KTH Architecture and the Built Environment

Aggregate provision and sustainability issues in selected European cities around the Baltic Sea

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Abstract

The aim of this master thesis was to analyze the general trends of aggregate provision from environmental point of view in selected regions around the Baltic Sea (on the example of Stockholm, Helsinki and Hamburg). The study also aimed to learn from the experiences of other regions and to find out ideas that could be used for the achievement of sustainable aggregate provision in the region of Stockholm.

The study is focused on the flow of primary, secondary, recycled and reused aggregates. The main attention was concentrated on such strategic issues as decreased use of primary aggregates, sustainable transportation, and recycling/reuse. Methodology used is literature review and interviews. Data were grouped using DPSIR (drivers-pressures-state-impact-response) framework. Such pressures on the environment as greenhouse gas emissions and particles emissions during the main stages of aggregate provision were analyzed using LCA approach.

Study results show that Hamburg has good examples regarding aggregates recycling and management of construction and demolition waste (CDW). Helsinki has well established statistics on material flow and environmental state in the region. And Stockholm has good examples regarding the use of primary aggregates. It was also observed that geological conditions and policy instruments are the main factors influencing on the current system of aggregate provision in the studied regions.

It was concluded that aggregates transportation has the largest impact on environment in terms of greenhouse gas emissions and particles emissions if to compare with other analyzed stages of aggregate flow. Thus there is a strong need for aggregates prioritization in land use planning, transport regulations, knowledge on CDW, new standardization and better statistics on aggregate flow.

Key words: *aggregates, sustainability, construction and demolition waste, recycling, indicators, transportation, DPSIR, LCA.*

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ACRONYMS AND GLOSSARY

Acronyms

ALSF	Aggregates Levy Sustainability Fund
BGS	British Geological Survey
BSU	Geological Survey of Hamburg
CDW	Construction and Demolition Waste
DPSIR	¨Drivers-Pressures-State-Response¨ framework
EC	European Commission
EEA	European Environment Agency
EU	European Union
FINNRA	Finnish Road Administration
GDP	Gross domestic product
GTK	Geological Survey of Finland
HMFS	Hållbar materialförsärjning i Stockholm län (in English- *sustainable aggregate provision in the County of Stockholm*)
INFRA	Aggregates department (Finland)
LCA	Life Cycle Assessment
R&D	Research and Development
RTK	Regionplanekontoret (in English- *Regional Planning Office*)
RUFS	Regional Utvecklingsplan För Stockholmsregionen (in English- *Regional Development plan for the region of Stockholm*)
SBMI	Sveriges Bergmateriaindutri (in English- *Swedish Aggregates Producers Association*
SCB	Statistiska centralbyrån (in English- *Statistics Sweden*)
SGU	Sveriges geologiska undersökning (in English- *Geological Survey of Sweden*)
UEPG	European Aggregates Association
UN	United Nations
USDA	United States department of Agriculture
WRAP	¨Material change for a better environment¨ (British organization that works with local authorities in order to promote recycling)
YTV	Helsinki Metropolitan Area Council

Glossary

Byggherrar	construction clients, property developers
Länsstyrelsen	the County Administrative Board
Ballast	aggregate
Hållbart	sustainable
Miljö	environment
Avfall	waste
Försörjning	provision

DEFINITIONS

The expressions used in this report are defined in *Table 1.*

Table 1 Definitions of resources and commodities (BGS, 2009; Meulen et al, 2003; WRAP, 2009; EC, 2007)

Terms	**Description**
Aggregates	This term is defined by BGS (British Geological Survey) as granular or particulate material which is suitable for use, on its own or with a binder such as cement, lime or bitumen (in construction). Aggregates are used in concrete, mortar, roadstone or asphalt (drainage courses), or for constructional fill or railway ballast. Aggregates are the largest components of construction minerals.
Average living area per capita	This is a key indicator of housing quality and measures the adequacy of living space in dwellings (LaoAtlas, 2009).
Concrete	A common construction material consisting of coarse and fine aggregates mixed with cement and water.
Construction minerals	This term is defined by the BGS (2009) as all minerals used by the construction industry (for example in road making, in concrete, in house construction and as railway ballast). Construction minerals include: 1) aggregates; 2) cement raw materials (clay, limestone and chalk); 3) clay, shale and fireclay; 4) natural gypsum; 5) slate; 6) building (dimension) stone.
Construction and demolition waste (CDW)	Waste arisings resulting from the construction, dismantling or demolition of buildings or structures and (Scotland, 2009)
Data	Is the most basic component of indicator work, that show only the current situation but cannot be used to effectively interpret change in the state of the environment (SEI, 2004)
DPSIR	Is a general framework for organizing information about state of the environment (CEROI, 2009).
Environmental tax	A tax whose tax base is a physical unit (or a proxy of it) of something that has a proven, specific negative impact on the environment (OECD, 2001)
Fill material	Any aggregate or clay used for filling purposes.
GDP (gross domestic product)	is a basic measure of a country's economic performance (Sullivan, 1999)
Indicators	Are ssymbolic representations (e.g. numbers, symbols, graphics, colours) designed to communicate a property or trend in a complex system or entity (Stanners, 2007).
LCA (Life Cycle Assessment)	Is a common tool for evaluating the environmental burdens from the total life cycle of a product, ¨from cradle to grave¨, i.e. from the extraction of basic resources, through production and transportation, to use and disposal of the product (ISO, 1997).
Level	A section of a hierarchy or unit of analysis that is defined by its position on a scale (USDA, 2004).

Primary aggregates (primary material)	Is the term used for aggregate produced from naturally occurring mineral deposits and used for the first time. The two principal types of primary aggregates are crushed rock (limestone, igneous rock and sandstone) and sand and gravel (BGS, 2009)
Recycled aggregates (recycled material)	Materials which are produced from reprocessing aggregates previously used in construction. Recycled aggregates consist of construction, demolition and excavation waste, road planings and rail ballast (BGS, 2009).
Reuse	Is defined as the substitution of pre-used aggregates for *primary aggregates* without processing (Scotland, 2009)
Scale	A specific geographically bounded area that has a relative size (USDA, 2004)
Secondary aggregates (secondary material)	Material which originates as a waste product from other quarrying activities (such as china clay or slate extraction), or is a by-product of certain industrial processes (such as blast furnace slag or power station ash) (BGS, 2009).
Ton-km	Unit of measure of goods transport which represents the transport of one tonne over one kilometre. The distance to be taken into consideration is the distance actually run (Eurostat, 1997)
Waste	Any substance or object the holder discards, intends to discard or is required to discard (Waste Framework Directive/ (European Directive (WFD) 2006/12/EC)

1. INTRODUCTION

1.1. General problem field

Aggregates play an important role in the development of infrastructure, as they are an essential resource for road building and concrete production. However aggregate provision is one of the largest sources of the negative environmental impact caused by the transportation sector.

It is estimated that aggregates account for approximately 40- 50 % of all goods transported by trucks in Sweden (Hultkvist, 2001). According to Fry (2007) aggregate transportation generates about 20% - 40% of the total carbon dioxide emissions produced by the aggregate industry as a whole. Moreover aggregates have destructive environmental impacts on the local environment. Such impacts are visual intrusions, noise, air, water and soil pollution and loss of biodiversity (Solar et al., 2007).

1.2. Specific problem area

The County Board of Stockholm (in Swedish- Länsstyrelsen i Stockholms län) has identified the regional environmental target that aims at improvement of aggregate provision (in Swedish- hållbart ballastförsörjning) in the region of Stockholm. This target is included in one of the 16 Swedish National Environmental Objectives- ¨Good Built Environment¨.

Specific problems addressed by the County Administrative Board of Stockholm during the target motivation are as following:

- 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;
- There is a lack of strategically located terminals and storage places for aggregate provision. This in turn increases transport distances. Moreover the levels of aggregate transportation by water are decreasing due to the conflicts of land use during the location of sea terminals (The County Administrative Board of Stockholm, 2009).

Strategies regarding sustainable aggregate provision were also identified by the Regional Planning Office (RTK) in Stockholm and the critical issues were subdivided into three groups: 1) decreased use of natural gravel; 2) sustainable transportation and 3) increased recycling (Norström et al, 2008)

1.3. Research problem

1.3.1. Aim

The aim of this master thesis was to analyze the general trends of aggregate provision from environmental point of view in selected regions around the Baltic Sea (on the example of Stockholm, Helsinki and Hamburg). The study also aimed to learn from the experiences of other regions and to find out ideas that could be used for the achievement of sustainable aggregate provision in the region of Stockholm.

