SAVONIA

The Utilization of Leftover Stones from Mines and Quarries in North Savo Region

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Bachelor's Thesis

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THESIS

Abstract

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Abstract

Geological Survey of Finland has offered a free access to the data gathered during the “Kaikki käyttöön” Project, which has become the base for the study on the logistics of mines and quarries operating in North Savo region, Finland. The Final Thesis is based on both the data gathered by the “Kaikki käyttöön” Project and research literature. Currently quarrying operations in North Savo region result in production of a large quantity of leftover stone material, which is staying unused and piled on the site.

Leftover stone material generated during mining varies greatly, from dust and sand-sized particles to large boulders. It can be a substitute for primary aggregates, which are used in construction process in very large quantities. Aggregates produced from leftover stone material are highly suitable for road construction and concrete production.

The aim of the “Kaikki käyttöön” Project is to study the possibility of recycling and re-using leftover stone material from mines and quarries, benefits and disadvantages of it, whether it could be implemented cost-efficiently in North Savo region of Finland, with the prospect of applying in other regions. Recycling and re-use of leftover stones has been rather limited mainly because of a high rate of transportation costs. One of the main goals of the project is to clarify and estimate transportation costs that occur, when transportation of leftover stone is performed by different transport modes. Transport modes observed in this research report are road, rail and water transport.

In the future, gravel and sand will be more difficult to obtain, and the production of crushed rock aggregates will accordingly increase. The price of aggregate material at the site where needed will increase depending on availability, longer transport distances and requirements for higher quality materials (Finland’s Mineral Strategy 2010, 15).

At present, transporting of crushed stone by road is expensive over long distances, more than several tens of kilometres. Intermodal transportation is effective in a “port-to-port” system. Accordingly, if mines and quarries are remote from existing infrastructure, it creates a need for new logistic and financial solutions.

Keywords
Leftover stone, utilization, transportation, North Savo, Finland

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1 INTRODUCTION

1.1 Project overview and objectives

Finland's mineral strategy aims at increasing efficiency of management and sustainable utilization of mineral resources. Recycling and re-use of stockpiled waste minerals associated with construction industries reduce the environment impact of the minerals sector and increase its productivity (Finland's Mineral Strategy 2010, 17).

Dependence on minerals has grown over a long period of time, and no change to this trend can be seen. The utilization of minerals is closely related to higher living standards and well-being. Modern society requires the use of mineral-based products in the construction and maintenance of housing and other buildings, railroads, road networks and other infrastructure. *For example, constructing one kilometre of motorway demands 50 000 tonnes of aggregates; building a typical family house makes use of 250 – 400 tonnes of aggregates* (Finland's Mineral Strategy 2010, 3).

Annual aggregate production in Finland is about 120 million tonnes, and the aggregates sector is the biggest extractive industry in Finland with respect to tonnage. Approximately 22 tonnes of aggregate materials per resident are used annually in Finland. The term aggregate is applied to either crushed rock or gravel and sand. Production of crushed rock has increased in recent years due to the limited availability of gravel and sand (Finland's Mineral Strategy 2010, 9). The goal of the "Kaikki käyttöön" Project is to reduce the use of untapped raw materials. The study focuses on utilization of leftover stone material for infrastructural construction purposes from mines and quarries in North Savo region, Finland.

The project offers a new approach to organize the management of mining and natural stone leftover rock in areas where there is high quarrying volume. The project will create a tool for the natural stone and mining industry to develop products from leftover stone material referring to requirements of construction as a part of mine planning during the active life cycle of the mines. The purpose of the project is to integrate stone residues from mines and quarries into a part of regional construction aggregates accounting, land-use planning and stone raw materials trading, in which case they could be taken into account in the future design of the building as a source of raw material.

The project will be implemented as a pilot in North Savo 2013-2014 and the model produced in it can be applied in the future in separate projects elsewhere in the country. The project will generate direct and indirect benefits to decision-makers, licensing authorities, land-use planners, as well as mining and construction companies. The project will support the North Savo natural resource economy strategy, and in particular development of the mineral plan towards the regional strategic program goals. The project offers directly usable knowledge base for ongoing mineral economy database development and for secondary materials accounting. The results will be used, above all, by companies and authorities.

The Geological Survey of Finland (Kuopio) was the main coordinator of the "Kaikki käyttöön" Project. Savonia University of Applied Sciences was a partner of the project, supporting the research with directly usable knowledge base for ongoing mineral economy development. Industrial partners of the project are Yara Suomi Oy, Palin Granit Oy, Betonimestarit Oy, and Savon Kuljetus Oy.

1.2 Functional modules of the project

The "Kaikki käyttöön" Project consists of three functional modules:

M1) Inventory and product development of waste rocks

M2) Applications and logistics

M3) Marketing, communication and training.

The Module 1 is aimed to define suitability of leftover stone material from mines and quarries for different applications referring to quality standards. Module 2 consists of assessment of logistical possibilities within feasible area around the site, taking into account the volume and quality specifications of leftover stone material. Marketing and communications Module (M3) includes not only distribution and presentation of the results of the project to stakeholders and the public, but also implementation of the results of the project as part of the aggregate supply systems.

This Final Thesis is based on the data gathered for the study on logistics of mines and quarries operating in North Savo (M2). Operations of mines and quarries form a large amount of raw stone, which is likely to become raw material for industrial applications. Stockpiled leftover rock can be considered as a raw material for roads, building foundations or concrete factories, landscaping, construction of the walls and ramparts, harbour construction, depending on its geological and geochemical characteristics. The potential for use of mining and quarrying waste is mainly constrained by transport aspects. That is why the major outcome of the research was to find out the most efficient and economically successful logistic scenario. Transport modes observed in this research report are road, rail and water transport.

The transportation costs and infrastructure capability assessment have not been researched specifically for utilization of leftover stones from mines and quarries in North Savo region, Finland. This makes the research work necessary and actual (of current interest).

Transportation technology and costs require to be considered in every leftover stone utilization project, since the distance between the supply point and the demand point for leftover stone material could vary. The cost of transportation usually greatly exceeds the mining cost. As the distribution of mineral resources is uneven, leftover stone transportation is an important concern from business, economic, and environmental viewpoint.

Road, rail and water transport modes were compared by determination of price. Estimations were calculated for all transport modes in costs per kilometre and costs per tonne – kilometre. Different logistic scenarios were observed and analyzed. Transhipment costs of intermodal transport were defined and estimated. Therefore, comparison of using different transport modes is more accurate and can be applied in making logistic decision.

1.3 Research methodology

1.3.1 Research focus and limits

Leftover stone material is generally stored at the site due to economic reasons connected with transportation costs. The quantity of mining residues that is piled varies and mainly depends on the mining method. Open pits generate much more leftover material than underground operations. According to the relevant exploration step, it is possible to define two main types of leftover material: leftover stones and tailings (process waste). Tailings are not taken into account in the present research. Leftover stones can be also categorized as inert (no fee), normal (should be dumped) and problem material.

One main focus of this research was to create cost estimations of delivering leftover stone material from mines and quarries performed by different transport modes. Limitation of this study is geographical coverage. Result of this research work is mainly applicable for mines and quarries operating in North Savo region. In other countries or other parts of Finland these costs can differentiate. Infrastructure capability assessment was also observed for local mines and quarries, but logistic solution and suggestions can be applied in different projects of utilization of leftover stone material from mines and quarries.

