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SUSTAINABILITY INDICATORS
RESULTS AND DEVELOPMENT

LIFE12 ENV/FI/000592 UPACMIC

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CONTENT

1. INTRODUCTION

The objective in UPACMIC project is to promote the utilization of alternative construction materials in new mining facilities and remediating the existing ones. New kind of constructions in the UPACMIC project utilizes industrial by-products and surplus soils safely, ecologically and cost-effective way. Sustainability indicators has been monitored during the project time, for example carbon footprint and the methodology of LCA which results are presented in own reports *"C2 Carbon footprint final report 2022"* and *"B3 Final report quality control summarizing report 2022"*.

The project has developed sustainability indicators which can be used for measuring and controlling the sustainability of the methods and practices proposed by the UPACMIC project. The aim of this report was to develop an indicator model that can be used to assess the environmental, economic and material impacts of mining construction when alternative materials are used in constructions. With the indicators can be compared usage of different materials and effect of the different material solutions. The indicator model can be applied at the project design stage to assess the impact of different options to support decision-making or to monitor the impact of completed projects.

When new type of construction solution is in development and research stage, indicators are important implement to evaluate and compare construction solutions to conventional alternatives. Indicator development in the future should be done based on previous experiences in construction work with evaluated materials. Construction work in UPACMIC project has been documented step by step, what makes easy to notice problems and example factors which increased costs in construction phase.

2. INDICATORS

The importance of sustainable use of natural resources and material as well as resource efficiency is growing. The objective is to reduce the use of natural resources by using alternative materials in mine construction and, also effective use of natural recourses when needed. Production and consumption of materials relates to the adequacy of natural resources, climate change mitigation and the work against other environmental problems. The sustainable use of natural resources and the more efficient use of materials can reduce environmental impacts throughout the life cycle.

Consumption of natural resources indicators are essential for comparing the usage of alternative materials with traditional construction. These indicators can also be used at the design stage when planning the rations of non-renewable natural materials and alternative construction materials. Even a target for the quantity of alternative materials can be set for the project. Comparing straightly doesn't present a real picture from utilization. It's important to remember that waste disposal, like burning, needs also intermediate storing and transportation.

Non-renewable materials, such as virgin natural rock materials, can be replaced by recycled materials or by-products which match the properties of the material to be replaced by it. Soil and rock materials are non-renewable natural resources, but they can be reused. Local soil could be improved with dosing suitable alternative materials and this way it can lower or prevent virgin natural material needs and depletion of natural material sources.

Surplus soils are materials which have been removed from their original place, example away from a way of new tailing sand basin place. Surplus materials in some cases can be used elsewhere inside the project or utilized by another project, landfill is not a right place clean rock or soil material in nowadays. Properties in surplus soils varies, which affects the possibilities for consumption. There are compact materials like clay, which can be used in dense structures and sometimes surplus soils are processed into higher-quality products or landfills.

It is important to include climate impacts in the indicator model, as the utilization of reused materials can often reduce CO_2 emissions. Alternative construction materials have often significantly lower carbon footprint than traditional materials, as these materials are not manufactured as building materials, but are generated as waste or by-products from other processes. Production of by-product or waste materials are zero emissions, only material handling generate emissions.

Impact of the transportation and distances between the origin of the material and construction site should be estimated early in the project. In some cases, the utilization of alternative material would reduce environmental impacts, but the emissions of transportation rise so high that environmental benefits are not achieved. This was situation with fiber clay cover structure piloting in UPACMIC project. During the piloting project of alternative material structures is decided to be more important than GHG emissions that are generated during project. Because piloting gives positive experience and practical knowledge of utilization. It will give more likely inspire for using those methods and applications in other application in new potential locations. Projects results replication and up-scaling most likely prevent more GHG emission than the pilots were generated so eventual total impact would be negative.

Indicators for transportation and costs of the project are necessary for the design. It’s important to estimate distances, because often transportation affect clearly from many expectations. When the material demand is defined, can be calculated how much usage of waste and other alternative materials can affect in total costs. The utilization saves producer from waste taxes (70 €/t in Finland from 2021), so utilization also benefits the producer. If material is not utilized there is still costs from material handling, transportation, waste handling, landfill sites maintaining and eventually landfills closure which costs the producer needs to pay. The real price of waste can be +100 €/t, but the total cost depends a lot on material and location.

2.1 Material efficiency

Material efficiency describes how much in tons different materials are consumed or will be consumed in construction project. Indicators also verifies environmental impacts of the construction. Amount of material is calculated in tons for each material type, which are: non-renewable natural materials, alternative construction materials and surplus materials. If the project has a target for the quantity of alternative materials, that can be monitored with this indicator.