1.3.2. Objectives

The main objectives of the master thesis were as following:

- to draw the picture of the system of aggregate provision;
- to identify which stakeholders are responsible for aggregate provision on the regional level;
- to find out which available data and indicators can be used for the comparison of the systems of aggregate provision in the studied regions;
- to compare the main trends of aggregate provision in the studied regions (taking into account drivers, pressures, state, impacts and responses);
- to find out the most critical stages of aggregate flow which have negative impact on the environment (using LCA);
- to present recommendations for the achievement of sustainable aggregate provision on the regional level.

1.3.3. Research Questions

In order to achieve objectives of the thesis, the following research questions were raised:

- What is the definition of aggregates and aggregate flow?
- What is the present situation of aggregate industry in the world, Europe and countries of the case-studies?
- Which stakeholders are responsible for aggregate provision in the studied regions?
- Which available data and indicators of sustainable aggregate provision can be used for the comparison between the studied regions?
- Which are the similarities and differences concerning aggregate provision in the studied regions?
- Which stages of aggregate flow in the studied regions have the main negative impact on environment?
- Which measures are already done and could be done in the future in order to achieve sustainable aggregate provision?

1.3.4. Scope of the research

Materials studied in the given project include three types of aggregates. They are:
1) primary aggregates: rock, sand and gravel;
2) manufactured secondary aggregates: fly ash (is used as an example when calculating the consumption patterns in the studied regions);
3) reused and recycled aggregates: recycled concrete, asphalt, recycled soil, brick.

Metropolitan area of Helsinki, Stockholm County and Federal State of Hamburg were chosen as territorial units for comparison of aggregate provision between the cities.

The study is focused on the whole life-cycle of aggregate flow (starting from the extraction of the primary raw materials and finishing with the waste disposal, see *Figure 5*).

1.3.5. Delimitations

Those stages of aggregate provision that have no significance for the comparison between the studied cities or where the data were inaccessible were ruled out of the analysis. They are as following:

- Land recovery after extraction activities was excluded from the study due to its insignificance with regards to the aim of the study.
- The storage of aggregates was not included in the study due to the lack of available data regarding this issue.
- The stage of aggregates use in construction was excluded due to its insignificance with regards to the objectives of the study. This stage is mostly investigated when considering and comparing the properties of selected aggregates during their life cycle (e.g. in Olsson, 2005; Mroueh, 2000 etc.). Thus when considering the whole system of aggregate provision on the regional level it was assumed that considering this stage would be too complex and at the same time not important for the achievement of the aim of the study.
- Secondary aggregates were excluded during the Life Cycle Assessment (due to the lack of statistical data regarding this type of aggregates in the chosen regions).

As far as the negative impacts of aggregate provision are concerned, only pressures on the environment (such as emissions to air) were considered.
Negative impacts on other sustainability aspects were excluded from the study. They are as following:

- Environmental: land degradation, noise, water pollution, energy use, leaching into soil, atmospheric emissions (such as heavy metals, CH4, NOx, SO_2, VOC, CO)
- Socio-cultural aspects (health and safety, cultural heritage etc.)
- Economic aspects (expenses for road maintenance, traffic congestions etc.).

1.3.6. Limitations

The limitations encountered during the master thesis performance are as following:

- Language problems- risk of misunderstanding
- Different terminology and classifications used in the studied countries- risk for misunderstanding
- Existing statistical data for different years in the studied cases

- The statistical quality of data varies per country
- Inaccuracy when converting the currency
- Limited availability of data

Some of the main limitations and delimitations of the study are further discussed in the chapter of ¨Discussion¨ (see p 57 - 58).

2. METHODOLOGY

In order to find the answers for my research questions, the study was performed in the following sequence of work (as shown on *Figure 1*): literature review, interviews, comparison and analysis, discussion and conclusions. Such external activities as Symposium on ¨Rock and Gravel¨ in Oskarshamn and Workshop on ¨Sustainable aggregate provision¨ in Stockholm were also an important part of the study.

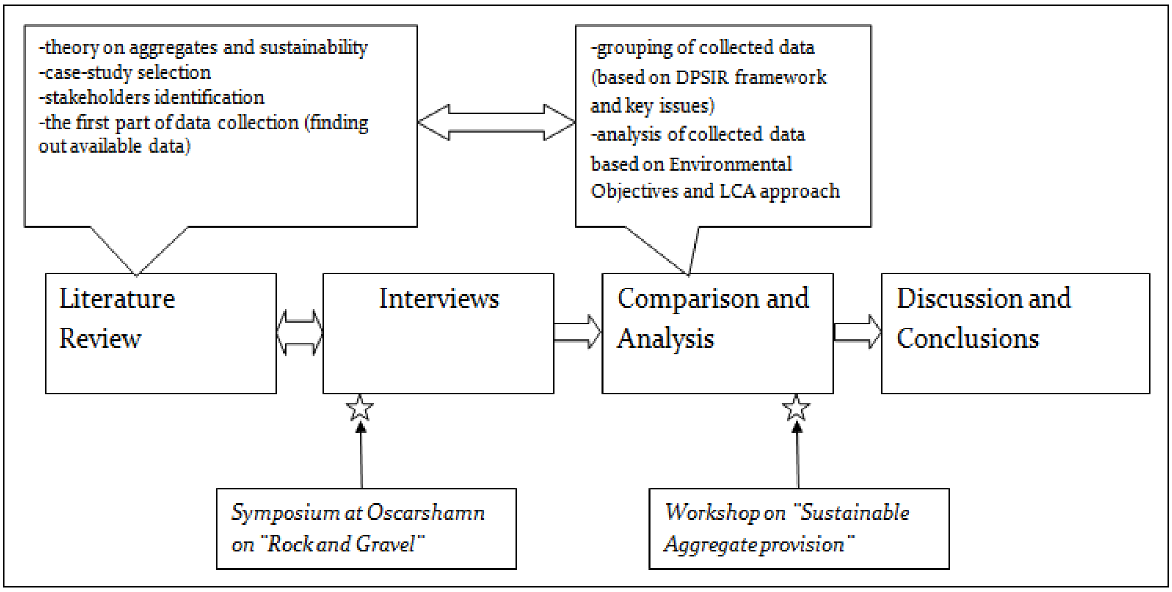


Figure 1 Stages of work

2.1. Literature review

Literature review was done during the first 6 weeks and was further performed throughout the whole process of the study. A literature search involved reviewing all readily available materials (unpublished or published studies), such as: internal company information, magazines, annual reports, company literature, on-line data bases, and any other published materials.

Literature review included study on the theory regarding aggregates and sustainability, case-study selection, stakeholders participating in aggregate provision and collection of the initial data in the studied regions. The procedures of case-study selection and data collection are described below.

Case-study selection

The main criteria for case-study selection were:

- metropolitan areas around the Baltic Sea (in order to secure possible further cooperation with Stockholm);
- the metropolitan area included in the list of cities proposed by RTK (the Office for Regional Planning and Traffic) for international comparisons in terms of sustainability work. Such choice criteria is explained by the fact that all those cities have dynamic and successful sustainability characteristics and similar structure to the one in Stockholm (RTK, 2008);
- the region is developing strategies regarding the solutions of problems connected with aggregate provision.

Having done an extensive literature review and evaluated all the choice criteria, the following metropolitan areas were selected as the case-studies: Helsinki (Finland), Hamburg (Germany) and Stockholm (Sweden) as the base for discussion.

Helsinki was selected due to the fact that it has several new initiatives in the promotion of sustainability in aggregate supply (for example, promoting sustainability in aggregate supply by developing a web-based accounting system) (Räisänen, 2005).

Hamburg was selected because Germany has the highest level of aggregates production in EU (UEPG, 2009). And, secondly, the German states have formulated a goal of minimizing transportation of building materials (Meulen et al, 2003). So it was interesting to see how Hamburg is fulfilling this goal.

Selection of key stakeholders for each city was based on the knowledge (gained during the literature review) about the main actors of aggregate provision in Stockholm.

Data collection

The data was collected by literature review and interviews with the key stakeholders.

The first part of data collection was done by literature review. The process consisted of the following steps:

1) proposal of available data that could be used for comparison based on the previous knowledge gained about the current system of aggregate provision in Stockholm;
2) grouping of available data according to strategic issues for each stage of aggregate flow;
3) collection of accessible quantitative and qualitative data about the current state in the studied regions (using such database as Urban Audit as well as official web-pages of the cities);
4) identification of data gaps.

2.2. Interviews

Interviews were performed during the period of 7-8 weeks. The key stakeholders in three cities (Stockholm, Helsinki and Hamburg) were interviewed on this stage.

The interviewing methodology combined the e-mail and telephone survey. The interviewing process constituted of the following stages:

- Preparation of the brief project description and the written questionnaire for the potential interviewees;
- Sending of the prepared document by e-mail to the key stakeholders;
- Organization of the telephone meeting with the interested stakeholders;
- Telephone meeting (following the questions and information provided to the interviewees before).