Freight rates are applicable for transporting crushed rock material, it was considered as more preferable and the most demanded use of leftover stones as a raw material. Transportation cost of delivering larger particles, e.g. boulders could be optimized with changing the most preferable vessel type and loading equipment.

Logistic planning through the project is aimed to improve transportation of raw materials and reduce transport emissions.

Assessment of direct and indirect benefits of different types of possible transport modes, considering transportation of leftover rocks requires collecting the data for logistic analysis (APPENDIX 1) and creating a system of indicators for comparison of different transport modes.

1.3.2 Data mining

Research process was started with analysing of the data from the GTK archives, sending inquiries to the freight forwarding companies and interviewing potential customers. Reference list includes research reports and research studies about mining operations, logistics of mines and quarries and bulk transportation. Rules and regulations, concerning mining operations are in the research scope. The main goal of literature review was to study all the aspects of logistics of mines and quarries, pros and cons of using different transport modes, the main influencing factors and the structure of transportation costs. In addition, Finnish transport statistics is observed.

Company interview was the main data collection method used in this qualitative research. Excursion to the Siilinjärvi mine (Yara Suomi Oy) and visit to the Varpaisjärvi quarry (Palin Granit Oy) took place in the end of September 2013 and provided the latest information considering quantity and quality of leftover stones on the site. Interview with Betonimestarit Oy supplied the project with facts for assessment of end use for leftover material from mines and quarries in North Savo region. This research would have lacked a lot of important data without interviews and cooperation with transportation companies. Research reports, concerning environmentally friendly logistics were reviewed.

2 RE-USE OF MINING AND QUARRYING LEFTOVER STONE MATERIAL

2.1 Mining activity

Mining activity refers to the extraction and enrichment of refinement of metallic ores, coal and industrial mineral deposits. In Finland, the range of commodities exploited by the mining industry, fall under the operational jurisdiction of the Mining Act (503/1965). These commodities are grouped into four categories:

1) Metallic ores

2) Industrial minerals

3) Gemstones

4) Marble and soapstone.

Quarrying of other dimension stones and crushed rock aggregate requires permitting and compliance under the distinct Land Extraction Act (555/1981) (Mine Closure Handbook 2008, 11). The mining life-cycle includes three main steps: exploration, production and rehabilitation.

The exploration stage involves selection of the most perspective territory based on a detailed analysis of geological, geochemical and geophysical data, supported by reconnaissance investigations. The goal of an exploration is to give an estimation of potential reserves. In some cases, the exploration process may continue for many years or even decades before either sufficient information is available, or circumstances are appropriate for commencement of planning a full-scale mining operation (Mine Closure Handbook 2008, 11 - 12). If it is planned to start mining operation, then a formal written application for a mining permit must be made to the Ministry of Trade and Industry. When the application has been processed and recorded in the national mining register, the applicant is issued with a permit granting the rights to commercially exploit the resources defined in the concession area (Mining Act, Section 40). Mining techniques can be divided into two common types: open pit and underground operation. According to the mining technique, the amount of leftover stone material varies. Open pit mining operations result in higher strip ratio. [Strip ratio = Amount of leftover stone / Amount of ore mined].

Various options exist for using leftover stones during mining, for example by backfilling of galleries and tunnels, and providing structural support. Leftover stone material can also be used above ground, as required for earthworks at the mine site (Mine Closure Handbook 2008, 13).

The duration of mining operations depends on the size and grade of the deposits and methods used, as well as prevailing commodity market prices. Although mining may occur over years of several decades, commodity price fluctuations might result in temporary breaks in production, or even lengthy periods of closure. When all economically recoverable ore has been mined, preparations for decommissioning and mine closure commence. The closure process not only deals with the cessation of technical operations, but also includes site rehabilitation, which involves both landscape restoration and prevention of mitigation of any potential environmental and safety risks (Mine Closure Handbook 2008, 11 - 13). FIGURE 1 presents the mining life-cycle process, from exploration through to closure.

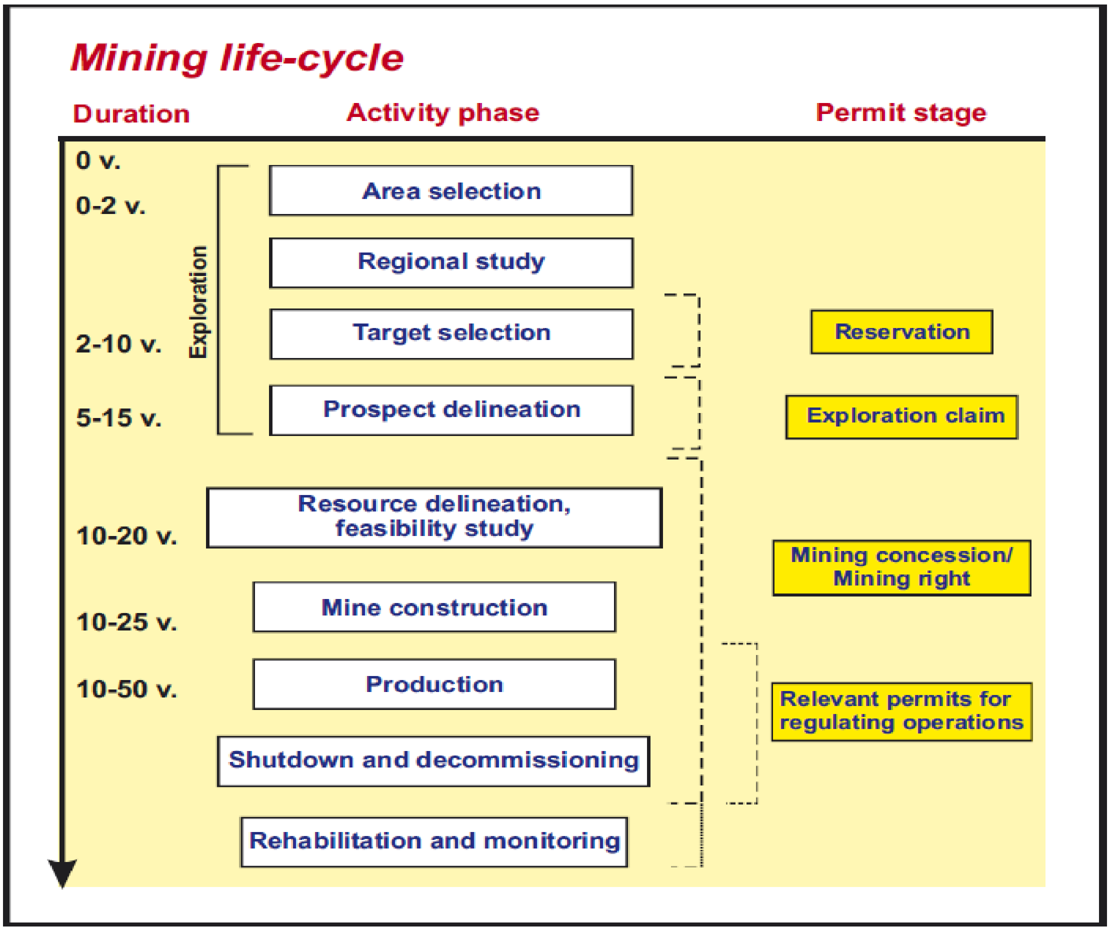


FIGURE 1. Mining process life-cycle; time scale at left is indicative of duration of various phases of activity (Mine Closure Handbook 2008, 13)

2.2 Definition and legislation of mining waste

Waste legislation is represented in the Waste Act (1072/1993) and Decree (1390/1993) and the Government Decision on landfill sites (861/1997). Under the Waste Act, waste means any substance or object, which the holder discards or intends, or is required, to discard (Waste Act, Section 3).

