional unit 1000 m^2 (Table 14). Then costs were scaled to real construction areas and results are presented in Table 15. Figure 6 illustrates the total costs of all structures in every phase.

Table 14. Cost dividing during construction per FU.

	Material [€/FU]	**Loading [€/FU]**	**Transportation [€/FU]**	**Construction [€/FU]**	**Total [€/FU]**
Moraine Nivala	2091	156	364	754	3365
Fibre clay Mänttä	0	81	4744	936	5761
Fibre clay Oulu	0	81	5265	936	6282
Fibre clay Äänekoski	0	81	4107	936	5124

Table 15. Total cost dividing during construction.

	Material [€]	**Loading [€]**	**Transportation [€]**	**Construction [€]**	**Total [€]**
Moraine Nivala	243 027	18 134	42 349	87 661	391 171
Fibre clay Mänttä	0	3 556	207 613	40 949	252 117
Fibre clay Oulu	0	4 599	297 973	52 955	355 527
Fibre clay Äänekoski	0	3 939	199 150	45 364	248 453

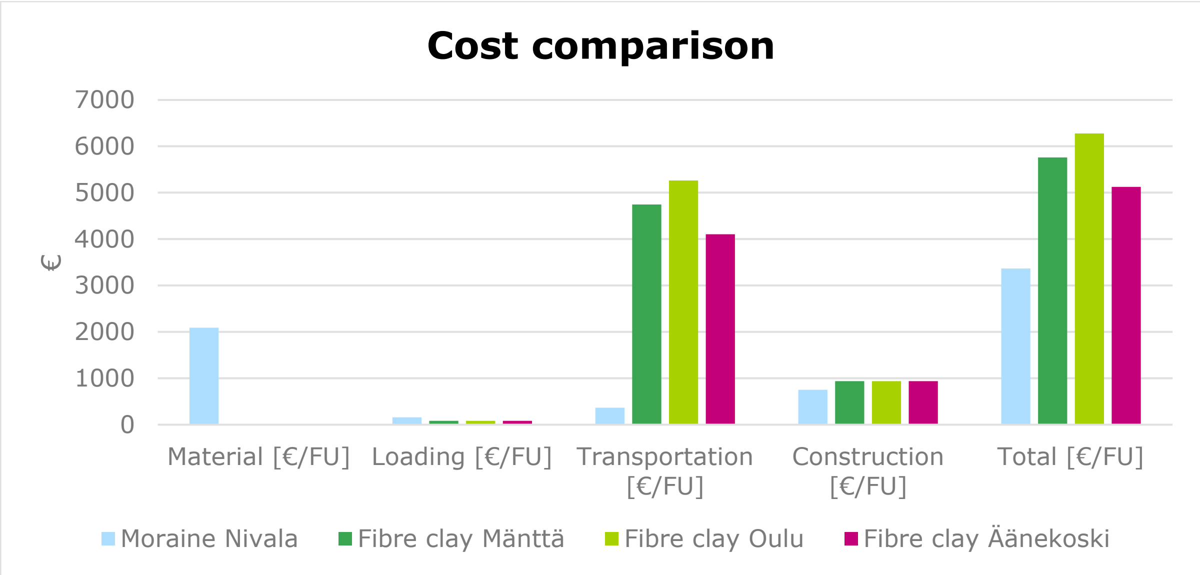

Figure 6. Fibre clay structures costs comparison by functional unit 1000 m²^{2}.

Summary

In general fibre clay is about 1,5 times more expensive material to be used, which were result from long transportation distances. Fibre clay from Äänekoski seems to be cheapest of clays which is logical because it is not as dense as fibre clay from Oulu. If the transportation costs of fibre clays are ignored, the material itself is cheaper than moraine. The fibre clays can be considered as better material because they are more consistent and have more homogenous structure. The quality of the moraine varies more than clays. Therefore, it can be expected that their performance as cover structure is also better than moraine and the probability of failures is smaller. However, the fibre clay is partly biodegradable which need to take account to maintain layer thickness after some time, but degradation clogs the layer and water permeability decrease.

4.2 Alternative cover structure case

In this alternative case, fibre clay production distance is imaginary (50 km from Hitura site). The moraine transportation distance (37 km) is as well a bit longer than previously. The 37 km is distance from Ylivieska quarry to Hitura using main roads. The route is shown in the figure 7. This case will show better positive impacts when construct with utilizing by-products. The construction stages and vehicles used in the construction process are similar for those previously describe (Table 8).