During interviewing the quantitative and qualitative data was collected, as well as data gaps were identified.

In order to validate collected data the method of research triangulation was used, where several stakeholders were asked about the same set of data (and when needed the additional literature review was done). The questionnaire and the data quality are shown in Appendix 4, Appendix 5 and Appendix 7.

2.3. Comparison and analysis of the results (DPSIR framework and LCA)

The obtained data were grouped and presented according to DPSIR (Driver-Pressure-State-Impact-Response) framework. DPSIR is a general framework for organising information about state of the environment (CEROI, 2009). This framework was used in order to see the causal link between the measured issues of aggregate provision.

According to the DPSIR framework there is a chain of causal links starting with ¨driving forces¨ (economic sectors, human activities) through ¨pressures¨ (emissions, waste) to states (physical, chemical and biological) and ¨impacts¨ on ecosystems, human health and functions, eventually leading to political ¨responses¨ (prioritisation, target setting, indicators) (see *Figure 2*)

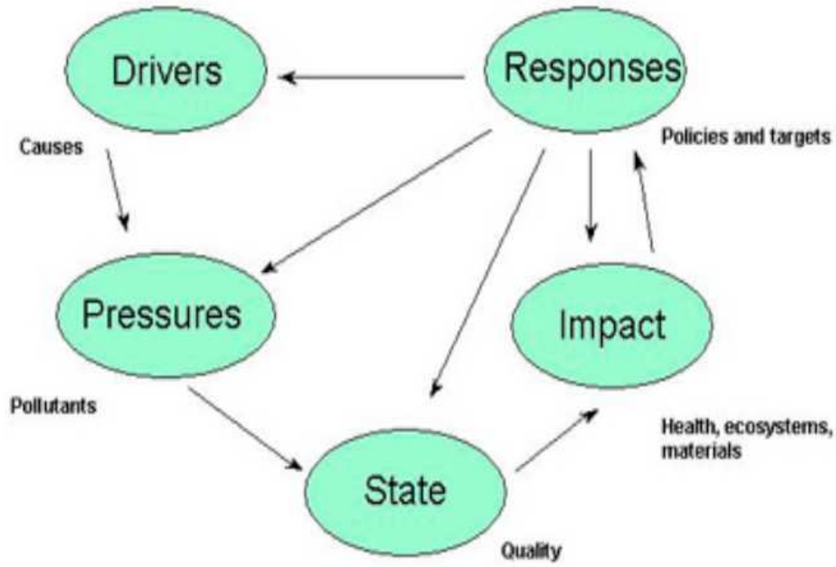


Figure 2 The DPSIR assessment framework (Kristensen, 2004)

The framework is seen as giving a structure within which to present the indicators needed to enable feedback to policy makers on environmental quality and resulting of the political choices made or to be made in future (Kristensen, 2004).

The conceptual DPSIR framework proposed for analyzing general trends of aggregate provision is shown in the *Table 2*.

Table 2 DPSIR conceptual framework for assessing the general trends of aggregate provision

DPSIR	Proposed
Driving forces (economic sectors, natural factors)	Population, Population growth Need for infrastructure, housing Lifestyle (housing area/capita) Economical growth, Prices Geology
Pressures on the environment 1) human activities that are causing pressures;	Energy and natural resources use Production of waste (CDW, from quarrying activities) Production of noise Transportation
2) pressures on the environment (partly assessed by LCA approach)	Emissions to air, water and soil
State (current situation of the environment)	Environmental quality (water, air, soil and biodiversity)
Impact	Depletion of non-renewable resources Human health and safety (accidents) Cultural Heritage Landscape alterations Loss or damage to biodiversity Economy
Responses	Environmental Policies and Targets Macroeconomic policy measures (pricing, taxes) Sector-specific policies (application of new technology, new standards etc.)

<u>Identification of Drivers (D)</u>

In order to identify the drivers, the following question was asked: ***What are the main causes (or driving forces) of the current system of aggregate provision?***

According to Kristensen (2004) driving forces are derived from economic sectors, human activities and natural factors. So it was assumed that the main drivers from economic sectors and human activities are: population growth, population density, lifestyle (expressed in average living area) and economic development. These factors increase the demand for new constructions and consequently, demand for aggregates. This in turn may lead to higher pressures.

Prices of material, taxes for waste disposal and transportation costs may be related to other economic drivers. The consumption patterns as well as waste management trends strongly depend on the prices or taxes. Too low prices for aggregates may lead to higher rate of aggregate consumption. Too low taxes for waste disposal lead to fewer incentives for waste separation and recycling (Kristensen, 2004).

Geology (being a natural factor) is also an important driving force in terms of quantity of primary aggregates extracted from geological deposits. Poor geology in the region may condition the increasing transportation distances and consequently more negative impacts on the environment.

Drivers (D) of the current system of aggregate provision in the studied regions represent the quantitative data collected with the help of interviews and literature review.

Identification of Pressures (P)

Two questions were asked during the identification of pressures: ***What activities in aggregate provision cause pressures on the environment? What are these pressures?***

Consequently, Pressures (P) were subdivided into two groups:

1) human activities that cause pressures (data collected during interviews and literature reviews):

It was concluded that aggregate provision (and human activities connected with it) causes the following pressures on the environment: land use, energy and natural resources use, emissions to air, water and soil, waste production, noise production.

According to Fry (2007) aggregates transportation causes the highest pressure from aggregate industry. That is why aggregate transportation (being the major source for air emissions and noise production) was chosen as another pressure.

2) pressures on the environment that are caused by the mentioned human activities (quantitative data analyzed by LCA approach, where pressure categories were identified using Swedish Environmental objectives).

In order to compare and analyze some of the main pressures on the environment caused by aggregate provision in the studied regions it was decided to use Environmental Goals for Stockholm County as a basis for selection of the impact categories.

As explained in Theoretical framework, the most relevant Environmental Goals for aggregate provision are: Good Built Environment, Reduced Climate Impact and Clean Air (see *Table 3* that provides indicators for each goal).

One of the main criteria for the selection of indicators for the study was their relevance to aggregate provision and data accessibility and comparability. Consequently the indicators chosen for analysis are as following:

1) particles emissions to air (that relates to the *Goal of ¨Clean Air¨)*
2) CO_2 eq emissions (that relates to the Goal of *¨Reduced Climate Impact¨)*

Such indicators as volumes of natural gravel extracted and total volumes of landfilled construction and demolition waste (that relate to the Goal of *¨Good Built Environment¨*, see *Table 3*) are shown in the section of Pressures related to human activities (see p 45).

The chosen impact categories (particles emissions and CO_2 emissions) were analyzed and compared using LCA (Life Cycle Assessment) approach (which is explained further, see also the definition in the *Table 1*).

System boundaries for the Life Cycle Assessment

The analyzed system includes such processes as material production (extraction and processing), transport of material, recycling and waste disposal. The use of aggregates in construction and the processes of demolition were excluded from analysis. Industrial products and waste (in other words, secondary aggregates) were also excluded from the study (due to the lack of data) (see *Figure 3*).

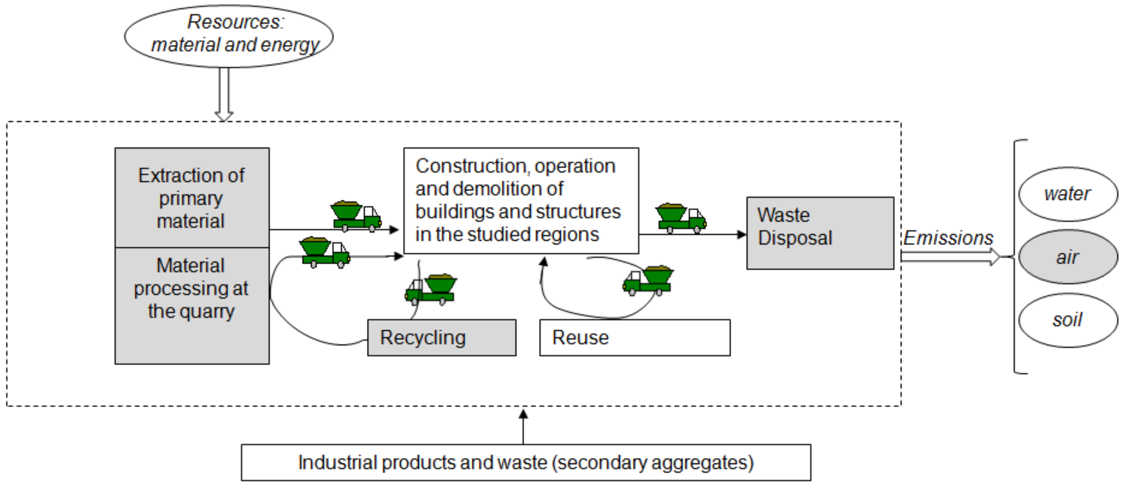


Figure 3 System boundaries (grey boxes and circles show the processes and impact categories included in the study; aggregate transportation is marked with the truck symbols)(developed after Erlandsson, 2009)

The *functional unit*, that was chosen for the study is one tonne of used aggregates (primary and recycled).