With the indicator it’s possible to compare amount of used material and differences between in materials amount. Amount of alternative material might be bigger than non-renewable material needs in the construction. In virgin materials usage case, there is also needed excavation and screening before actual construction work. Materials’ transportation (amount of transportation) costs can also estimate with this indicator, but the indicator doesn’t take attention to distance of the material production. Comparing alternative materials consumption to virgin materials in percentage could give indication how ecological the construction project is. It is important part of this indicator. In the future it could be general objective of the project to extend of idea about replace virgin materials with alternative materials where it is possible. Indicators is presented in table 1.

Table 1. Material efficiency indicators.

Indicator	Unit	Description
Virgin materials	t	Quantities of virgin aggregates, soils and other construction materials and products
processed aggregates	t	
unprocessed aggregates	t	
other soil materials	t	
other materials and products	t	
Alternative construction materials	t	Quantity of waste and by-product materials used, recycled products and surplus soils transported from elsewhere
industrial by-products	t	
waste utilization	t	
transported surplus soils	t	
recycled products	t	
reusable construction products	t	
removable construction products	t	
Excavated material	t	Quantity of waste generated by the project
dumping	t	
utilized by the project without processing	t	
processed material utilized by the project	t	
utilized elsewhere without processing	t	
processed material utilized elsewhere	t	
Total consumption of materials	t	
Total consumption of alternative materials compared to virgin materials	%	Percentage comparison between alternative and virgin materials

2.2 Greenhouse gas emissions

Greenhouse gas emissions -indicators presents global warming potential of the construction. Calculations and results are divided on three group which are material production, transportation and construction emissions in CO_2 eq. Emissions are calculated based on operative emissions calculations instructions. Maintenance and end of life are not included in the calculation because structures' end of life (which means destruction or demolition) is impossible to evaluate due to their type of permanency.

Virgin materials excavation and screening cause emissions, but alternative materials production emissions are 0, because they are by-product, waste or surplus materials. Only material handling cause emissions. Global warming potential is calculated directly using factors that gives CO_2 equivalent (kg).

Table 2. Greenhouse gas emissions-indicators.

Indicator	Unit	Description
Greenhouse gas emissions	kg CO_2 eq	Greenhouse gas emissions during construction in CO2 equivalents
material emissions	kg CO_2 eq	Emissions from the production of materials
transportation emissions	kg CO_2 eq	Emissions from transportation
construction emissions	kg CO_2 eq	Emissions from working machines
Total emissions	kg CO_2 eq	

2.3 Transportation

Materials are transported from material production facility to construction site and inside construction site to temporal storing or utilization. Transportation causes a lot of costs, so this indicator is necessary for material choosing. Transportation also causes GHG-emissions.

Long transportation distances are one of the obstacles in utilizing alternative materials, because material production location is rarely near construction site. But utilizing waste materials, the production company could spare of waste taxes and landfilling costs. So, it's justified, that they take a part in transportation costs. However, this part must estimate exact so the right material can be chosen. Indicators are presented in table 3.

Table 3. Transportation indicators.

Indicator	Unit	Description
Material transportation to construction site	tkm	Material transportation from production to construction site
Material transportation out of the construction site	tkm	Material transportation from construction site to storage or disposal

2.4 Costs

For cost indicators should selected most meaningful values, that generate largest portion of total costs. Those are generally material cost, transportation cost, and construction cost. By calculating those values for every structural solution, can be estimated different structural and material solutions economical plausibility. Maintenance costs can be estimated to be about same between material solutions, so those doesn't affect to the result of comparison.

Table 4. Project's cost indicators.

Indicator	Unit	Description
Material costs	€	
Transportation costs	€	
Construction costs	€	
Total costs	€	

3. RESULTS

3.1 Material efficiency results of UPACMIC

Of UPACMIC project pilot structures usage of alternative or surplus materials were 71 % of potential virgin material usage (table 5). Percentage is calculated compared replaced virgin natural materials total weight to combination of that weight and used virgin natural material. This approach was selected because alternative materials' bulk density is often lower than replaced material so direct weight to weight comparison would have given unreliable result.

Table 5. Material efficiency results of UPACMIC project.