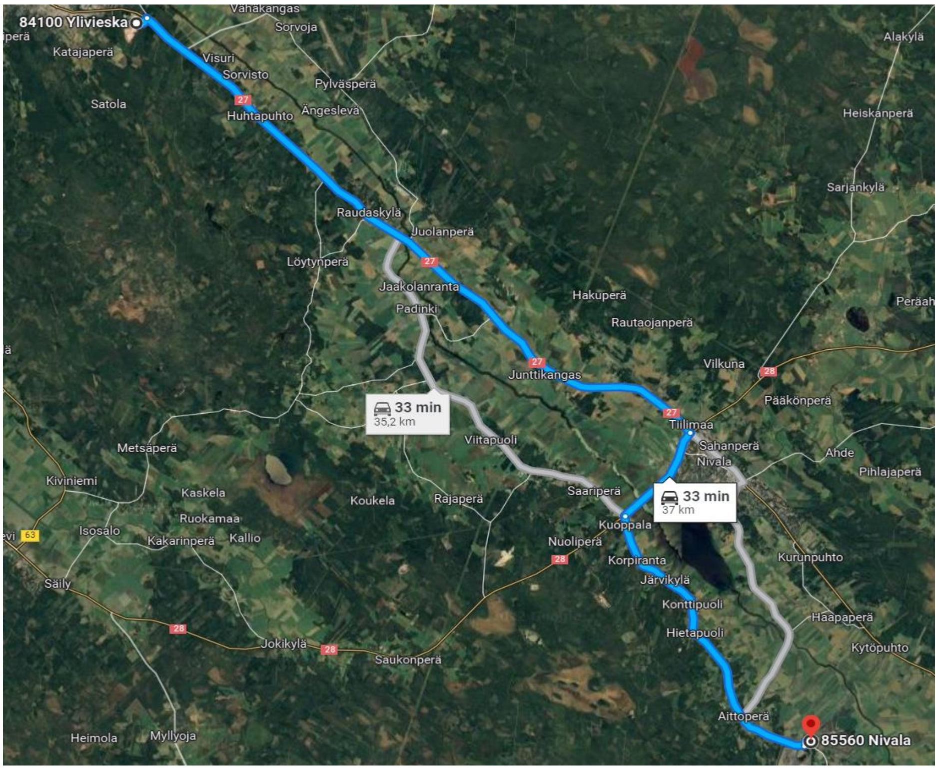

Figure 7. The route from Ylivieska quarry to Hitura using main roads.

Structures, loading and transportation methods are as previously. Only varying parameter is transportation distances which are in Table 16.

Table 16. Distance and driven kilometers per FU.

	Material	Distance to Hitura mine [km]	Driven kilometers/FU [km]
Option 1	Moraine	37	383
Option 2	Fibre clay	50	362
Option 3	Fibre clay	50	473
Option 4	Fibre clay	50	369

Results

Table 17. Results of the GHG emission per FU of alternative fibre clay cover structure piloting in Hitura mine.

	Materials [kg CO_2 eq]	**Transportation** [kg CO_2 eq]	**Construction** [kg CO_2 eq]	**Total emissions** [kg CO_2 eq]
Nivala	375	766	293	1 435
Mänttä	32	724	362	1 118
Oulu	32	948	362	1 342
Äänekoski	32	739	362	1 134

Table 18. Results of the energy consumption per FU of fibre clay cover structure piloting in Hitura mine.

	Materials [MJ]	**Transportation** [MJ]	**Construction** [MJ]	**Total energy consumption** [MJ]	**Total consumption per tonne of material** [MJ/tonne]
Option 1 Moraine	2 514	11 571	3 951	18 037	43,57
Option 2 Fibre clay (Mänttä)	1 310	10 925	4 884	17 119	59,18
Option 3 Fibre clay (Oulu)	1 310	14 305	4 884	20 499	54,12
Option 4 Fibre clay (Äänekoski)	1 310	11 161	4 884	17 355	58,73

Table 19. Results of the depletion of natural resources per FU of fibre clay cover structure piloting in Hitura mine.

	Materials [kg]	**Transportation** [kg]	**Construction** [kg]	**Total consumption** [kg]	**Total consumption per tonne** [kg/tonne]
Option 1 Moraine	414 026	370	127	414 524	1001
Option 2 Fibre clay (Mänttä)	14	50	157	521	1,80
Option 3 Fibre clay (Oulu)	14	458	157	629	1,66
Option 4 Fibre clay (Äänekoski)	14	357	157	528	1,79

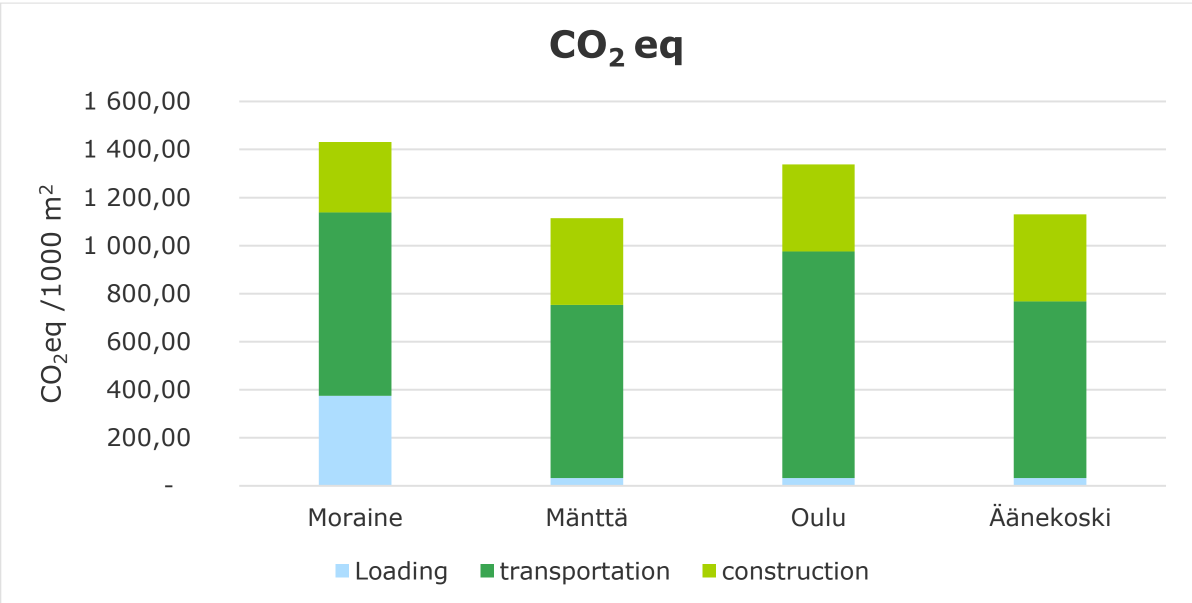

Figure 8. Results of the GHG emission per FU of fibre clay and moraine cover structure scenarios in Hitura mine.