The following *material production chains* were considered:

- Primary aggregates (see *Figure 19* that shows the quantities of quarries for natural gravel and crushed rock in Stockholm and Helsinki):
  - Natural sand and gravel- starting point: gravel pit
  - Crushed rock- starting point: rock quarry
- Recycled aggregates- starting point: processing plant, quarry or construction site.

The *time period* of aggregate flow used for analysis is supposed to be not more than 1 year, since the stage of aggregates use is not included in the study.

The *geographical boundaries* are the regions of the studied cities: 1) Stockholm (Stockholm County), 2) Helsinki (Helsinki Metropolitan Area) and 3) Hamburg (Hamburg Federal State).

Other boundaries: the production of machinery used for aggregates extraction, processing and transportation as well as land recovery after quarry activities are not included in the study.

Several *scenarios* were proposed in order to see the change in emissions when the transport distances and transport modes are changed.

Data used for calculations are shown in Appendix 4 and Appendix 5.

Identification of State (S)

The indicators for the State answer the following question: ***What is the current state of the environment in the studied region?***

The State of the environment (S) in the studied regions represents the quantitative data (regarding the emissions to air in the studied regions) collected with the help of literature review.

Identification of Impacts (I)

When identifying the indicators for impacts (I) the following question was asked: ***What are the impacts from aggregate provision?***

The section of impacts (I) is described as the qualitative information received from literature review. Providing the difficulties in measuring both direct and indirect impacts from aggregate provision on the regional levels, no quantitative data were found and compared regarding the impacts in the studied regions.

Identification of Responses

The indicators for responses (R) answer the following question: ***Are there any policies or targets that aim to reduce the impacts?***

Responses (R) were analyzed with the help of qualitative information obtained from interviewing key stakeholders and literature review. The interviewed stakeholders expressed their opinion about which main responses from the government are expected to be done in order to solve the problems regarding aggregate provision and which ones exist already. These responses were subdivided according to three strategic issues defined by RUFS: transportation, use of primary aggregates, recycling and reuse (see p. 11).

2.4. Discussion and Conclusions

Discussion and Conclusions were the final stage of the master thesis, where the best experiences were summarised and recommendations provided

This section was performed in the form of comparison of the studied regions and discussing data quality and methodology chosen.
Recommendations for the improvement of aggregate provision in Stockholm and a proposal for continued research were provided in conclusions.

3. BACKGROUND AND THEORY

3.1 Theory on aggregates

The following chapters describe the definition of aggregates and identify the aggregate flow, what is important to understand when comparing the current systems of aggregate provision.

A short overview about the modern situation of aggregate provision in the world and in the studied regions is also provided.

3.1.1. Definition of aggregates

Aggregates are a granular material used in construction for their granularity. The most common natural aggregates of mineral origin are sand, gravel and crushed rock. They are produced from natural sources extracted from quarries and gravel pits and in some countries from sea-dredged materials (UEPG, 2009).

Aggregates are crucial resources for the infrastructure development activities, such as road building and concrete production. For example, 1 m^2 of built area consists of about 2 tons of aggregates; the construction of one house uses up to 400 tons of aggregates; the construction of 1 km of motorway uses up to 30,000 tons of aggregates and the construction of 1 meter of railway for a High Speed train (TGV) uses up to 9 tons of aggregates (UEPG, 2009). The main end-users of aggregates are shown in *Figure 4*.

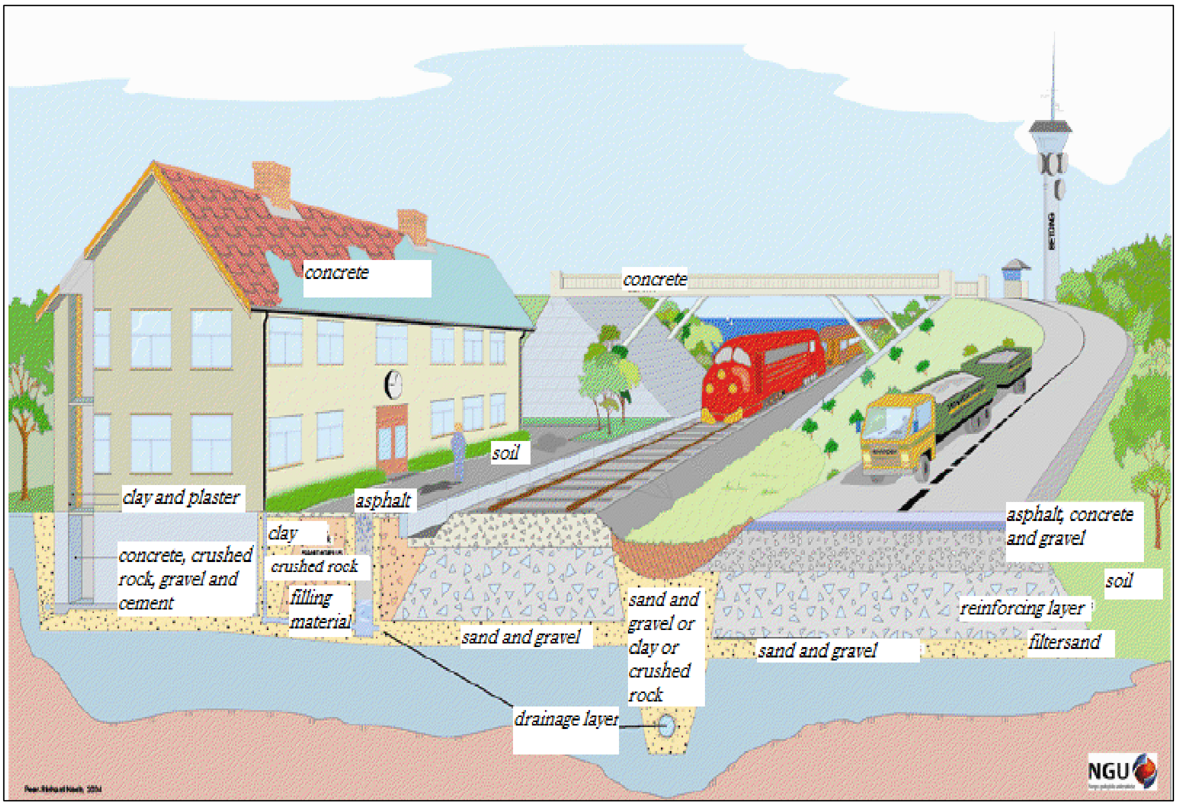


Figure 4 Examples of main consumption areas for aggregates (translated after NGU)

Aggregates are subdivided into three types:

1) Primary aggregates (which are extracted from the geological deposits)
2) Secondary aggregates (which are taken from industries in non-construction sector)

3) Reused and recycled aggregates (which were previously used in construction)

Primary aggregates include the following types of materials:

1) Rock, which may be subdivided into crushed rock and cut and broken rock (see Appendix 1). Crushed rock is mainly used for aggregate production (Meulen et al, 2003).
2) Sand, which is used for concrete and mortar production;
3) Gravel: mostly rounded stony material, which is used for concrete production and as a drainage media (Meulen et al, 2003);
4) Soil materials are mostly used as a filling material. Brick, tile and pipe clay is also considered as soil materials (McNally, 1998)

Secondary aggregates are earthy and stony waste materials and industrial by-products, used as alternatives to primary materials (Meulen et al, 2003). They are usually by-products from other industrial processes not previously used in construction. The examples of such industrial processes are: energy and heating plants, waste burning plants, steel industry, paper and mass industry etc. Secondary aggregates are divided into manufactured and natural depending on their sources. Examples of manufactured secondary aggregates are pulverized fuel ash (PFA) and metallurgical slags. Natural secondary aggregates include china clay sand and slate aggregate (WRAP, 2009). Secondary aggregates are used for such products as ready-mixed concrete (made of 80% aggregates), pre-cast products, asphalt (made of 95% aggregates), lime and cement (UEPG, 2009).

Recycled aggregates are produced from a variety of material: arising from construction and demolition (concrete, bricks, tiles), highway maintenance (asphalt planings), excavation and utility operations. There are two methods of producing recycled aggregates: in situ at the site of the arisings, or ex situ in a central plant (WRAP, 2009).

3.1.2. Aggregate flow

Material flow is a systems approach used to understand what happens to material from the time it is extracted, through its processing and manufacturing, to its ultimate disposition (USGS, 1998).

In the case of primary aggregates material flow starts with the extraction of primary aggregates from their source (geological deposits). The sources of secondary and recycled aggregates are different industrial processes and construction materials (see *Figure 5*).