The extracted soil, waste rock and tailings generated in mining and stored in the mining concession or its auxiliary are and which either can be used in the mining operations or can be further processed, are considered by-products of mining as per the Mining Act (Section 40).

Under the Waste Act (1072/1993), by-products are defined as waste if the holder discards, or intends or is required to discard them.

Waste rock and tailings which permanently is deposited on the mine site and which are defined as waste are either inert waste, non-hazardous waste or hazardous waste (Mine Closure Handbook 2008, 121).

The organization of appropriate waste management is an important aspect of mining activity. Before beginning operations, the operator must pledge a guarantee to ensure waste management (Environmental Protection Act, Section 42). Since 2002, the Northern Finland Environmental Permit Authority has observed in its environmental permit decisions that crushed waste rock, which conforms to the product properties of crushed rock aggregate and similar crushed rock (i.e. waste rock which is similar in its properties to normal building stone) and, which is delivered for use in building or other operations directly or after a reasonable period of storage, shall not be defined as waste (e.g. Northern Finland Environmental Permit Authority decision of December 20, 2002 no.77/01/1 diaryNo.123/00/1). Accordingly, their use is not a subject to an environmental permit.

The Eastern Finland Environmental Permit Authority observed in its decision of June 6, 2005 No. 53/05/2 diary No. ISY-2004-Y-210:

“Extracted soil and rock, which are used without any further processing for earthwork construction or improvement within 36 months of the discounting of mining operations, shall not be considered waste but shall instead be considered by-products. By-products that remain unused after the above period must be delivered to a previously designated deposit area.”

The handling of by-products is treated on a case-by-case basis in permit procedures, and the issue of waste management is resolved separately for each mine. Operators must present sufficiently detailed plans for how and when the materials are to be used. What is essential for materials not to be considered waste is that they must be specifically identified and actually used. Regardless of whether by-products are classified as by-products or as waste, it is important to submit a plan for their use to the Environmental Permit Authority when applying for the environmental permit. This makes the use of the material clearer (Mine Closure Handbook 2008, 89). Institutional or commercial recovery or disposal of waste requires an environmental permit (Environmental Protection Act, Section 28).

3 POTENTIAL UTILIZATION AND TRANSPORTATION OPTIONS FOR LEFTOVER STONE MATERIAL IN NORTH SAVO REGION, FINLAND

3.1 Current situation

Leftover stone material is generally stored at the sight due to different reasons connected with transportation cost, specific properties of the rock and lack of promotion. Stone residues from mines and quarries can be developed into a product, which is suitable for different applications. It can be considered as a raw material for road construction, concrete factories, and landscaping or harbour construction, depending on its quality characteristics.

Study case research is based on recent information from data gathered by the "Kaikki käyttöön" Project.

3.1.1 Palin Granit Oy

Palin Granit Oy Varpaisjärvi quarry is a dimension stone quarry in North Savo region. It is located in municipality of Lapinlahti, 12 km northeast from Varpaisjärvi.

a)  b) 

FIGURE 2 (a, b). Dimension stone quarry view in Varpaisjärvi, Palin Granit Oy (Photo: Kimmo Karenlampi, GTK)

The main products of the dimension stone Varpaisjärvi quarry are stone blocks and slabs. Black, fine grained diabase with density of 3080 kg/m^3 is quarried in Varpaisjärvi. The annual amount of all extracted stone is approximately 25 000 m^3.

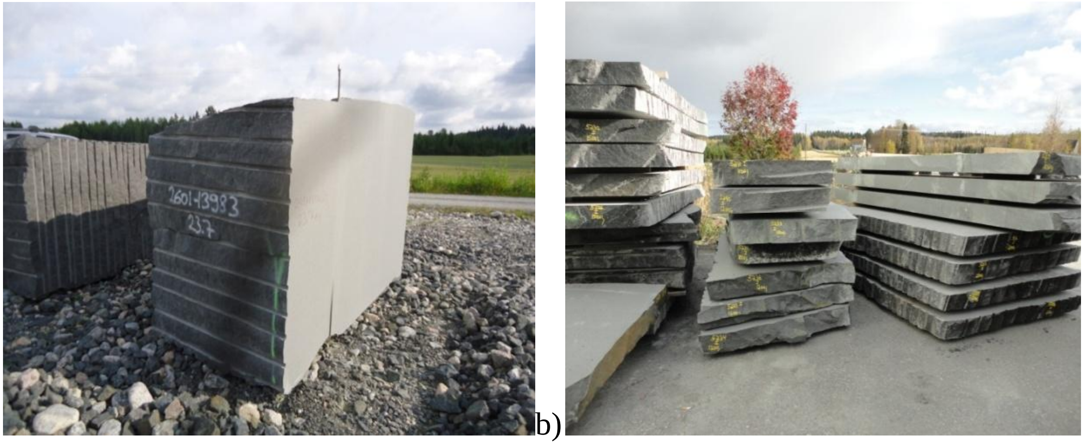
a) b)


FIGURE 3 a) stone blocks in Varpaisjärvi, Palin Granit Oy; b) stone slabs in Varpaisjärvi, Palin Granit Oy (Photo: Kimmo Karenlampi, GTK)

Presently, the total amount of leftover stones, including large blocks which doesn't fulfil the high quality demand for granite blocks, which can be used to substitute primary aggregates amounts to 300 000 m^3 .

Scrap stone and low quality stone are moved by dumpers to the pile, which is mainly formed with large boulders. Diabase is highly suitable for road construction and water-based projects, concrete for industrial and civil construction due to its density, hardness and strength. The utilization of this kind of material is rather limited for different reasons, like high level of transportation costs, limited logistic possibilities, CE-labelling. Nevertheless, leftover stone from Varpaisjärvi quarry is a valuable raw material, which can be implemented in large and small scale applications for infrastructure construction.

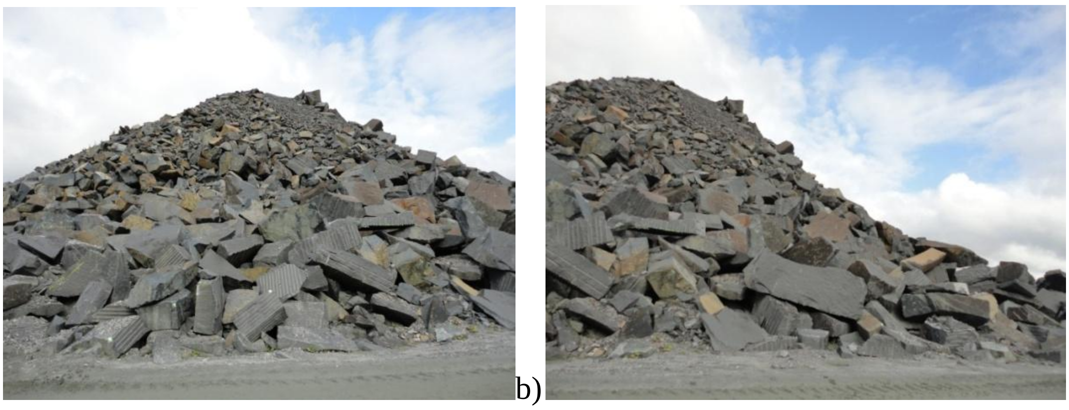
a) b)


FIGURE 4. Leftover stone pile view in Varpaisjärvi, Palin Granit Oy
(Photo: Liudmila Alexandrova, GTK)

Palin Granit Oy has a permit for crushing rocks. There are only 2 crushing permits in the region. Thus and so, the oversized blocks are not the biggest issue, they could be crushed with hydraulic hammer at the site. Sorting of material is not needed in view of homogeneous waste rock pile. The amount of the leftover stone ensures that customer's needs are fulfilled. Quality of stone and homogeneity in a stockpile are the strengths which give a competitive opportunity to develop recycling operations in Varpaisjärvi to comply with the best modern environmentally friendly practices.