In this case using fibre clay constructions have almost same environmental effects caused by CO_2 eq emissions as moraine (figure 8). Fibre clay is less dense than moraine which cut transportations environmental impact. Moraine layer is also 50 mm thinner than fibre clay layers but still produces more CO_2 eq emission. When comparing more closely, using moraine causes mush higher depletion of natural resources. When the distance is almost same than moraine, fibre clay utilization is more environment friendly solution.

4.3 Alternative case LCC

Work and structures are same than in original case, but in this alternative case every fibre clay producer is at the distance of 50 km from construction site and moraine is transported from quarry which located 37 km a way. Fibre clays transportation cost are estimated directly by dividing previous case's cost to match shorter transportation distance. Example Mänttä's fibre clays transportation is calculated as 16,4 €/t x 50 km/282 km = 2,91 €/t.

Table 20. Transportation costs.

	€/km	**€/tonne**
Moraine	2,2	
Fiber clay Mänttä		2,91
Fiber clay Oulu		4,91
Fiber clay Äänekoski		4,66

Table 21. Cost dividing during construction per FU.

	Material [€/FU]	**Loading** [€/FU]	**Transportation** [€/FU]	**Construction** [€/FU]	**Total** [€/FU]
Moraine Nivala	2091	156	842	754	3843
Fibre clay Mänttä	0	81	841	936	1858
Fibre clay Oulu	0	81	1860	936	2877
Fibre clay Äänekoski	0	81	1377	936	2394

Table 22. Total cost dividing during construction.

	Material [€]	**Loading** [€]	**Transportation** [€]	**Construction** [€]	**Total** [€]
Moraine Nivala	243 027	18 134	97 933	87 661	446 755
Fibre clay Mänttä	0	3 556	36 811	40 949	81 315
Fibre clay Oulu	0	4 599	105 259	52 955	162 813
Fibre clay Äänekoski	0	3 939	66 752	45 364	116 055

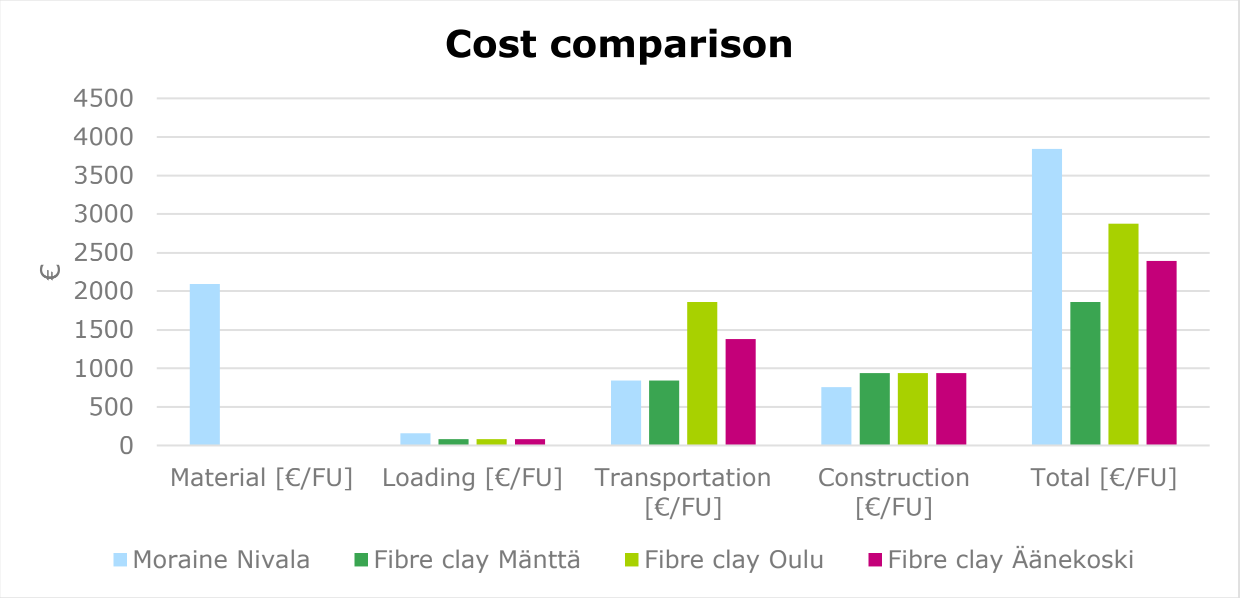

Figure 8. alternative cases fibre clay pilot structures costs comparison by functional unit 1000 m^2.

As can see from comparison of figure 6 and 8, the long transportation distance of fibre clays affect the most in life cycle cost analysis but if construction site would be closer then fibre clays are more cost-effective materials than moraine This LCC comparison indicate that fibre clay is cost effective solution for cover structures when site is nearer the producer. when taken account that fibre clay has much better water permeability properties than common moraines it is even more viable option when it can be utilized closer the source.

5. VERTICAL SEALING BARRIER PILOTING IN KUOPIO

The vertical sealing barrier piloting in Kuopio Sorsasalo's waste center is still ongoing and it is estimated to be finished at end of year 2022. For simplify the calculations it is assumed from this point on that structure is already finished. The vertical sealing barrier was about 2000 m^2 tight wall, which surrounded by drainage and backing layers. Thickness of the compacted clay layer was 1000 mm, and its purpose is to stop water end up from dangerous waste area to normal waste area. On both side of that is 500mm thick dranage layers which purpose is to prevent water standing against the clay wall. On both side is supporting layer which thickness is 5 m. Layers are shown in figure 9.

Figure 9. Vertical sealing barrier.

Reference structure is the conventional alternative when the sealing structure is made of virgin materials. The FU unit is 1 wall m^2 from horizontal viewpoint perpendicular to wall. Whole structure is total 2000 FU units.