Primary, secondary and recycled aggregates are further processed and either directly used for construction purposes or they are further used for the production of construction materials (such as concrete and asphalt for instance).

Aggregates are transported and stored several times (in most of the cases) before they are finally used in construction. Material is moved using all of the main transport modes: road, rail and water. Most primary aggregates are transported by road (Fry, 2007).

The end-of-use of aggregates is seen in the form of construction and demolition waste (CDW), that is created after construction activities or demolition of old buildings and structures. CDW can be either deposited at landfill or incinerated for energy production, or reused and recycled (becoming a new source for construction materials).

As seen in *Figure 5* it is clear that aggregate flow is the cyclic process. And from a ¨sustainable¨ point of view a closure of this cycle may be established by aiming at a near 100% recycling of construction and demolition waste (Hendriks et al, 2001).

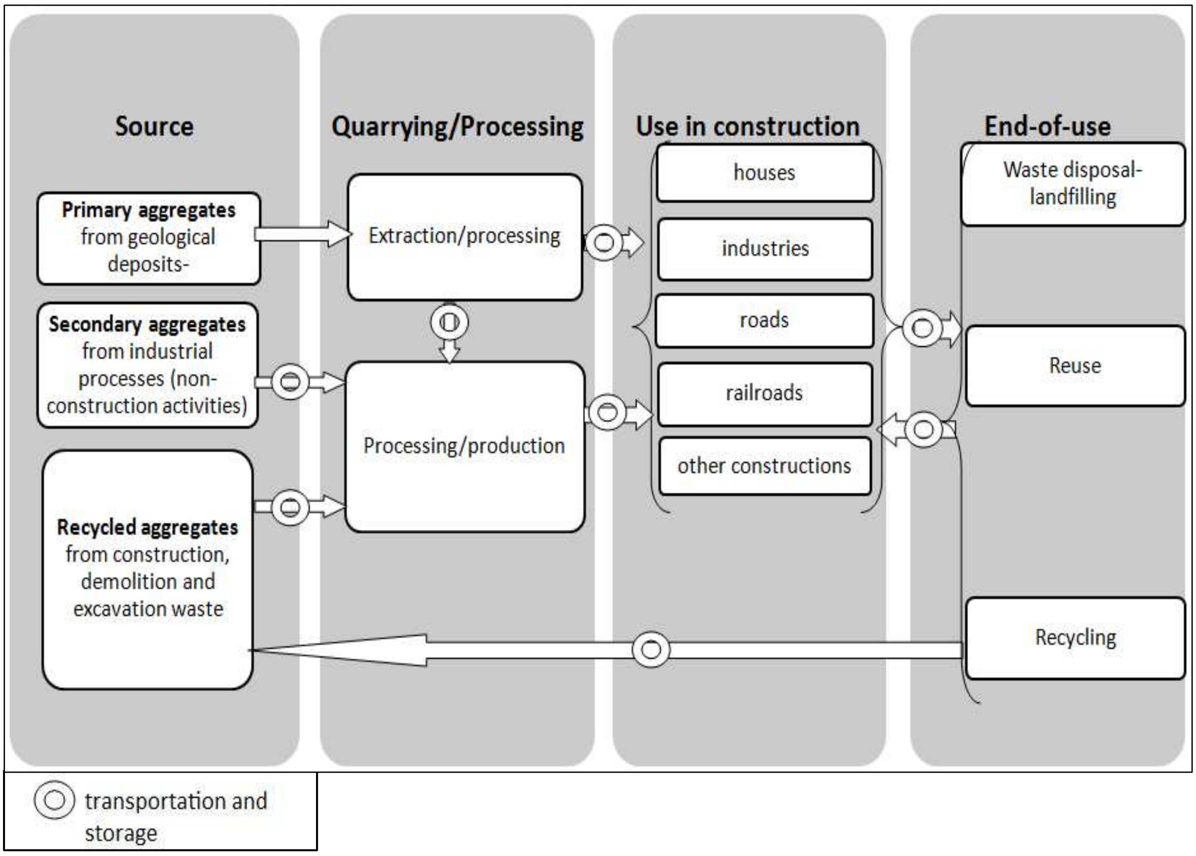


Figure 5 Scheme of aggregate flow, based on USGS (1998), WRAP (2009)

3.1.3. Current situation of aggregate provision

Global trends

Natural aggregate extraction is the most important mining industry in the world in terms of production volume (15,000 million tons per year), and is second only to fossil fuels in terms of production value (70.060 million euro) (Regueiro et al., 2002 in Solar, 2007).

However a global aggregate mining industry faces a range of challenges due to the increasing demands of the rising global population. According to the forecasts the global demand for construction aggregates is expected to rise nearly four percent annually through 2011 to over 26 billion metric tons (26,000 million tons) (Freedonia, 2007). Consequently, such fast rising global demand leads to large economic, social and environmental threats and creates a need for finding new sustainable solutions (Aston, 1999).

Europe

More than 3 billion tons (3.000 million tons) of sand, gravel and crushed stone are produced annually to meet the demands of the European building and construction industries (UEPG, 2009). It consists of more than 30,000 extraction sites across Europe and a majority of operators in the sector are small and medium sized enterprises. The average annual aggregates production represents 7 tons per EU citizen. The European aggregates industry plays a key role by providing essential materials for the European construction sector (UEPG, 2009).

Sweden

The most used primary aggregates in Sweden are: sand and gravel (20%), till (2%), crushed rock (64%) and others (14%), which include crushed rock from the crushers and residual stones from the quarrying. In general, Sweden consumed 99,4 Mton of primary aggregates (10,8 ton/capita) in 2007 (SGU, 2007). About 1.8 Mton of recycled and 0.2 Mton of secondary aggregates were produced in Sweden in 2006 (UEPG, 2009).

The biggest quantity of aggregates was used for road construction (about 49%), 19%- for filling (soil, for instance), 12% concrete production and 20% for other uses (see *Figure 6*) (SGU, 2007).

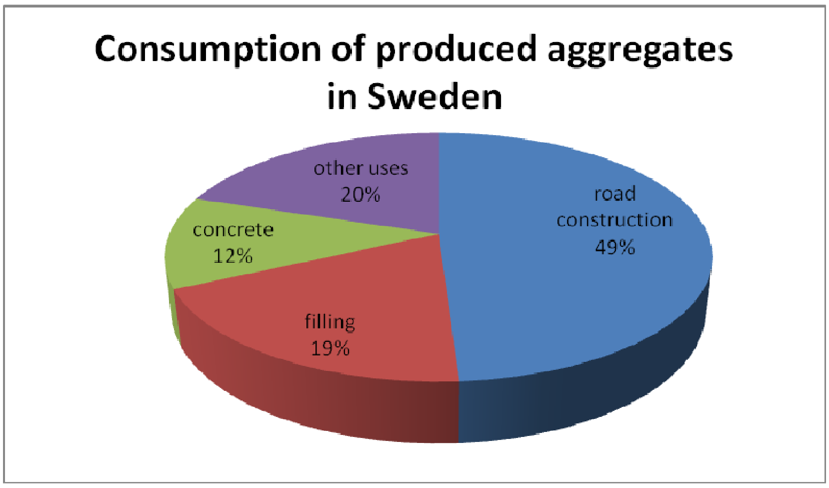


Figure 6 Estimated consumption areas of aggregates in Sweden in 2007 (SGU, 2007)

Finland

In terms of production aggregates are the largest extractive industry in Finland. The total amount of primary aggregates used annually is 95 Mton (17,8 ton/capita) (Johansson et al, 2008). About 54% of the total aggregate production in Finland is sand and gravel and 46%- crushed rock and crushed gravel (UEPG, 2009). About 0,5 Mton of recycled aggregates were produced in Finland in 2006 (UEPG, 2009).

As shown in *Figure 7*, the main consumption areas of aggregates in Finland are road construction (40%), house building (25%), concrete (12%), asphalt (10%) and other uses (13%) (Kärkkäinen, 2002).