Rocks are currently used for infrastructure construction within the mine. Annual quarry needs for aggregates are 3000 – 5000 tonnes. Leftover stone material from the Varpaisjärvi quarry has been also sold outside. In 2006 about 10 000 tonnes of crushed rock were sold for all purposes in the near-by area. In 2009 approximately 37 000 tonnes of aggregates was produced for local customers. During the recent years boulders have been locally used for farmhouses (about 500 - 600 m^3).

3.1.2 Yara Suomi Oy

Yara Suomi Oy runs the Siilinjärvi phosphate mine, which is the only one in Europe. It is located about 20 km north from Kuopio. The main product is the apatite concentrate which is a raw material for phosphoric acid.

a)  b) 

FIGURE 5 (a,b). Open pit mine view in Siilinjärvi, Yara Suomi Oy (Photo: Joonas Toivanen, GTK)

Production is performed from two open pits: Särkijärvi main pit and satellite pit Saarinen. Residues from Siilinjärvi mine have different technical properties and mineral content, resulting in different potential applications for a material. The main types of leftover material resulting from mining at Siilinjärvi site are fenite, diorite and diabase. All the stockpiles of the coarse material mainly consist of rocks which vary in size from construction aggregate (average diameter size of 5 – 50 mm) to larger blocks that cannot be easily crushed (less than 5 %). Table below presents estimated leftover stone material amount during 2012 – 2034 years from the main pit in million tonnes. Amounts of estimated leftover stone material are classified by type of material and location of its extraction. Granit gneiss and fenite from Satellite pit amounts to 10 million tonnes (selectively loaded).

Table 1. Estimated leftover stone material amount during 2012 – 2034 years from the main pit in million tonnes, Yara Suomi Oy.

Type of material	Location of extraction (Northwest, Northeast, Southeast, Southwest, West)					Total	Selectively loaded
Fenite	NW	NE	SE				
	21.1	30.7	14.8			66.6	46.5
Diorite				SW	W		
				1.3	9.9	11.2	7.8
Diabase	NW	NE	SE	SW	W		
	8.8	5.3	4.4	16.1	14.1	48.7	9.8
Total						126.5	64.1

a)

b)


FIGURE 6 (a, b). Leftover stone pile view in Siilinjärvi, Yara Suomi Oy (Photo: Satu Hietala, GTK)

All estimations about the volume of potentially reusable material should take into account corrections, considering the usage of leftover stone within the mine. In 2012, the usage of leftover stones was about 2 million tonnes and 1 million tonne of diabase and diorite was loaded selectively to pile for further needs. 1, 4 million tonnes of mixed leftover material were used in dam construction.

The current total annual amount of extracted ore and leftover stone is about is about 10.7 million tonnes and 13-14 million tonnes resp. During few years 2014 – 2020 strip ratio will be high [Strip ratio = Amount of leftover stone / Amount of ore mined]. In year 2014 the strip ratio is 1.6, which means that mining of one tonne of ore will generate about 1.6 tonnes of leftover stone. When operating with huge amounts of leftover stone it is essential to promote innovative approaches to recycling and re-use of residues from mining operations.

3.2 Transport overview and assessment of infrastructure capability

In Finland, at the end of the year 2011, there were 78 139 kilometres of highways, 5 944 kilometres of railways and 9 791 kilometres of inland waterways (Transport and Communications Statistical Yearbook for Finland 2012, 23). According to the Transport and Communications Statistical Yearbook for Finland (2012, 40), 87 % of goods are transported by road within Finland. Water transport predominates in international transportation (Chart 1).

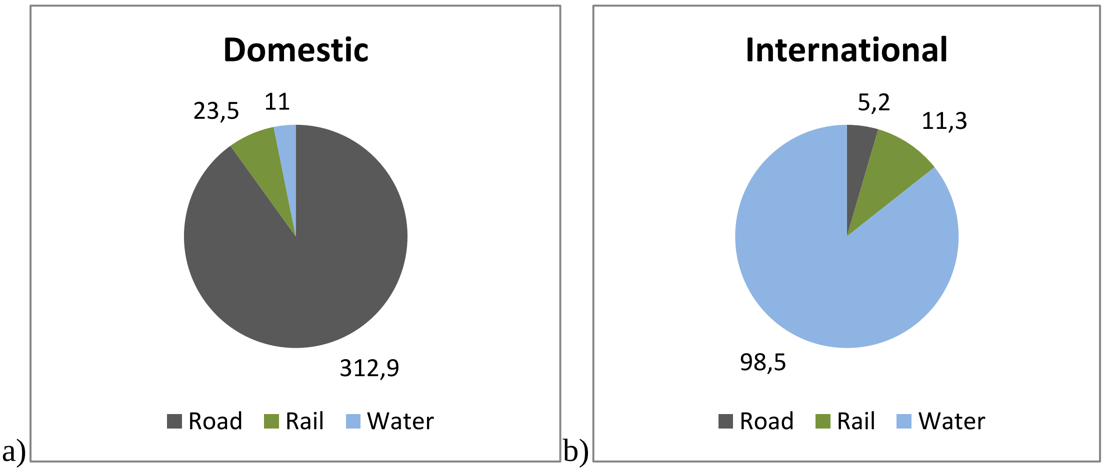


CHART 1 (a, b). Goods transportation in million tonnes, 1980 – 2011 (Transport and Communications Statistical Yearbook for Finland 2012)

Transportation technology and costs need to be considered in every leftover stone utilization project, since the distance between the supply point and the demand point for leftover stone material could vary. The cost of transportation usually greatly exceeds the mining cost. As the distribution of mineral resources is uneven, leftover stone transportation is an important concern from business, economic, and environmental viewpoint.

Crushed stone belongs to bulk cargo and can be transported in uncovered cars and stored in open yards. Delivery technology from the point of production to the end user depends on availability of railway path, access to water way or highway.

The choice of particular transportation mode for each case depends on a wide variety of factors, such as freight rate, distance to the site, loading and unloading facilities, volume of material to be delivered and etc. Logistic possibilities include transportation by road, rail and water. Transportation of leftover stone can be performed in different scenarios. If rail or water transport is used, then also another transport mode has to be used for pre-haulage and post-haulage. In many cases pre-haulage and post-haulage are performed by road transport. Mine or quarry is usually a starting point in logistic chain, when delivery of crushed stone takes place.

3.3 Road

Road haulage is very attractive and essential for pre-haulage and post-haulage in terms of flexibility. Trucks can be easily loaded and simply tip their load off at the discharging place.

In Finland, the Finnish Transport Agency is responsible for maintenance and development of the state-owned road network.

FIGURE 7. Large detailed road map of Finland (www.vidiani.com)

The Finnish National road 5 doubles as E63 and runs through the following municipalities: Iisalmi, Lapinlahti, Siilinjärvi, Kuopio, Leppävirta, and Varkaus. The Finnish National road 5 is classified as a Main road Class I, E 63 belongs to a Main road Class II. Regional road 582 is a connection between Varpaisjärvi and Lapinlahti, e.g. the Finnish National road 5 and E63.