Table 23. Alternative cover structures compared in the LCIA.

Structure	Description
Structure	Surplus and waste materials
Reference structure	Virgin materials (moraine, gravel, sand, crush)

The following environmental impact categories have been chosen for the assessment: ***energy consumption, global warming potential*** and ***depletion of natural resources***.

Material production

Materials which are used in sealing structure in Kuopio were waste or surplus materials. Materials production doesn't produce emissions. Moraine, gravel and sand are virgin materials and therefore the emissions from the production have been taken into account in the LCIA. NCC quarry from Mäntsälä [12] is used as reference when calculating virgin materials impact to LCIA.

Table 24. Materials.

Original structure	**Description**	**Volume (m^3)**
Compact layer	Surplus clay from Mäkelä and Hamula	2000
Drainage layer	Ash from Riikinvoima Oy	1950
Supporting backfill	Surplus soils, Hitura's sediment from water treatment and ash from Mondi Powerflute Oy	24 000
Alternative structure	**Description (NCC product)**	**Volume (m^3)**
Barrier layer	Moraine (Rock Fines 0/3)	2000
Drainage layer	Gravel (Coarse rock 6/32)	1950
Supporting backfill	Gravel and sand (All-In Rock 0/150)	24 000

Transportation

Table 25. Transportation.

Material (Original structure)	**Volume** [t]	**Distance** [km]	**CO_2 eq** [kg]	**CO_2 eq** [kg /wall m^2]
Surplus clay (Mäkelä)	450	270	6457	3,2
Surplus clay (Hamula)	2 550	22	2795	1,4
Ash from Riikinvoima Oy	2 535	82	10 357	5,2
Sediment from Hitura's water treatment	3 600	206	36 951	18,5
Ash from Mondi Powerflute Oy	2 250	1	112	0,06
Waste materials from waste center	28 500	0,3	992	0,5
Material (alternative structure)	**Volume** [t]	**Distance** [km]	**CO_2 eq** [kg]	**CO_2 eq** [kg/wall m^2]
Moraine, barrier layer	3 000	21	3 139	1,6
Crush, drainage layer	2 925	21	3 061	1,5
Sand and gravel, support layer	35 250	21	36 883	18,4

Waste material such as surplus soil is estimated to be transported approximately 300 m distance.

Construction

The construction stages and vehicles used in the construction process are similar for all alternative structures (Table 26). At the first construct compact layer with an excavator. After that, the compact layer support with other layers. Backing layer is compacted with a dumper. Working methods and working hours are same in both constructions.

Construction work is calculated by using information from constructor who estimated that working speed were 3 m^2/h. When wall's area is about 2000 m^2 that make total work time 667 h. Constructor said also that they used 1 dumper and 2 excavators which were 30 tonne and 22 tonne. Dumper was used as compactor as it drove multiple time over supporting layers during transportation. Due to that there was no need for additional compacting. The dumper was estimated to be like normal earth moving vehicle factor wise and bigger excavator power usage were estimated to be 130 kW but other factors as average excavator in Lipasto's databank [2].

Table 26. Construction vehicles and their GHG emissions.

Stage	Working machine	Working hours	CO_2 emission [kg]	CO_2 emission [kg / wall m^2]
Spreading of the material	Excavator 30T	667	21 791	10,9
Spreading of the material	Excavator 22T	667	17 633	8,8
Compacting & transportation	Dumper	667	25 287	12,6

Results

The climate impacts of the sealing structure piloting alternatives are presented in Table 27.

Table 27. Results of the GHG emission of the sealing structure piloting in Kuopio.

Structure	Materials [kg CO_2 eq]	Transportation [kg CO_2 eq]	Construction [kg CO_2 eq]	Total emissions [kg CO_2 eq]	Total emissions per wall m^2 [kg CO_2 eq/m^2]
Original structure	975	57 971	64 712	123 604	61,8
Alternative structure	114 788	43 083	64 712	222 582	111,3

Energy consumption is estimated from calculated power usage using **Lipasto databank's values**. This approach is selected because there is not real fuel consumption data from transportation and construction. Materials production energy consumption is not calculated for original structure because values for crushing and screening are not available. For alternative structure is used Mäntsälä quarry information [12]. Energy consumption of the sealing barrier material alternatives are presented in Table 28.

Table 28. Results of the energy consumption sealing structure piloting in Kuopio.

Structure	Materials [MJ]	Transportation [MJ]	Construction [MJ]	Total energy consumption [MJ]	Total consumption per wall m^2 [MJ/m^2]
Original structure	-	868 125	874 082	1 742 207	871
Alternative structure	1 507 050	653 176	874 082	3 034 308	1517

Depletion of natural resources is calculated from power consumption. There is also taken account moraine, gravel and sand consumption which leads much bigger consumption of nonrenewable materials. Results are presented in Table 29.

Table 29. Results of the depletion of natural resources in sealing structure piloting in Kuopio.

Structure	Materials [kg]	Transportation [kg]	Construction [kg]	Total consumption [kg]	Total consumption per wall m^2 [kg/m^2]
Original structure	0	27 780	32 065	59845	9,9
Alternative structure	89401	20 902	32 065	142 367	71,2

Summary

Kuopio's sealing structure environmental effects are clearly smaller in original constructed structure than alternative structure by using only virgin materials. By using virgin materials the construction GHG-emissions are bigger and depletion of natural resources grows clearly. The energy consumption is bigger in original structure than alternative structure because Hitura's water treatment sediment was transported for a long distance. Most important thing to notice is that distance affects alternative materials CO_2 emission.

The figure 10 shows scenario where the original structure is made without water treatment sludge transportation cost, when the emission of the structure is almost half compared to the virgin material's structure. The sludge from Hitura is transported to Sorsasalo anyway so transportations emissions is not caused directly by construction of vertical sealing barrier.