Indicator	Unit	Description
Virgin materials	t	Quantities of virgin aggregates, soils and other construction materials and products
processed aggregates	15,3	Inert layer (gravel)
unprocessed aggregates	60 775,7	Moraine
other soil materials	6	Humus
Total	**60 797**	
Alternative construction materials	t	Quantity of waste and by-product materials used, recycled products and surplus soils transported from elsewhere
industrial by-products	81 977,8	fiber clay, branch pieces, ash, gypsum, tailing sand
waste utilization	37 100	digested sludge, water treatment sediment, waste soils
transported surplus soils	3000	Surplus clay from Mäkelä and Hamula
Total	**122 077,8**	
Excavated materials		
utilized by the project as such	28 849,9	surplus soils from Hitura
Total consumption of materials	211 725	
Consumption of alternative and excavated materials compared to virgin materials	71 %	

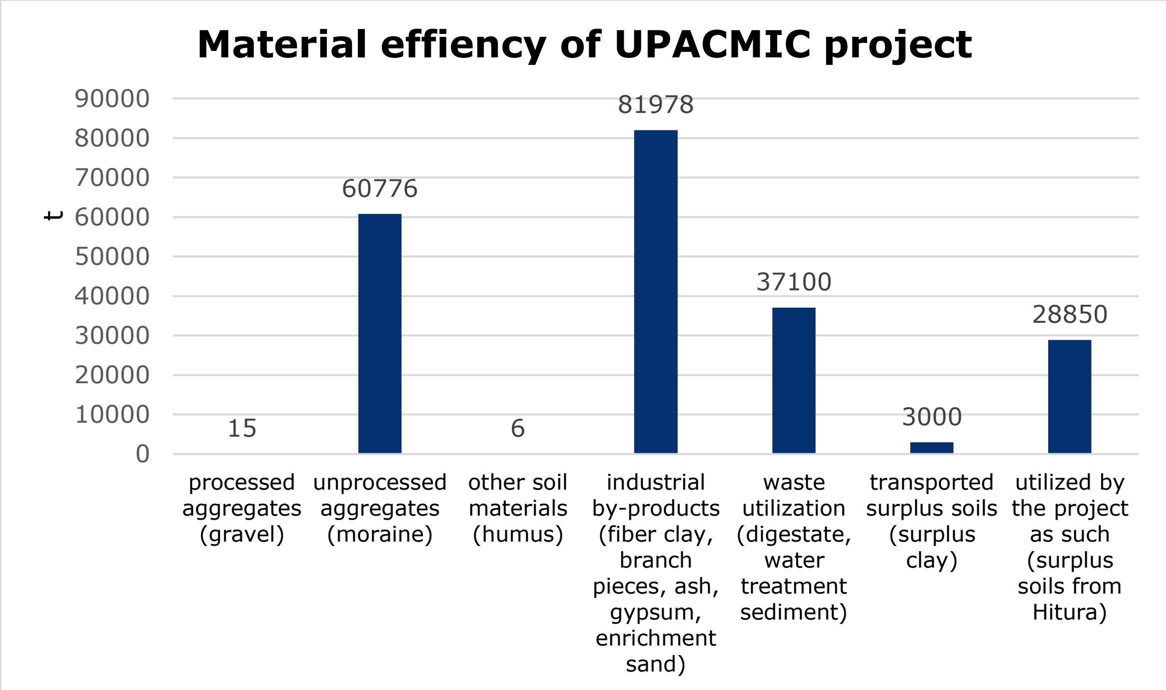

Figure 1. Material efficiency of UPACMIC project.

As you can see in figure 1, the UPACMIC project's pilot structures are constructed mostly with industrial by-products like fiber clay, ash and gypsum. Material efficiency in construction of isolative structure in Kuopio is at highest level about 99 % because all material which are utilized are already deposited on that area or would be deposited. Only geotextiles for separating functional material layers needed to buy new. In Hitura phase II was utilized nearby surplus soils for pre crushing sites covering structures which saves natural moraine resources.

3.2 Greenhouse gas emissions of UPACMIC

Transportation produces most CO_2-emission of UPACMIC project, results are presented in table 6 and figure 2. Material production rarely located near construction site, which add up cost and generate CO_2 -emissions. Utilization of waste or by-product materials causes less emissions in production, because only the emission from loading is considered belong to the material productions emission. Material production caused least emissions in piloting structures of UPACMIC. Secondary highest emissions were in construction work, but there weren't differences in working machines with different materials. It's also important to keep in mind that waste or by-product incineration or disposal causes emissions.

Table 6. Greenhouse gas emissions of UPACMIC project.