Starting from October 2013, the new Finnish regulation for highway transportation allows usage of 76 tonne-vehicles. This makes the price level lower than in case of using conventional 60 tonne-vehicles. Before max payload for trucks was 40 tonnes, now it has been increased up to 50 – 55 tonnes.

Table 2 below represents average price for highway transportation of consignments with load of 40 tonnes. Loading or unloading costs and taxes are not included in Table 2. All the costs presented in Table 2 are based on interviews with experts from

Savon Kuljetus Oy. Savon Kuljetus Oy is a local (North Savo, Finland) company and a partner of the project with experience of transporting coarse minerals by road.

Table 2. Average price for highway transportation of consignments with load of 40 tonnes.

Costs of transportation by road	Distance (km)			
	20	30	40	60
Total costs (€)	150	200	250	400
Costs per tonne (€/t)	3.75	5.00	6.25	10.00
Costs per tonne-kilometre (€/tkm)	0.19	0.17	0.16	0.17

Accordingly, the longest possibly sensible transportation distance is about 30 - 40 kilometres. Loading cost range will be 0.5 € – 1.0 € per tonne. The break-even point in this scenario is about 60 kilometres. Under that point road transport is more expensive than intermodal transport.

3.4 Rail

Rail shipping is one of the possible ways of transporting coarse minerals. Usually, rail transport provides “terminal-to-terminal” service. In comparison to road transportation, rail transportation is less frequent.

In Finland, the Finnish Transport Agency is in charge of management, development and maintenance of the railway network. VR Ltd runs passenger and freight transport on the railway network. VR Ltd holds a monopoly for domestic rail transport in Finland and international rail transports to Russia. An international rail connection exists between Finland and Russia via Niirala.

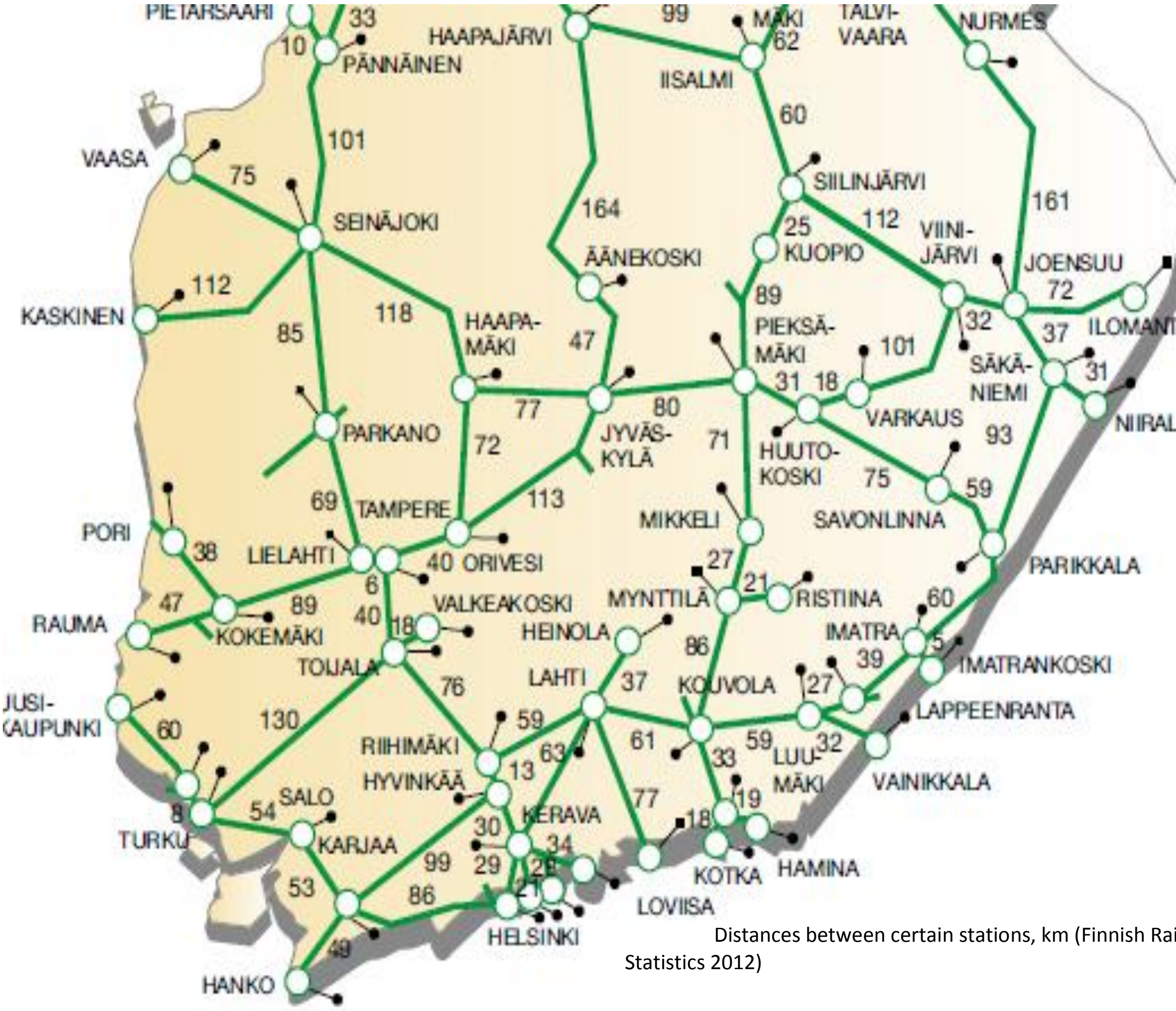


FIGURE 8. Distances between certain stations, km (Finnish Railway Statistics 2012, 13)

Loading sites in North Savo area:

- Iisalmi (private)
- Siilinjärvi (private)
- Varkaus (private).

Crushed stone can be loaded into an open hopper car which is a type of railroad freight car used to transport bulk commodities or a gondola car (rail), which is an open-top type of rolling stock that is used to carry very dense material. Any particular scenario should be negotiated with VR Ltd every time separately. The rate is totally dependable on routing, shipment size, transported goods and amount of needed shunting work, as well as on handling capacity of customer tracks in departure and arrival station for optimized solution for loading/unloading operations. Required open bottom or capsized wagons are currently fully used in other transportations. Due to lack of suitable wagons for transportation of crushed stone by rail is rather limited. Indicative, nonbinding rate for transporting crushed stone by a block train with payload of 1 000 tonnes up to 60 kilometers is 10 € - 12 € per tonne. In case customer will provide wagon fleet, indicative rate would be 10 - 20 % lower. Rates are based on cost structure analysis calculated for each case. Loading or unloading costs and taxes are not included in cost estimation. All the costs are based on interviews with experts from VR-Group Ltd.

Cost estimation for rail transport is 0.18 € per tonne-kilometre, which is more expensive than road transport, while delivering crushed stone for a distance about 60 kilometres. Transhipment costs will increase the freight rate and should be taken into account when planning intermodal transportation, including road transport. Loading/ unloading cost range will be 1.0 € - 2.5 € per tonne.

3.5 Water

Water transportation is a beneficial option when a high volume of low-value items needs to be transported. The use of waterways highly depends on the geographical location. According to the Transport and Communications Statistical Yearbook for Finland (2012, 40), water transport has a leading position in international transportation.