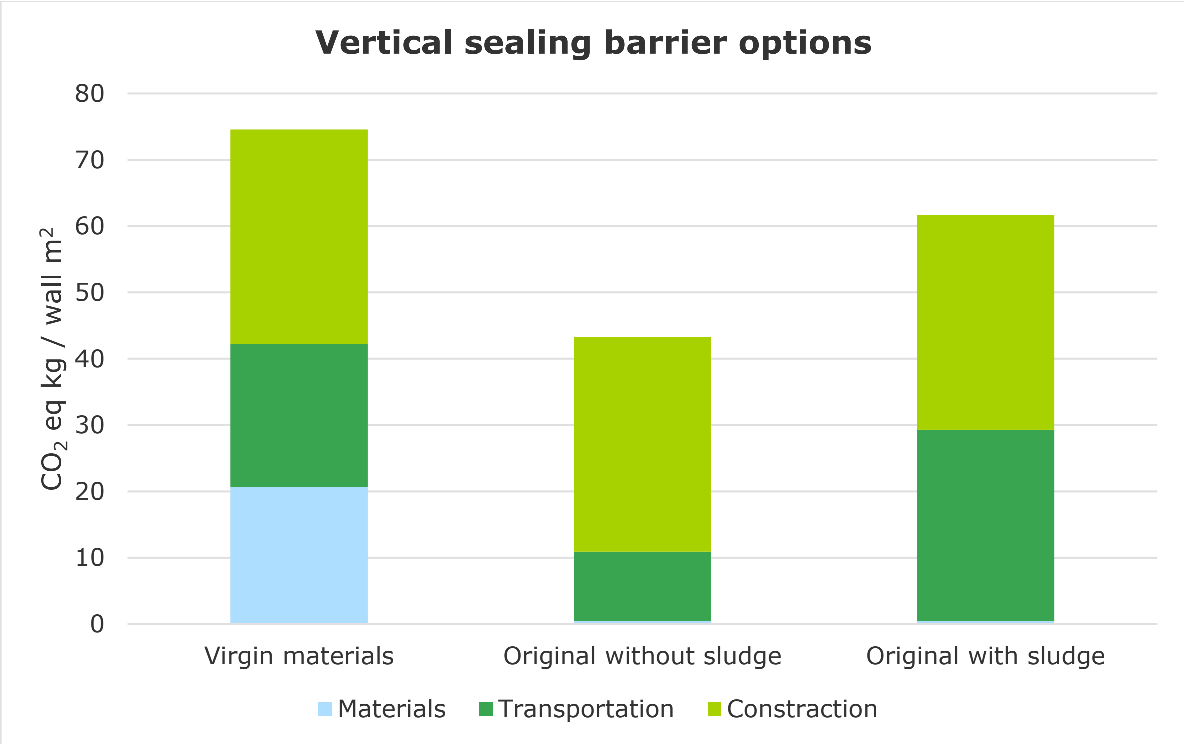

Figure 10. Results of GHG emissions of the sealing structure options.

Virgin materials has assumed to be produced in single quarry and from virgin soil that needed to be crushed. The data can vary between quarry's and that may create some over or under estimations. This comparison gives at least direction of how big impact would be if virgin soils would be used.

5.1 LCC of vertical sealing barrier

Functional unit for LCC is 1 m^2 of wall. The compared structures are original, original without Hitura's wastewater treatment sludge transportation and structure with virgin material.

Table 30. Work costs of used machinery.

Working machine	**€/h**
Doosan 21,5 tonne (excavator)	75

Doosan 30 tonne (excavator)	85
Dumper	95

All materials transportation cost is calculated using constant value 2,2 €/km. Surplus and secondary materials are free in original case and only compared alternative structures materials need to bought prices has estimated from billings.

Table 31. Material purchasing costs.

Material	**Price** [€/tonne]
Moraine (sealing layer)	5,05
Gravel (drainage layer)	13,25
Sand (support layer)	9

Total cost of structures is calculated first and then it is divided by area of structure which is 2000 m^2 to get cost per functional unit 1 m^2. Total cost is in Table 33 and cost per functional unit is in table 32.

Table 32. Cost dividing during construction per wall m^2.

	Material [€/m²]	**Transportation** [€/m²]	**Construction** [€/m²]	**Total** [€/m²]
Original structure	0	32	85	117
Original (without transportation of sludge from Hitura)	0	11	85	96
Alternative structure	186	24	85	294

Table 33. Total cost dividing during construction.

	Material [€]	**Transportation** [€]	**Construction** [€]	**Total** [€]
Original structure	0	63 548	170 000	233 548
Original (without transportation of sludge from Hitura)	0	22 958	170 000	192 958
Alternative structure	371 156	47 557	170 000	588 713

In figure 11 is compared all structures total prices and each cases material, loading, transportation and construction costs.