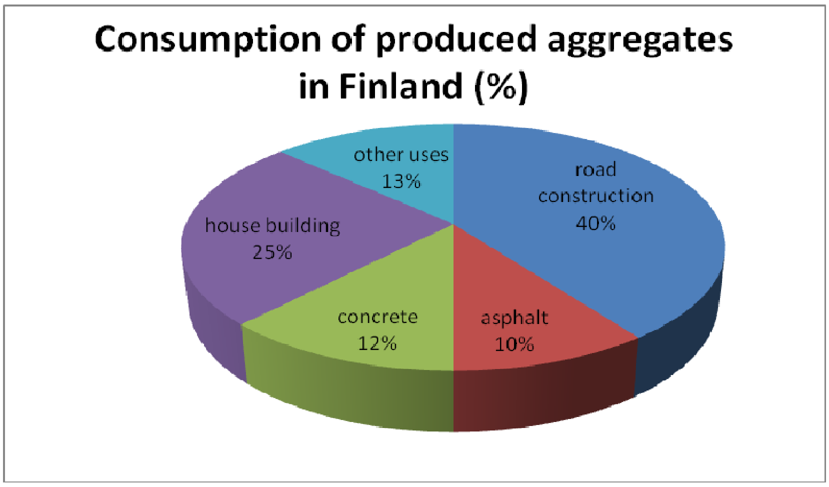


Figure 7 Estimated consumption areas of aggregates in Finland in 2002 (Kärkkäinen, 2002)

Germany

Germany is EU´s largest producer of sand, gravel and crushed rock. The total amount of primary aggregates extracted in Germany in 2006 was 547Mton (50,6%- sand and gravel and 49,4 %- crushed rock, including crushed gravel), that accounts to approximately 6,6 tons/capita. Apart from the primary aggregates Germany produced also about 48Mton of recycled and 30 Mton of secondary aggregates (UEPG, 2009).

Data regarding the estimated consumption areas of aggregates in Germany were not found.

The estimated volumes of aggregates consumed in the studied countries are shown in the *Figure 8*.

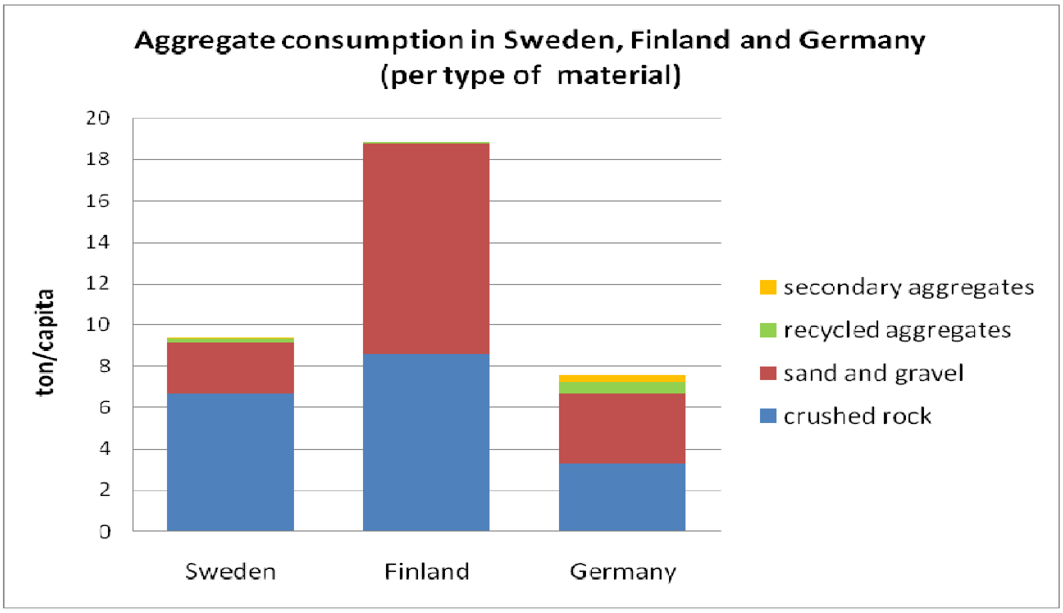


Figure 8 Aggregate consumption in Sweden, Finland and Germany (UEPG, 2005)

3.2. Theory on sustainability and indicators

The chapters below describe the concept of sustainability and the definition of indicators. This theory was helpful in order to develop and organize sustainability indicators used for comparison of the systems of aggregate provision between the studied regions.

3.2.1. Definition of sustainable development

The concept of sustainable development was introduced in 1987 in the Brundtland Report, where it was defined as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987). In other words, sustainable development must not endanger the natural systems that support life on earth: the atmosphere, the waters, the soils, and the living creatures including people (Langer, 2003).

Sustainable development, as elaborated in Agenda 21 (during the Rio Conference in 1992) and confirmed at the World Summit on Sustainable Development (in Johannesburg, 2002), has three main objectives:

- social (dignified human life);
- economic (competitiveness, often also growth);
- environmental (respecting ecological limits)

The fourth objective, institutional (aiming at public participation, empowerment of communities, peace and justice) was also developed by the UN Commission on Sustainable Development. Although very few institutional indicators were developed (Stanners et.al., 2007).

3.2.2. Definition of sustainability indicators

Indicators and Indexes are the most common methods used to measure the progress towards sustainable development.

Indicators are symbolic representations (e.g. numbers, symbols, graphics, colours) designed to communicate a property or trend in a complex system or entity (Stanners, 2007). Indicators can be also defined as parameters, or values, which build on data (SEI, 2003). Data show only the current situation but indicators, on the other hand, can be used to effectively interpret change in the state of the environment (SEI, 2004).

Indicators of sustainability should be used as tools for knowledge, information transfer and as a solid base for decision making. The selected set of indicators should express a need for balance: (a) among stakeholders; (b) between the process of defining indicators and the set of chosen indicators, and (c) among the dimensions of sustainability (Solar, 2007).

However Stanners (2007) claims that most strategies for sustainable development have assembled indicators for each of the pillars while neglecting the links between them. The development of sustainability indicators that show these links is still seen as one of the major challenges within sustainable development projects and programs (Stanners, 2007).

3.2.4. Sustainability indicators on different territorial scales

Sustainable development is studied and monitored at different scales and contexts of environmental, social and economic aspects. The focus ranges from the global scale to the scale of separate countries, regions, sectors of industry etc. Defining scale is a necessary prerequisite for understanding the relationships between indicators and selecting the appropriate measurement methods (USDA, 2004).

Some examples of sustainability indicators on different territorial scales (such as global, national, regional) are described below.

Global scale

The main principles for future sustainable development around the world were identified during the UN Conference on Environment and Development in Rio in 1992.

UN developed a set of Sustainability Indicators on a global scale, and they were organized by themes according to three dimensions of sustainability: social, environmental and economic *(UN, 2007)*

National scale- Sweden

One of the strategies for sustainable development in Sweden was the presentation of 16 Sweden´s Environmental Objectives by the Riksdag (Parliament) in 1999 (Naturvårdsverket, 2009). The objectives define the quality and state of Sweden's environment and of its natural and cultural resources that are sustainable in the long term. The system of environmental objectives consists of national, regional and local environmental objectives, progress being monitored respectively by central agencies, the county administrative boards, and local authorities (Naturvårdsverket, 2009).

They are as following:

- *Reduced Climate Impact*
- *Clean Air*
- *Natural Acidification Only*
- *A Non-Toxic Environment*
- *A Protective Ozone Layer*
- *A Safe Radiation Environment*
- *Zero Eutrophication*
- *Flourishing Lakes and Streams*
- *Good-Quality Groundwater*
- *A Balanced Marine Environment*
- *Thriving Wetlands*
- *Sustainable Forests*
- *A Varied Agricultural Landscape*
- *A Magnificent Mountain Landscape*
- *A Good Built Environment*
- *A Rich Diversity of Plant and Animal Life (Natutvårdsverket, 2009).*

Regional scale- Stockholm County

In order to follow up and monitor the achievement of the Swedish Environmental Objectives on the Regional level the County Administrative Board of Stockholm developed a set of region-specific indicators relating to the national environmental quality objectives. The proposed indicators regarding aggregate provision in Stockholm are shown in the next chapter.

Municipal (local) scale

At the Rio Earth Summit in 1992, the United Nations agreed that the best starting point for the achievement of sustainable development is at the local level. In fact, two thirds of the 2500 action items of Agenda 21 relate to local councils (Encyclopaedia of Sustainable Development, 2009).

Each local authority has to draw up its own Local Agenda 21 (LA21) strategy following discussion with its citizens about what they think is important for the area (Encyclopaedia of Sustainable Development, 2009).

3.3. The concept of sustainability in aggregate provision

The following chapters explain how the concept of sustainability can be integrated into the sphere of aggregate provision. These chapters provide already existing indicators for measuring sustainability of aggregate provision on different territorial levels.

3.3.1. Sustainable aggregate provision

As described in Introduction (see page 11), one of the main critical issues that were identified by the Regional Planning Office in Stockholm (RTK) in order to achieve sustainable aggregate provision are: 1) decreased use of natural gravel; 2) sustainable transportation; and 3) increased recycling (Norström et al, 2008).

Decreased use of natural gravel should in first turn be promoted in order to protect ground water zones in Stockholm. Moreover according to the concept of sustainability, aggregates (being a natural resource) should be maintained and preserved for the future generations (Langer, 2003).