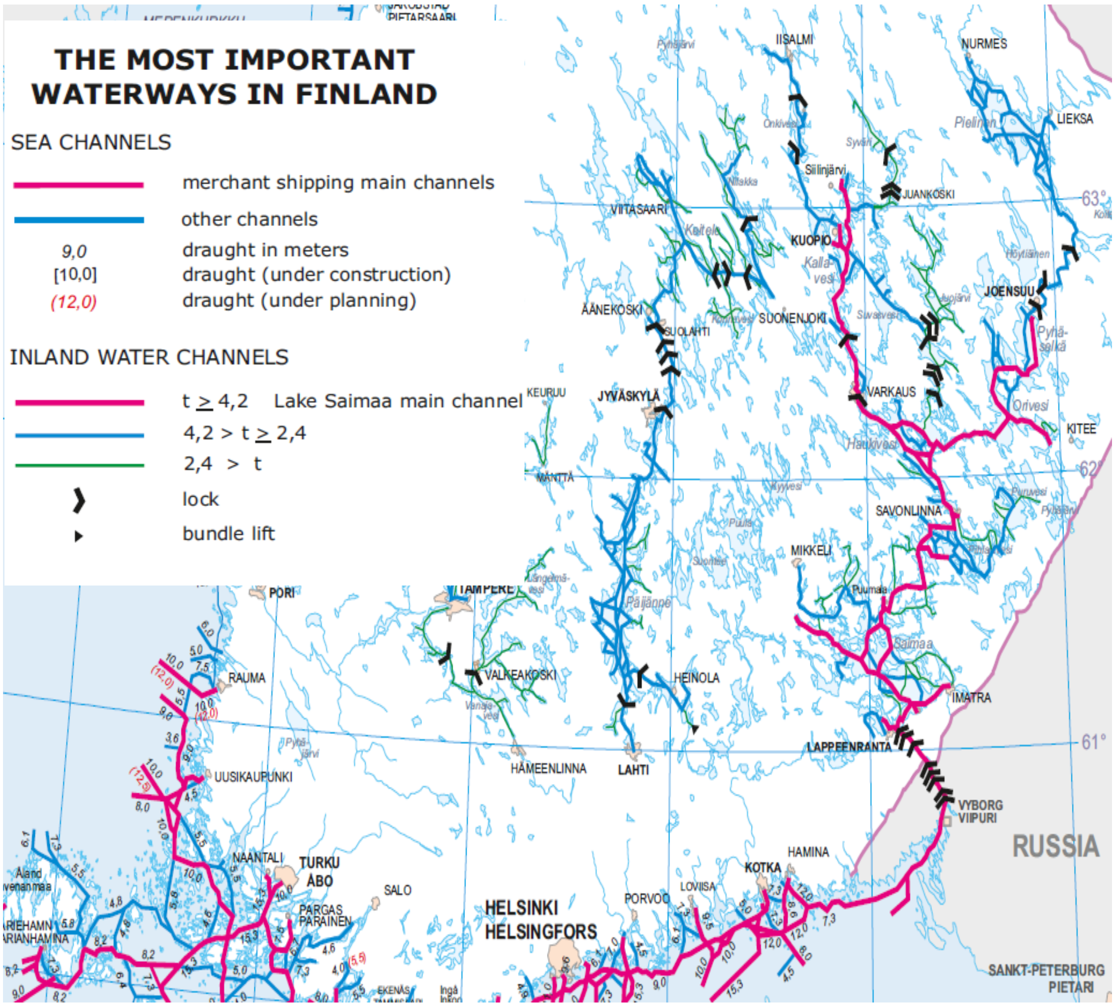


FIGURE 8. The most important waterways in Finland (www.liikennevirasto.fi)

In North Savo area there are deepwater channels, with the draught of 4.2 meters from Varkaus to Kuopio and to Siilinjärvi. There is sea connection via the Saimaa Canal. From Kuopio to Iisalmi there is so called main channel, draught 2.4 meters.

Maximum sized vessel has a length of 82.5 meters, beam 12.6 m, draught 4.2 m and capacity of 2 400 tonnes. For a draught of 2.4 meters and less: barge and pusher length can be about 100 meters with payload about 1 500 – 1 800 tonnes.

Loading sites in North Savo area:

- Kemira (Yara Oy quay)
- Kuuslahti loading place (conveyor)
- Peltosalmi (Iisalmi)
- Kumpusalmi (Kuopio)
- Port of Varkaus.

If quarry has an access to a navigate river, aggregates can be moved by a dry bulk cargo barge or a hopper barge. Transportation by barge is the cheapest technique, considering “port-to-port” transportation. Total costs highly depend on the initial and final leg of transport, accomplished by road. Accordingly, in some cases, barge transportation could be non cost-effective or could not be performed at all. For example, leftover stone material stockpile in Varpaisjärvi is located nearby the shore of Lake Syväri, but transportation by water could not be performed because the draught is only 1.5 meters and freight traffic via Lake Syväri is not possible.

Freight rate in case of transporting crushed stone by water is totally dependable on total volume of shipping, the distance between ports of origin and discharging ports, loading/ discharging time and costs and both way haulage. Maximizing of import-export balance is a crucial issue in water transportation. Total volume of import and export cargoes in North Savo region of Finland is presented below in Table 3.

Table 3. Cargo carried by vessels by ports and commodity group, 2012 (http://portal.liikennevirasto.fi)

Import

Port	Timber, wood-chips	Cole, coke	Chem-icals	Crude min-erals, ce-ment	General cargo	Other merchan-dise	Total
	tonnes						
Varkaus	12 761	48 115	-	24 511	7 746	11 795	104 928
Kuopio	-	24 129	-	7 388	-	7 280	38 797
Siilinjärvi	-	-	8 724	2 103	-	-	10 827

Export

Port	Sawn wood	Wood pulp	Ores, con-centrates	Fertilizers	Crude min-erals, ce-ment	Total
	tonnes					
Varkaus	21 098	9 146	-	-	-	30 244
Kuopio	-	-	4 571	-	10 345	14 916
Siilinjärvi	-	-		119 384	17 635	137 019

The capacity of the terminal yard in Siilinjärvi is loading a ship with 2 500 tonnes pay-load per day. Fairways are open 7 - 8 months per year as maximum. Fertilizer ship-ments take place in average 4 times a week. If planning an increase in import, then investment is required.

Figure 7 represents import – export ratio in ports of Varkaus, Kuopio and Siilinjärvi in 2012. In ports of Varkaus and Kuopio import predominates. In case of Siilinjärvi port, export traffic highly exceeds import.