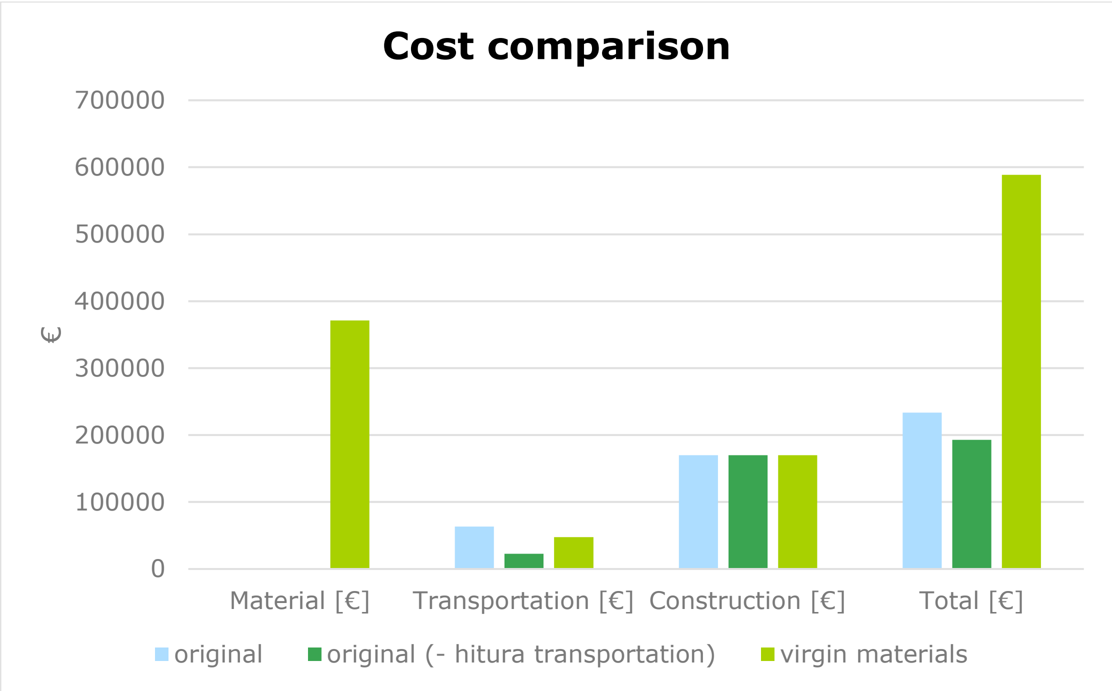

Figure 11. Vertical sealing barrier pilot structures costs comparison by total prices.

As can see from figure 10 the original structures cost is about 2/5 - 1/3 from alternative virgin material structure. It conforms about main idea of UPACMIC and resource efficiency idea, that if construction sites own material can be utilized it is most cost efficient and environmental solution. It can be discussed does Hitura's wastewater treatment sludges transportation cost belong to construction costs, while it is anyway transported to Sorsasalo's landfill area.

6. SURPLUS CLAY COVER STUCTURE IN HITURA

The surplus clay cover structure piloting in Hitura mine was about the size of 3,3-hectare area. The thickness of the clay layer was 500 mm. Structure is shown in figure 6. Reference structure is the conventional alternative, when the cover structure is made of moraine originated from Nivala or nearest fibre clay originated from Oulu.

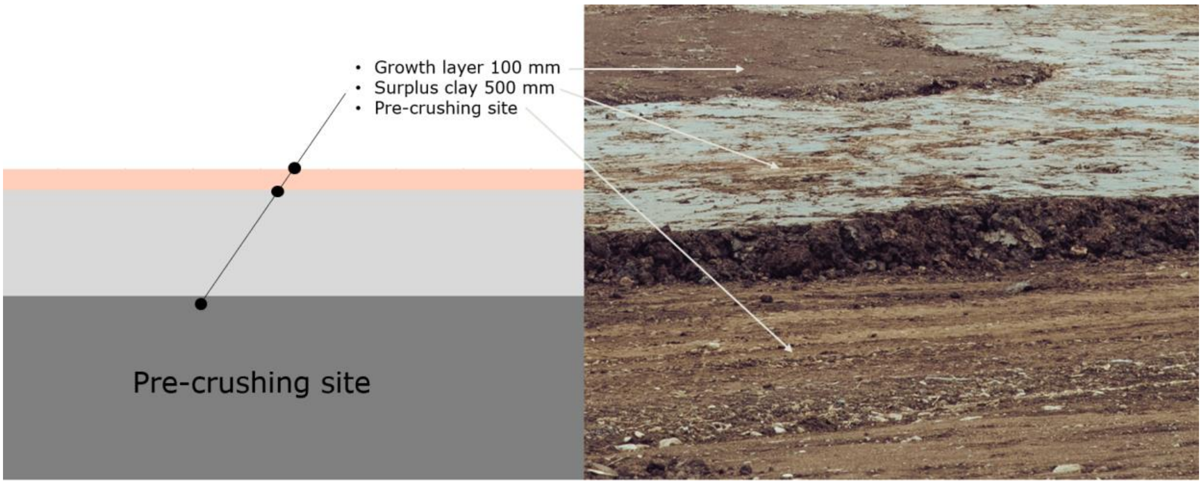

Figure 12. Pre-crushing site cover structure.

Table 34. Alternative cover structures compared in the LCIA.

Alternative structure	Description
Structure	surplus clay, origin from Hitura
Reference structure	moraine, origin from Nivala
Fibre clay structure	fibre clay, origin from Oulu

The functional unit (FU) of the LCIA is 1000 m^2 of the cover structure. Soil (growth layer) is not included in the assessment because it is equal in all cover structures in this project. Laboratory works is not included because the suitability of the materials must be verified for each construction material. The following environmental impact categories have been chosen for the assessment: ***energy consumption, global warming potential*** and ***depletion of natural resources***.

Material production

Surplus clay and moraine which was used in structures alternative are virgin materials and therefore the emissions from the production have been taken into account in the LCIA. Since the clay used in the construction of the cover structure were not processed, the aspects of materials production are mainly related to its excavation. The differences in environmental effects consist of transport distances and equipment.

Table 35. The materials used in the different structure alternatives.

Material	Thickness [mm]	Area [m²]	Volume [m³]	Volume/FU [m³]
Surplus clay	500	33 941	17 000	500
Moraine	500	33 941	17 000	500
Fibre clay	500	33 941	17 000	500

Transportation

Surplus clay is transported using tractor and ERT Granger 18T JLV cart. With on drive tractor can transport 18 tonne clay. Cassette truck is estimated to be able to transport 40 tonne moraine at a time.