Improving the ways of aggregate transportation would lead to mitigating negative environmental, social and economic impacts caused by truck traffic (such as associated impacts in terms of energy use and CO_2 emissions) (EEA, 2009). Moreover transportation of aggregates by road is a source of such pollutants as NO_x, SO_x, particles etc., which cause local or regional air quality problems (Mroueh, 2000).

The visual illustration of the benefits received from aggregates recycling is shown in *Figure 9* (where A- volumes of primary aggregates and B- construction and demolition waste that is landfilled). This option saves costs of transport, supply of natural raw materials and the landfilling of construction and demolition waste (Hendriks et al, 2001).

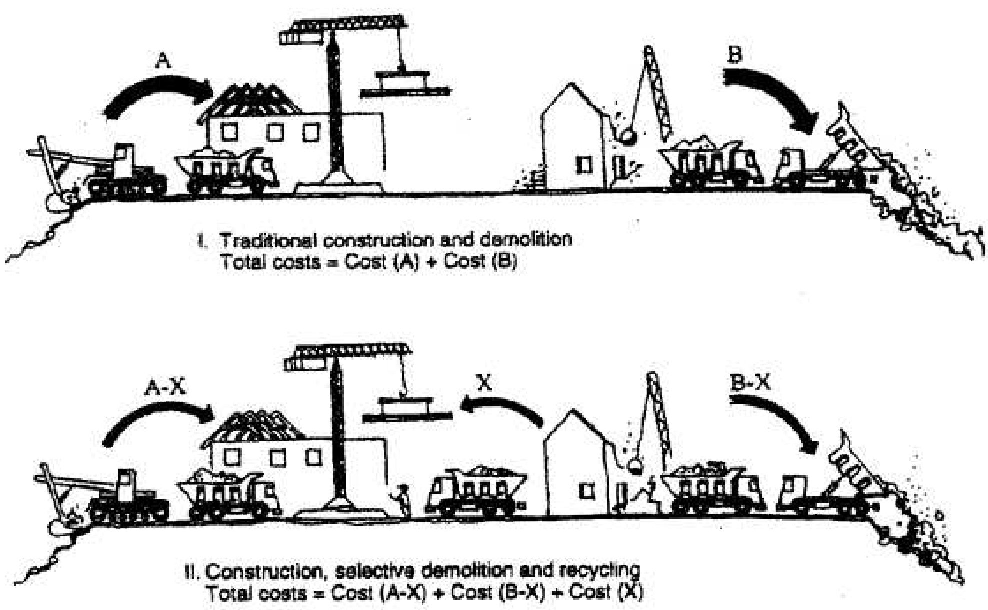


Figure 9 Economic model of total costs of traditional and selective demolition (Lauritzen (1998) in Hendriks et al (2001)

Thus, in order to secure sustainability in aggregate provision there is a need to assess the potential negative impacts arising throughout the whole aggregate flow and to find the optimal solution to the sourcing and application of aggregates (WRAP, 2007).

3.3.2. Indicators of sustainability in aggregate provision at different territorial levels

Solar et al (2007) claims that in order to achieve sustainable aggregate provision several actions should be done, including issuance of policy statements, elaboration of objectives, establishment of actions, identification of indicators and monitoring. The author also states that indicators deserve a special attention, as they measure progress as well as the effects of actions taken to protect and enhance natural and human systems (Solar, 2007).

As written in the previous chapter about sustainability indicators, ¨defining scale is a necessary prerequisite for understanding the relationships between indicators¨ (USDA, 2004). Thus there is a special need for identifying the scale of sustainability monitoring in aggregate provision.

Aggregate provision is managed on the following geographical levels:
1) global/international
2) national
3) regional
4) large inter-regional (inter-municipal) projects
5) municipal
6) individual small and large projects (Svedberg, 2009).

Since the potential of aggregate supply is very large on the global scale, there is almost no risk of running out of aggregates on the Earth (Langer, 2003). Consequently, few sustainability indicators were developed for aggregate provision on the global scale.

However aggregates of a good quality and for an intended use can be really scarce on the national, regional or local level (Langer, 2003). The importance of local aggregate supply may be explained by the fact that long distances of material transportation not only add up to the overall cost of the product, but also to the environmental costs (Langer, 2003).

So there is a necessity for measuring a sustainability of aggregate provision throughout the whole aggregate flow on the regional and local scales. Examples of existing indicators of aggregate industry on different scales (EU level, national, regional) are shown below.

EU level (international scale)

Most Member States have taken measures to implement the principles of sustainable aggregate provision. The emphasis has been on environmental protection, promoting reduced use of minerals, and recycling of materials (Wagner et al, 2005). Several indicators for monitoring sustainability during different stages of aggregate flow were developed at EU level.

The most relevant document that promotes sustainable development in the aggregate industry is the Communication on "Promoting sustainable development in the EU non-energy extractive industry" (Wagner et al, 2005). The objective of the Communication was to set the broad policy lines for promoting sustainable development by reconciling the need for more secure and less polluting extractive activities while maintaining the competitiveness of the industry (EC, 2000). The Communication raises two kinds of concern: 1) the use of non-renewable resources (¨for the future generation¨) and 2) the quality of the environment (Wagner et al, 2005).

As a result of this Communication, there were produced indicators which described the economic, social and environmental performance of the non-energy extractive industry.

The examples of those indicators at the Member States level are as following:

- *Sustainable access to resources*
- *Land granted for minerals extraction.*
- *Material demand*
- *Contribution to GDP*
- *Trade balance*
- *Sensitivity*
- *External cooperation in sustainable development of the non-energy extractive industry (EC, 2000)*

One of the primary purposes of those indicators is to provide information to decision makers and the public so as to ensure that the public debate about policy choices is grounded in fact (Solar et al, 2007).

However it should be noted that those indicators do not consider the whole aggregate flow. They measure sustainability only on some stages of aggregate provision, such as extraction of primary material from geological deposits and quarrying/processing of aggregates. However aggregate transportation and waste disposal were not covered by these indicators.

National level- Sweden

As described in the previous chapter Sweden has developed 16 Environmental Objectives as a national strategy for sustainable development. And among those 16 objectives the most relevant ones for sustainable aggregate provision were considered as following: Objective #1 ¨Reduced Climate Impact¨, Objective #2 ¨Clean Air¨ and Objective #15 ¨Good Built Environment¨.

The objective of ¨Good Built Environment¨ identified targets for the reduction of gravel use and protection of groundwater areas during gravel extraction.

Such objectives as ¨Reduced Climate Impact and ¨Clean Air¨ identified goals for the reduction of CO_2 emissions and other gases (e.g. PM10, NO_x, and SO2) from all types of industries. The fulfilment of these objectives involves finding new alternatives for transportation modes and fuel, as well as localisation of quarries in the strategic places near the market (Arell, 2005).

Regional level- Stockholm

In order to promote sustainable aggregate provision the County of Stockholm (in Swedish- Länsstyrelsen i Stockholms län) has identified a set of region-specific indicators relating to national environmental quality objectives. As described above, the most relevant environmental objectives for aggregate provision are ¨Good Built Environment¨, ¨Clean Air¨ and ¨Reduced Climate Impact¨.

Table 3 was developed during the study in order to analyze targets provided to these objectives and analyze their relevance to each stage of aggregate flow (V- relevant, Xirrelevant, N/A- non- applicable). Note, that the stage of "Use of aggregates in the construction industry" is excluded from the study.

Table 3 Regional Environmental Quality Objectives and their relevance to aggregate flow

Stage of aggregate flow / Goals and indicators	Excavation (extraction) from the source	Processing/ Aggregate production	Use	End- of - use	Transport and storage
Good Built Environment					
Planning (for transportation, green areas, water areas, energy and cultural environment)	**V**	**V**		**V**	**V**
Decreased noise level	**V**	**V**		**X**	**V**
Noise mapping	**V**	**V**		**X**	**V**
Protect quite places	**V**	**V**		**X**	**V**
Decreased volumes of gravel	**V**	**X**		**X**	**X**
Sustainable aggregate provision	**V**	**X**		**V**	**V**
Volumes of landfilled waste	**V**	**V**		**V**	**X**
Waste recycling from households, restaurants, kitchens, food industry	**N/A**	**N/A**		**N/A**	**N/A**
Energy use	**V**	**V**		**V**	**V**
Clean Air					
NO_x emissions	**V**	**V**		**V**	**V**
VOC emissions	**V**	**V**		**V**	**V**
Benzo (a) pyren	**N/A**	**N/A**		**N/A**	**N/A**
Particles emissions	**V**	**V**		**V**	**V**
Reduced Climate Impact					
CO2 emissions	**V**	**V**		**V**	**V**

Municipal (local) scale

Municipalities are important actors with regards to the achievement of sustainable aggregate provision. The most important strategy for this would be consideration of aggregate provision in the municipal plans, cooperation between municipalities and promotion of the use of recycled materials (The County Administrative Board of Stockholm, 2000).