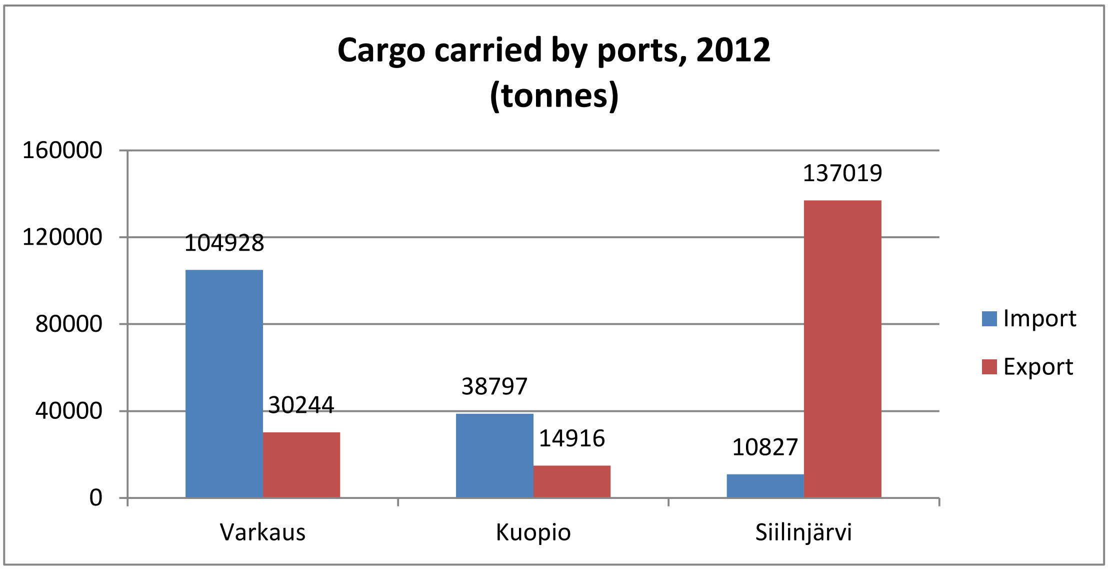


FIGURE 9. Cargo carried by ports, 2012 (www.liikennevirasto.fi)

Total freight costs will be affected by price of pre-haulage and post-haulage of the cargo, costs of loading/discharging of the vessel. Presently at Saimaa Canal there is very limited infrastructure outside of the present ports, which can be too far from mines and quarries of North Savo area, except Siilinjärvi mine, run by Yara Suomi Oy.

Loading and discharging costs depend on size of stone pieces, distance of quay storages, and type of barge, type of loading / discharging technique (crane or conveyor or screw). Accordingly, the loading/ unloading costs range is between € 1.50 - € 2.80 per tonne in both ends.

In North Savo area, barge transportation is possible via Iisalmi Canal, between Siilinjärvi and Iisalmi quays. The maximum payload of the vessel is about 1 800 tonnes, due to 2.40 meters draft in fairways. Related port costs are bending as there are no public ports at Siilinjärvi. Iisalmi port is owned by Finnish Transport Agency and the charge is a few hundred Euros per call. Freight estimation in this case is € 4.50 per tonne or 0.04 € per tonne-kilometre. Loading /discharging and taxes are not included. The cost estimation is based on interviews with the experts from the shipping companies in North Savo region, Finland.

4 PRELIMINARY FREIGHT COSTS OF SELECTED LEFTOVER STONE TRANSPORTATION SCENARIOS

4.1 Case study I: Siilinjärvi – Iisalmi logistic scenario

Every transport mode has different capacity or payload that can be transported per one shipment. Therefore, preliminary freight cost estimations are based on a yearly consumption of crushed stones by a company engaged in concrete production in North Savo region, Finland. Betonimestarit Oy is a partner of the GTK project and producer of concrete frames and elements. Betonimestarit Oy is based in Iisalmi, Finland. Crushed stone material amounts from 30% to 50% of aggregates needed for sustainable production process. In numbers the annual volume of required crushed stone material (12-16 mm) is up to 27 000 tonnes.

According to the first logistic scenario, crushed stone material can be transported by road from point of origin (Siilinjärvi mine) to the production site (Iisalmi). Shipment size is up to 40 tonnes, which is a payload of one road truck. Transportation by road is defined as "door-to-door" delivery. Estimated costs per one shipment, including loading charges amount to 380 € - 430 € (distance from Siilinjärvi to Iisalmi is about 62 km). Total cost rate is about 256 500 € – 290 250 € per year contract (taxes are not included).

The second alternative represents intermodal transportation, with a main haulage performed by rail mode. Shipment size is up to 1 000 tonnes, which is a payload of a block train. Cost estimate for transporting 1 000 tonnes of crushed stone in a block train is 13 500 € - 15 500 €, including loading/ unloading of the wagons (distance between Siilinjärvi and Iisalmi stations is 60 km). Total costs of intermodal transport will include transhipment costs in the beginning and the end of intermodal transport. In this case, annual costs that take place, when transhipping 27 000 tonnes of crushed stone by road and rail transport modes, amount to 405 000 € - 459 000 € (taxes are not included). Due to lack of the wagon fleet there is a limit in actual quotation for this logistic scenario.

Within the third option carriage of crushed stones involves water transport mode, where pre-haulage and post-haulage are made by road truck. Barge transportation has its strengths in the high payload, which amounts up to 1 800 tonnes per vessel, shipping via Iisalmi Canal. Fairways are open around 7 – 8 months per year. Cost estimation for a main haulage of crushed stone via Iisalmi Canal, including loading and discharging of the vessel equals to 13 500 € per shipment or 1800 tonnes payload (total length of Iisalmi Canal is 103 km). Annual contract cost estimation is about 250 000 €, including transhipment costs (taxes are not included).

Table 4. Comparison of three different logistic scenarios (taxes are not included)

Indicator	Road	Rail	Water
Average loading / discharging rate (€ per tonne)	0.75	1.75	1.5
Freight estimation (€ per tonne)	9.00 – 10. 00	10.00 – 12.00	4.50
Transhipment costs	-	1.50	1.75
Average transportation costs (€ per tonne)	10.25	16.00	9.25
Average contract costs (€ per year)	276 750	432 000	249 750

Estimating costs of transporting crushed stone material is based on interviews of freight forwarding experts. The main supply characteristics of competing transport modes are presented in the table below (applicable for a Study case I: Siilinjärvi – Iisalmi). Other than cost factors should be taken into account while making a decision about preferable transport mode (Table 5).

Table 5. Transport modes characteristics – comparison by mode

Characteristics	Road	Rail	Water
Shipment size (tonnes)	40	1 000	1 800
Average speed (km/h)	60	30	12
Safety	low	medium	high
Energy consumption/ emissions	high / high	medium / depending on type of vessel	lowest / lowest
Operational costs	high	high	lowest costs among all modes

Third logistic scenario, with the main haulage, carried by water transport mode, is the most cost effective and environmentally friendlier than other modes. Transhipment, which usually takes place in intermodal transportation, does imply high increase in total costs.

4.2 Case study II: Varpaisjärvi – Iisalmi logistic scenario

The second logistic scenario of transporting crushed stone material has another point of origin (Varpaisjärvi quarry) and the same end destination (the production site in Iisalmi).

Transportation by road in this case is less expensive due to decreased distance (about 40 kilometres by road №582 and E63). Estimated costs per one shipment, including loading charges amount to 270 € - 290 €. Total cost rate is about 182 250 € – 195 750 € per year contract (taxes are not included).

Intermodal transportation in the second logistic scenario is more expensive due to higher transhipment costs. Intermodal transportation with a main haulage performed by rail mode requires pre-haulage of the leftover stone material for more than 30 km by road. Shipment size and cost estimation for transporting of crushed stone in a block train is equal to the Case study I. Accordingly, annual costs that take place, when transhipping 27 000 tonnes of crushed stone by road and rail transport modes, amount to 527 000 € - 607 000 € (taxes are not included). Due to lack of the wagon fleet there is a limit in actual quotation for this logistic scenario.

Water transportation in the second logistic scenario is also constrained by the high road freight. The closest loading place to Varpaisjärvi quarry is the loading site in Siilinjärvi, which also requires over 30 kilometres pre-haulage by road truck. Annual contract cost estimation is about 365 000 € - 392 000, including transhipment costs (taxes are not included).