Table 36. The materials transport distances and total distance for FU.

	Transporting vehicle	Distance to Hitura mine [km]	Driven kilometers/FU [km]
Surplus clay	Tractor and trailer	0,3	35
Moraine	Cassette trucks	16	414
Fibre clay	Cassette trucks	167	3 163

Construction

The thickness of the original piloted cover structure (surplus clay) is 500 mm. The construction stages and vehicles used in the construction process are similar for all alternative structures (Table 37). The construction of the cover structure starts with spreading the material (moraine / fibre clay) with a bulldozer. After spreading, the compacting is done with a skid steer excavator. The compacting is done by driving over the material three times. Stocks of the excavator is 800 mm width and compacting work is calculated by excavator driven kilometers.

Table 37. Construction vehicles and their working hours per FU.

Stage	Working machine	Working hours / FU
Spreading of the material	Bulldozer	11
Spreading of the material	Excavators, skid steer	11
Compacting	Excavators, skid steer	0,4

Results

The climate impacts of all cover structures options is presented in Table 38.

Table 38. Results of the GHG emissions per FU of all cover structure options.

Structure	Materials [kg CO_2 eq]	Transportation [kg CO_2 eq]	Construction [kg CO_2 eq]	Total emissions [kg CO_2 eq]	Total emissions per tonne of material [kg CO_2 eq/tonne]
Surplus clay	158,7	70	707	937	0,91
Moraine	153,5	828	707	2475	1,63
Fibre clay	64,0	6331	707	7103	9,38

Energy consumption of all cover structures options is presented in Table 39.

Table 39. Results of the energy consumption per FU in all cover structure options.

Structure	Materials [MJ]	Transportation [MJ]	Construction [MJ]	Total energy consumption [MJ]	Total consumption per tonne of material [MJ/tonne]
Surplus clay	693	929,3	9551	22 753	21,98
Moraine	660	12509	9551	11 140	10,76
Fibre clay	289	95560	9551	105 399	139,14

Depletion of natural resources of all cover structures options is presented in Table 40.

Table 40. Results of the depletion of natural resources per FU in all cover structure options.

Structure	Materials [kg]	Transportation [kg]	Construction [kg]	Total consumption [kg]	Total consumption per tonne of material [kg/tonne]
Surplus clay	69	30	307	403	0,39
Moraine	1 035 067	400	307	1035774	1001
Fibre clay	28	3058	307	3939	4,5

Summary

Distance is the most effective factor between materials when comparing CO_2 emissions (figure 11). Materials production emissions consists of loading, and construction work is same with all materials. When taking account moraine effect to depletion of natural resources is other materials clearly much sustainable solutions.

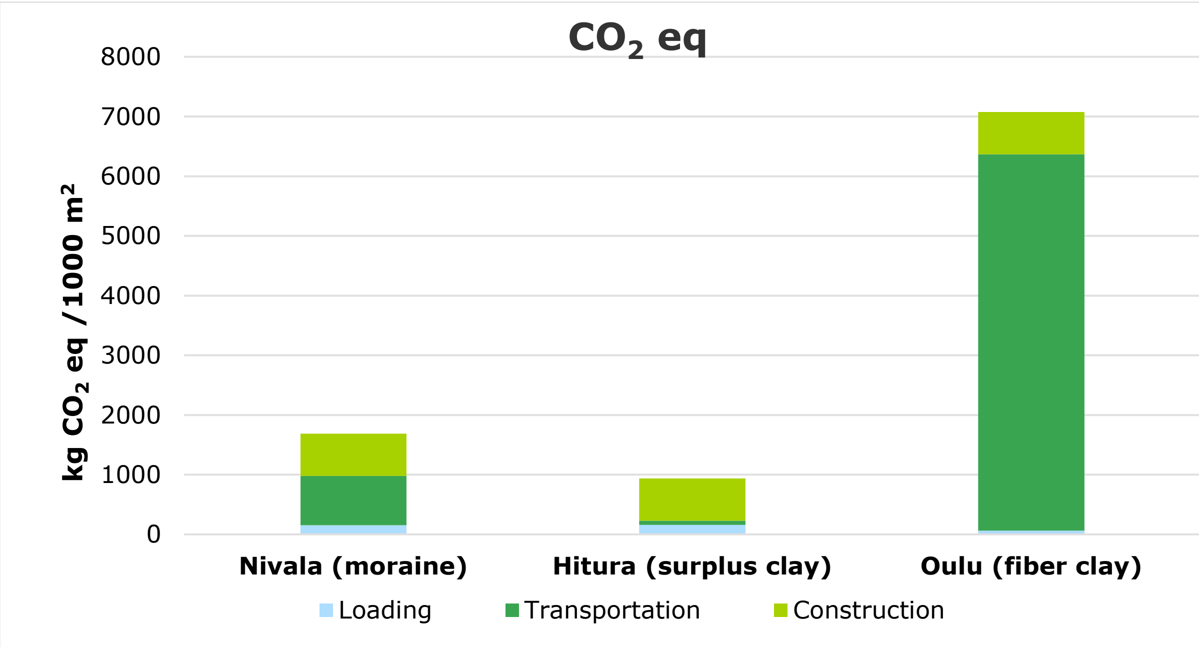

Figure 11. Results of the GHG emissions in all cover structure options.

6.1 LCC of Hitura surplus soil cover structure

Surplus soil was excavated mostly from nearby field. that excavation work needs also measure man with excavator which makes excavation cost higher. Construction's excavator work prices are higher because executive contractor is different than fibre clay covers.

Table 41. Work costs of used machinery.