Indicator	Unit	Description
Greenhouse gas emissions	kg CO_2 eq	Greenhouse gas emissions during construction in CO_2 equivalents
material emissions	49 372,3	Emissions from the production of materials
transportation emissions	582 561,6	Emissions from transportation
construction emissions	186 149	Emissions from working machines
Total greenhouse gas emissions	818 083	

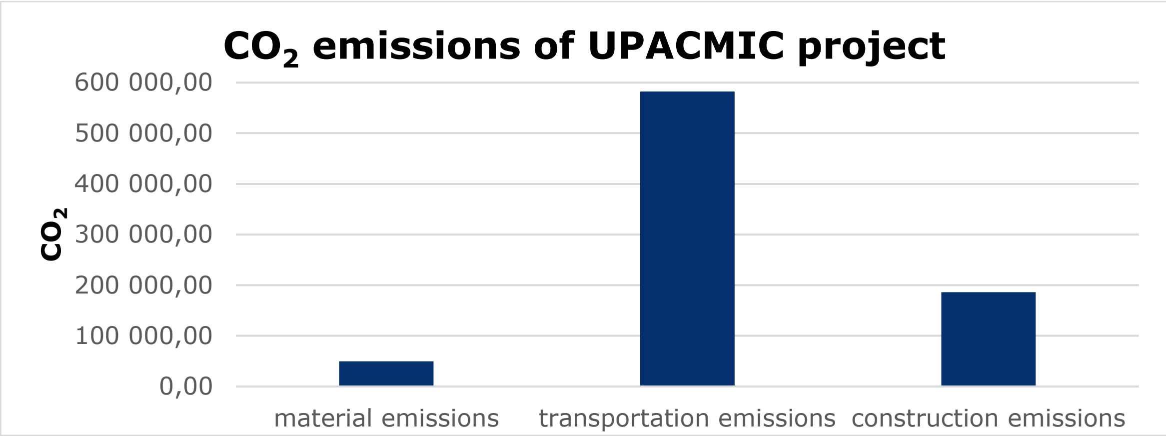

Figure 2. CO_2 emissions of UPACMIC.

3.3 Transportation of UPACMIC

Massive structures are required a lot of construction materials, which means many transportation kilometers. Transportation causes costs and CO_2 emissions, therefore it's important to notice in project designing. There was only material transportation from production to construction site in UPACMIC, because constructed cover layers were materials' disposal site. In UPACMIC project were utilized many waste and by-product materials. If those materials would need to be dispose as waste, transportation and loading to incineration plant or landfilling causes emissions and costs even the distance is shorter. These variables wasn't taken into comparison because complexity and great differences between materials. Results of the driven ton-kilometers are shown in table 7. Total transportation kilometers were 11 914 889 km, when average of transportation kilometers per ton is 56,3 km.

Table 7. Driven kilometers of UPACMIC project.

Indicator	Unit	Description
Driven kilometers	tkm	
Materials transportation	11 914 889	Material transportation from production to construction site

3.4 Costs of UPACMIC

Pilots' costs are calculated according to materials, materials transportation and construction. Those sections are selected for comparing different materials options and those values generate largest portion of total values. Most of pilot-projects' costs consist of three piloting structures: cover layers in Hitura mine (surplus clay, fiber clay and moraine) and the isolative structure in Kuopio Sorsasalo. Other piloting structures (Pyhäsalmi and reactive barriers in Hitura) have left out of the results, because test phase's costs are only a small part of the total costs. In table 8 and figure 3 are presented that over than half of total costs consist of transportation. Calculation doesn't include design process; it's supposed to be almost same with different materials. It's also important to notice that materials disposal like burning or landfill cause costs, which are not estimated. Those costs can be reduced by utilizing waste materials in construction.

Table 8. Costs of UPACMIC project's pilots.

Indicator	Unit (€)	Description
Material costs	318 571	Includes loading
Transportation costs	836 089	
Construction costs	467 015	
Total costs	**1 621 675**	