Table 4. Comparison of three different logistic scenarios (taxes are not included)

Indicator	Road	Rail	Water
Average loading / discharging rate (€ per tonne)	0.75	1.75	1.5
Freight estimation (€ per tonne)	6.25	10.00 – 12.00	4.50
Transhipment costs	-	6.50	6.50
Average transportation costs (€ per tonne)	7.00	21.00	14.00
Average contract costs (€ per year)	189 000	567 000	378 000

Estimated costs of transporting crushed stone material are based on interviews with freight forwarding experts.

4.3 Case study III: Transportation to the ports of Saint - Petersburg

The pilot area for the project is North Savo region; therefore, due to uneven distribution of minerals in the world, transportation over much longer distances should be taken into account. Saint –Petersburg area could be a potential market for crushed stone material with a sustainable demand. Export of crushed stone from Kuopio port to port of Saint-Petersburg was observed and discussed as a Case study II.

Lake Saimaa Deep Canal extends all the way from Kuopio to Vyborg, Russia. The draught of 4.2 metres allows usage of dry bulk cargo barge with 2 500 tonnes maximum payload. The main obstacle is both-way transportation, which should be handled for economically efficient business. As an example, logs and balance (pulp wood) could be transported from Russia to Finland. A bareboat charter will be an arrangement, which makes both-way transportation possible.

Long term contract will give an opportunity for investing in infrastructure, which leads to optimisation of operational costs. Currently, conveyor system is the most cost effective logistic solution in bulk transportation. The cost rate for loading/ discharging of the vessel using front loader & conveyor system is about 1.5 € per tonne. Hydraulic crane has a level of € 2 per tonne (front loader & crane). In the port of Kuopio one vessel can be charged in 6 hours, but in St.Petersburg discharging of one vessel can take 1 day. Accordingly, the loading/ discharging rates differ from 2 € per tonne to 3 € per tonne. Estimated freight costs for transportation of crushed stone to port of St.Petersburg by barge are about € 11.20 per tonne. Loading and discharging is not included. Estimation of total costs when “port-to-port” delivery of crushed stone takes place is calculated in the Table 6 below.

Table 6. Cost estimation for Kuopio – Saint-Petersburg logistic scenario (taxes are not included)

Indicator	Road
Freight estimation (€ per tonne)	11.20
Loading / discharging rate (€ per tonne)	2.00 / 3.00
Customs clearances rate (€ per tonne)	0.50
Total costs (€ per tonne)	16.70

The cost estimation is based on interviews with the experts from the shipping companies in North Savo region, Finland.

Shipping of crushed stone demands that both point of origin and destination point are situated near waterways. Any further pre-haulage and post-haulage of bulk by road usually turns out to be both expensive and inefficient. For example transportation of crushed stone from Varpaisjärvi quarry takes about 70 kilometers and will result in increase of total transportation costs by 10.50 € per tonne.

Presently, there are three large road construction projects in St. Petersburg and NW area. Some are under construction and some in planning phase (Table 7).

Table 7. Road construction in St.Petersburg and NW (http://www.spb-projects.ru)

Project	**Time limit**	**Volume of investment**	**Company client**
M-10 "Russia" (St.Petersburg - Moscow) 664 km in total, 308 km out of them is in NW area	2011-2018	> 1 billion Euro	Rosavtodor
Highway "Sortavala" (St.Petersburg – Priozersk – Sortavala – Highway R21 "Kola") more than 73 km	2013-2020	> 400 million Euro	Rosavtodor
Toll road "Onego" with border crossing point and logistic infrastructure (Petrozavodsk – border with Finland) 349 km in total	6-10 years	> 4 billion Euro	Construction is in the project

Because of high importance of reducing usage of untapped raw materials, the question about recycling and utilization of leftover stone from mines and quarries will become more and more of current interest. This thesis gives an overview of the cost structure and main barriers in transportation of leftover stone material from mines and quarries, and from North Savo area in particular.

Recycling of leftover stone is rather limited nowadays mainly because of high rate of transportation costs. Freight rates are evaluated as challenging by the companies for today. Even though, in the future, the price of crushed rock aggregates may increase due to limited extraction of primary aggregates and higher demand for secondary aggregates. Then the selection of optimal logistic strategy will mainly depend on infrastructural capacity. At present, transporting leftover stone material in North Savo region by road is expensive over long distances, more than tens of kilometers. The most effective logistic strategy is “port-to-port” transportation.

5 CONCLUSION

Aggregates are of the highest importance in the development of infrastructure, as they are an essential raw material for road construction and concrete production. Extraction of primary aggregates can substantially alter the landscape and affect groundwater reserves. That is why the volumes of natural gravel extraction should be decreased. Consequently, there is an urgent need to increase the level of aggregates recycling and the use of secondary aggregates (Miliutenko, S. Aggregate provision and sustainability issues in selected European cities around the Baltic sea.2009, 11).

Transportation of stone material is economically and environmentally expensive process. Crushed stone is always transported unpackaged in large quantities. As a dry bulk cargo it is usually dropped with a shovel bucket, into a barge, railroad car or truck. Transportation of leftover stones will be unique and different in each case, any combination of trucking, rail or shipping can be employed.

When comparing to rail and road transport, transportation by barge has the lowest line haul cost, which is 0.04 € per tonne-kilometer. Water transportation results in the lowest external (pollution) costs among other reviewed transport modes. Road transportation is economically efficient within several tens of kilometers. Delivery of crushed stone material by rail transport mode is limited due to current infrastructure capability.

While one truck’s normal payload is 40 tonnes, one barge may carry more than 60 trucks and both transport modes require one driver. Even though there are certain limitations to be considered in barge transportation. Water transportation is the slowest transport mode, compared to rail or road transportation. Operational time for shipping is limited and scheduled for 7 – 8 months per year.

Current market price for crushed stone in North Savo region, Finland is 10 Euro per tonne in average (including delivery). In this situation, the most sensible distance for delivering crushed stone by road from mines and quarries in North Savo region is not more than 30-40 kilometers. Delivery by barge should be taken into account if mine or quarry has an access to a navigate river.

Pricing for crushed granite stone in St. Petersburg is about 20 - 25 Euro per tonne (actual for 01.12.2013, 5-20 mm fraction, 20-40 mm fraction) without delivery. In this case all transport modes can be employed, depending on the particular project.

According to the Federal State Statistics Service of Russian Federation the sharp rise in price for construction aggregates is explained by the lack of building material in some regions.

The results of the logistic analysis can be in future adapted in Map Application, which is supposed to be an up-to-date database of all leftover stone material stockpiles in a map layout providing the information about volume, quality and estimated transportation costs.

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APPENDIX 1

Data for logistic analysis

GTK: Assessment of quality and applications of leftover stone considering quality requirements	**Legislation:** Mining Law, Land Extraction Act and Environmental Protection Act, Permits, etc.	**Producers:** Location, volumes of leftover stone material piled on the site, quality of raw stone material, infrastructural capability	**Potential market/ End users:** Location, volumes of leftover stone material needed for production, required quality of raw stone material, infrastructural capability	**Freight forwarders:** Freight estimated costs, time, distance by mode, frequency of shipments, capacity on the loading sites
↓	↓	↓	↓	↓
Data for logistic analysis				
↑	↑	↑	↑	↑
Study materials: Literature reviews, actual researches, guidelines, Project Plan and documentation	**GTK archives (current situation in mining):** Mining and quarrying in Finland and North Savo region (maps, reports)	**Vessels (manufacturers):** Capacity, operation process specifications	**Subcontractors:** Additional costs (rent of wagons, etc)	**Statistics:** Usage of aggregates within Finland and North Savo region