Working machine	**€/h**
Wheel loader	65
Bulldozer	90
Excavator, skid steer (surplus soil excavation)	125
Excavator, skid steer	94,5

Moraine and surplus soil are bought from contractors and local farmers. The fibre clay is free.

Table 42. Material purchasing cost.

Material	**Price** [€/tonne]
Moraine	5,05
Surplus soil	1,29
Fibre clay	0

Surplus soil is transported by tractor and that transportation cost is calculated using time that took to transport material to construction site. Transportation is done by tractor.

Table 43. Transportation costs.

	€/h	**€/km**	**€/tonne**
Moraine		2,2	
Surplus soil	55		
Fibre clay			13,9

Costs are calculated using four sector which are materials, loading, transportation and construction. Total cost is sum of those.

Table 44. Cost dividing during construction per FU.

	Material [€/FU]	**Loading** [€/FU]	**Transportation** [€/FU]	**Construction** [€/FU]	**Total** [€/FU]
Moraine	5227	390	911	2065	8592
Surplus soil	1335	750	190	2065	4340
Fibre clay	0	163	10529	2065	12757

Total cost of structures is calculated by multiplying by amount of FU units in full structure.

Table 45. Total cost dividing during construction.

	Material [€]	**Loading** [€]	**Transportation** [€]	**Construction** [€]	**Total** [€]
Moraine	177 401	13 237	30 913	70 086	291 638
Surplus soil	45 316	25 456	6 440	70 086	147 298
Fibre clay	0	5 515	357 373	70 086	432 975

In figure 12 is compared all structures total prices and each cases material, loading, transportation and construction costs.

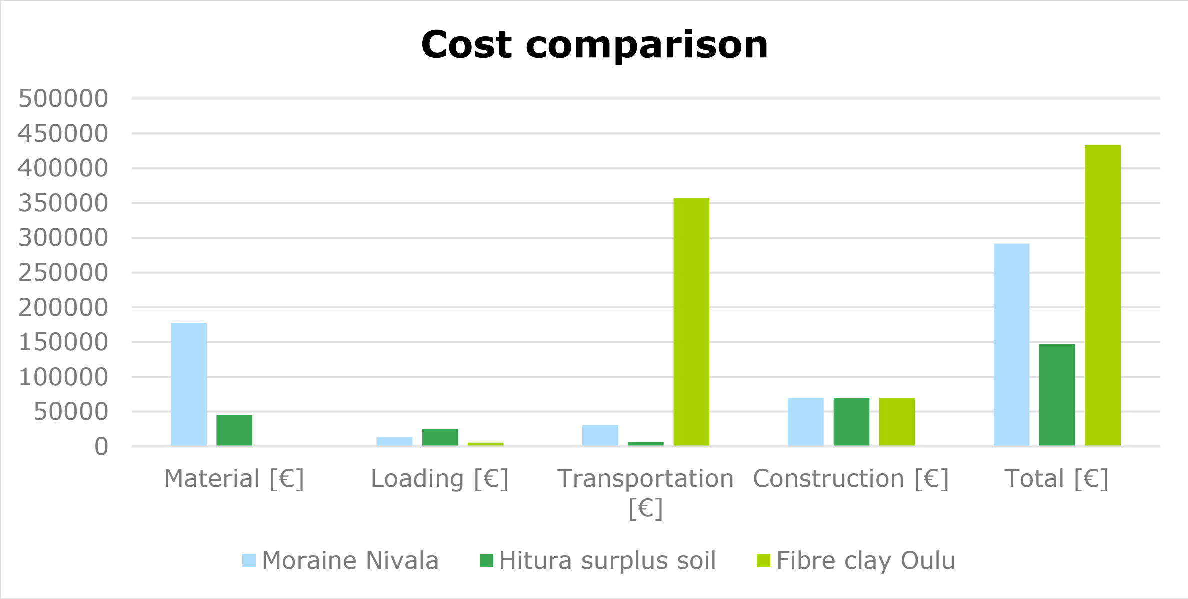

Figure 12. Pre crushing sites cover structure total costs comparison.

All figure's 12 case structures are same size so these can be compared directly by total cost. As can see original surplus structure is most cost-effective solution. Fibre clay from Oulu is most in attractive compared to other material solutions. If the site would be closer, the chart would looks different.

7. CONCLUSION

Surplus soils and materials seem viable option when considered costs and impacts on environment, but material sources need to be close to achieve the best results. UPACMIC (Utilisation of by-products and alternative construction materials in new mine Construction, LIFE12 ENV/FI/000592) project's pilots in Hitura were far from material producers which affect a lot to results of LCIA and LCC comparison. The UPACMIC project's goal was to demonstrate possibilities and viability of industrial by-products and surplus soils in mine environment and encourage utilizing new materials in exchange for natural resources. That was considered to be more important than fibre clay piloting carbon emission.

The fibre clay is partly biodegradable which needs to be taken into account to maintain layer thickness after some time, but degradation clogs the layer which makes it even less permeable, so its properties improve over time. Maintaining layer thickness was the reason behind different thicknesses of pilot structures (200 vs 250 mm). Another benefit of using fibre clay is that it doesn't crack when it dries as natural moraine does. That makes fibre clay sealing layer more durable against weather actions.

The transport distance affects the most to fibre clay utilization in emission and cost when compared direct cost and emissions. However, in the comparison undirect impacts were leaved out due to complexity. When material would be disposed as waste and not been utilized, indirect impacts would be for example landfill area establishing, maintenance and eventually closing. That would generate emission, energy usage, depletion of natural resources and costs. In Finland there is also waste tax which can be avoided when waste can be utilized as material. Rough estimation of total price of one tonne waste disposal is at least about 100 €. If indirect costs were taken in account, the cost comparison would look different. If this project encourages in the future fibre clay utilization closer of the source it would eventually overturn the emissions of these pilots.

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