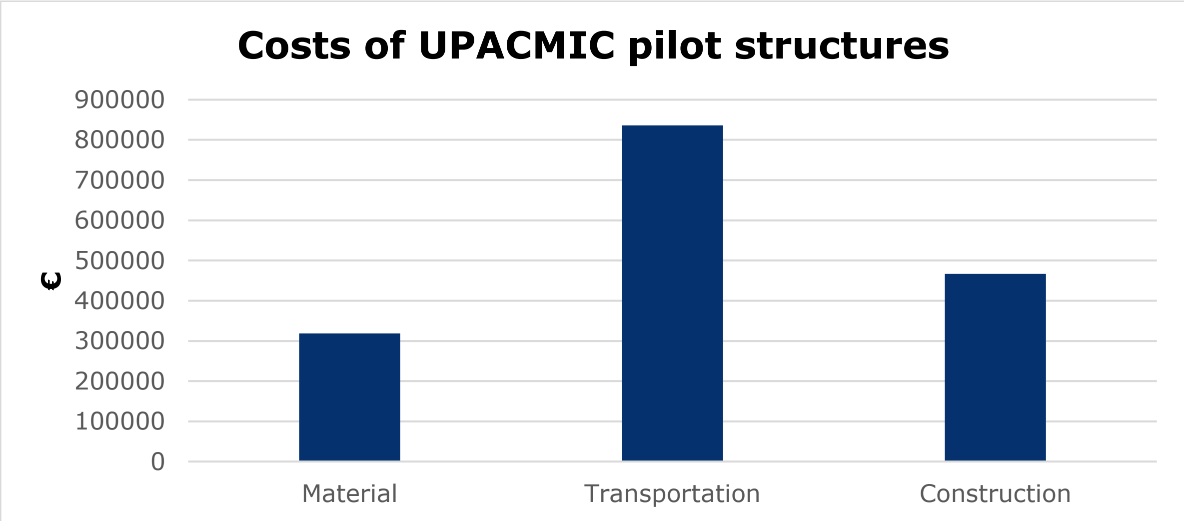

Figure 3. Costs of UPACMIC project's pilots.

3.5 Conclusions

Based on the results, can be noticed that the transportation effects the most in many perspectives. It's important to estimate distances in material survey phase because it effects significantly in many ways. Material emissions and costs could prevent or at least reduce with alternative materials like waste or by-product. Project evaluation doesn't take into account emission or negative effect, which unutilized materials waste incineration or disposal would cause. Alternative material pilot structures which are implemented during UPACMIC project is compared to alternative structures which are constructed using only virgin material. The comparison is presented in report *"B3 Final report quality control summarizing report 2022"*.

Long distances caused many negative effects for piloting targets. Fiber clay constructions were 1,5 times expensive than moraine cover layer. Distances from fiber clay production facilities were more than 150 km, when local moraine was brought from 16 km away. Fiber clay structures were less permeable than local moraine, so cover layers' properties were better by alternative material than original material. During the project was also noted that moraine's water permeability could be improved by ash, which is important knowledge for the future. Local material utilizations empowering will cut emissions and costs of transportation dramatically.

4. INDICATOR DEVELOPMENT

Comparing alternative and virgin materials usage directly isn't reasonable because there are many effective factors to assess construction project in nowadays. Same kind of materials, virgin or by-products, can be compared because basic production methods are same. Zero-waste policy and shift toward circular economy makes producers more wishful to do research for materials recyclability and utilization features instead of just dumping waste to the landfill. Also, nowadays the dumbing is last option for material that is suitable for earth construction, according UUMA4-program which goal is to promote the use of recovered materials in earth construction.

From recycle and eco-efficiency perspectives it must be estimate in future, how much emissions and costs burning, intermediate storing or disposal causes. Comparing utilizing emissions, cost and naturals resources consumption between different materials during whole lifecycle could offer better perspective from alternative and waste materials utilizing. Indicators should include implements for calculate real effectives and emissions, also includes payments for landfill and waste taxes. This way producer could take a part of extra cost which are caused by longer distance or possible materials processing before utilizing.

Waste and by-product materials could have chemical features which can be utilized example in seepage water treatment. There must be done research about the feasibility of the material before utilization. In the best-case producer could utilize their waste and consumer get necessary material. In this kind of cases total benefits are difficult to estimate reliably because estimations may be overestimated due to overlapping and possible double calculations.

For reactive structures has not indicators. Reactive constructions need monitoring after construction work. By monitoring can estimate performance of the construction. Indicator for material that supposed to rise pH, could be monitoring of construction's seepage water pH-levels: <4 (construction doesn't work correctly), 4-9 (construction works correctly), >9 (construction over overperform). Indicators could also be some toxic heavy metals concentrations, which based on local limit value of concentrations. With the same way indicator could be concentration differences monitoring in waterways before and after new constructions.

It is often forgotten the impacts that occurred if something is not be done. An example in this case the impact of uncovered tailing sand basin impacts over time is not considered. The impact that the tailings basin would causes in from of spreading harmful dust during dry times or acidic and harmful heavy metal containing seeping water during rainfalls. Impact of these can be negative effects for ecosystem and biodiversity outside of mining area and in sensitive water ecosystem. Monitoring this with indicator is hard but it can be estimated before construction and conform after actions.