4. INTRODUCTION TO THE STUDIED AREAS

This chapter explains the main geographical and demographical information about the chosen studied regions (Stockholm, Helsinki and Hamburg), which are located around the Baltic Sea (see *Figure 10*).

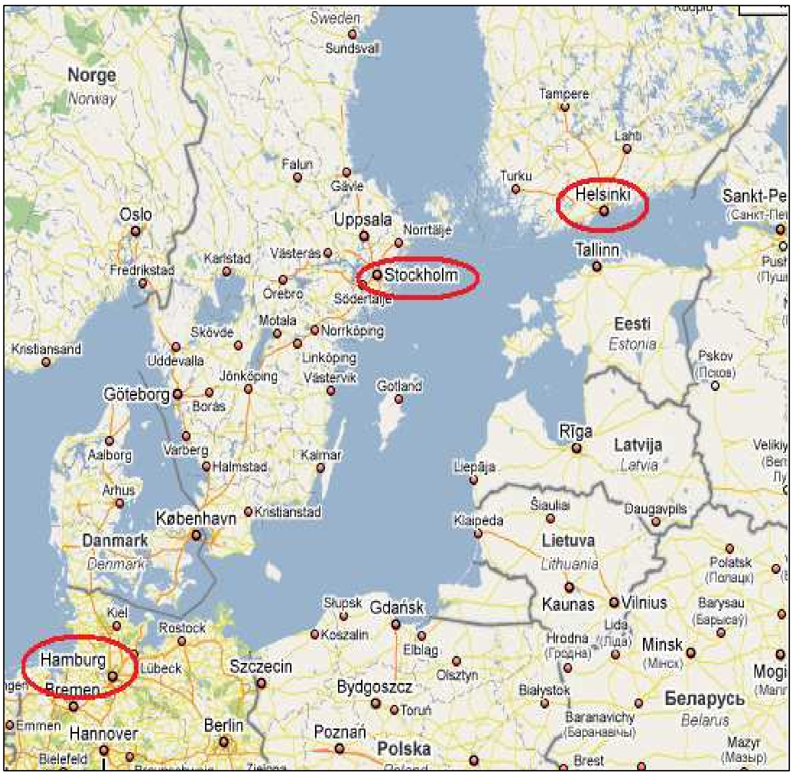


Figure 10 Location of the studied areas

4.1. Stockholm

The County of Stockholm (Stockholm Län) that consists of 26 municipalities (kommun) was chosen as the territorial unit for the study (see *Figure 11*).

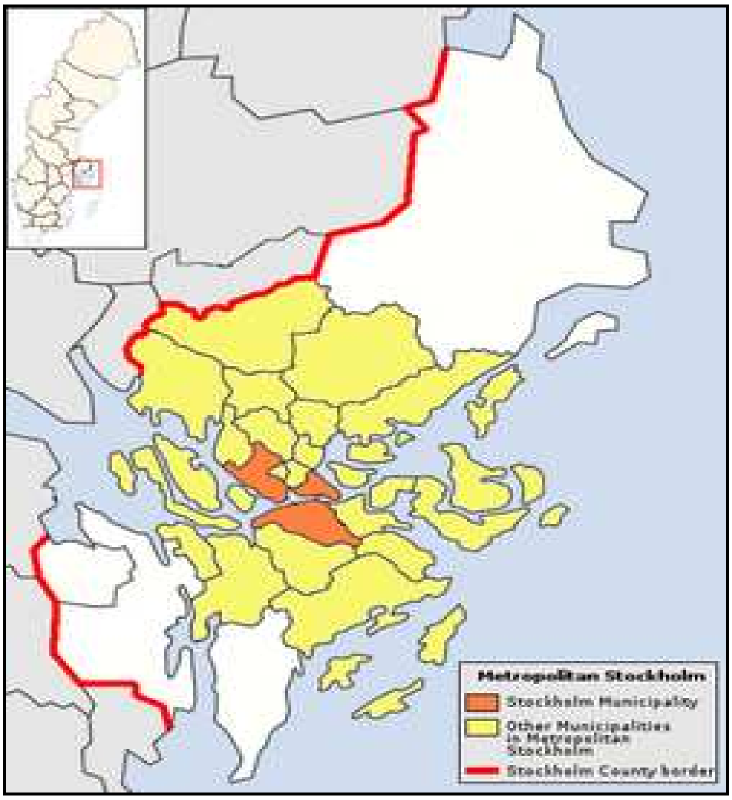


Figure 11 Map of the County of Stockholm (Nordelch, 2009)

The city of Stockholm is the capital of Sweden and Scandinavia's largest capital city in the region.

Stockholm County covers the area of approximately 6,488 km² with the population of about 1.981.263 (SCB, 2008).

Stockholm County has the largest population concentration in Sweden, with more than 1.8 million people, and is projected to grow to 2.4 million people within 30 years (Colding, 2005).

4.2. Helsinki

Helsinki Metropolitan area (that consists of Helsinki, Espoo, Vantaa and Kauniainen) was chosen as the main territorial unit for study. However since the government on the county level doesn´t have so much power regarding aggregate provision, some statistical data (for example regarding primary resources extraction) exist only for the the whole Uusimaa Region (*Nyland*- in Swedish) (see *Figure 12*).

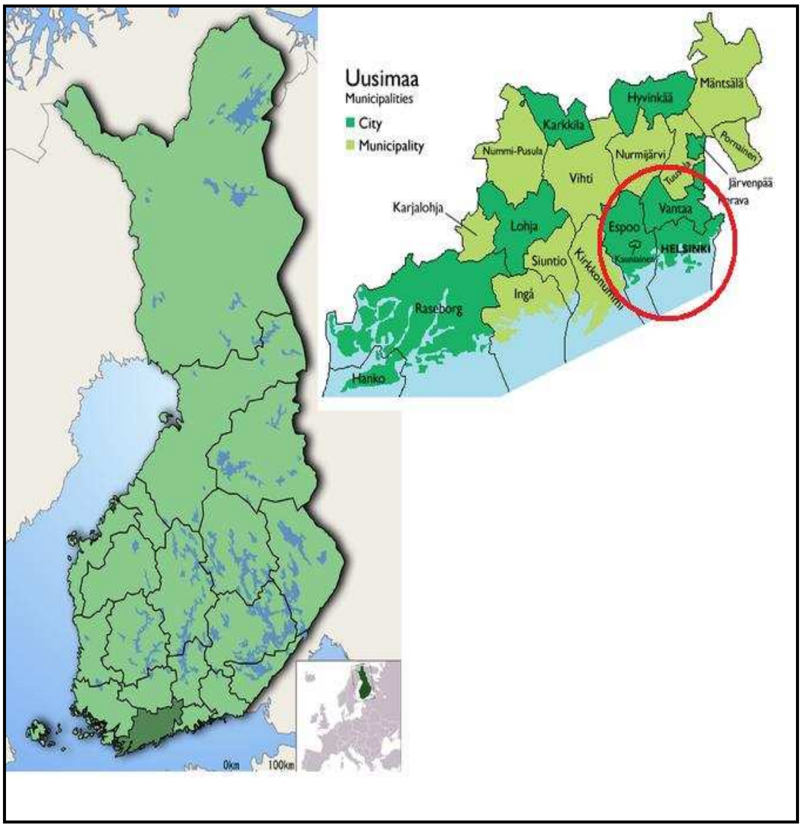


Figure 12 Map of the Uusimaa region that includes the Helsinki Metropolitan Area (Ningyou, 2006)

Helsinki is the capital and the largest city in Finland. It is situated in the southern part of Finland, on the shore of the Gulf of Finland, by the Baltic Sea.

The Metropolitan area of Helsinki occupies about 3,822.2 km^2 (Land Survey of Finland, 2009). The cities in the metropolitan area (Helsinki, Espoo, Vantaa and Kauniainen) have the population of about 1.3 million inhabitants (Population Register Center in Finland, 2008).

The population of the Helsinki Region is expected to reach 1.5 million by the end of 2025, and that of the Metropolitan Area 1.17 million. This means that the population of the entire region will increase by 300,000 (YTV, 2003).

4.3. Hamburg

Hamburg City (or in other words, Hamburg Federal State) was chosen as territorial unit for the study. Hamburg metropolitan area was excluded from the study due to its complexity (as it belongs to several Federal States: Hamburg, Lower Saxony and Schleswig-Holstein) (see *Figure 13*).

Hamburg is the second largest city and the principal port in Germany. The city is located directly between Continental Europe to its south, Scandinavia to its north, the North Sea to its west, and the Baltic Sea to its east.

The Federal State of Hamburg is made up of 7 boroughs (German: *Bezirke*) and subdivided into 105 quarters (German: *Stadtteile*). There are also 180 localities (German: *Ortsteile*).

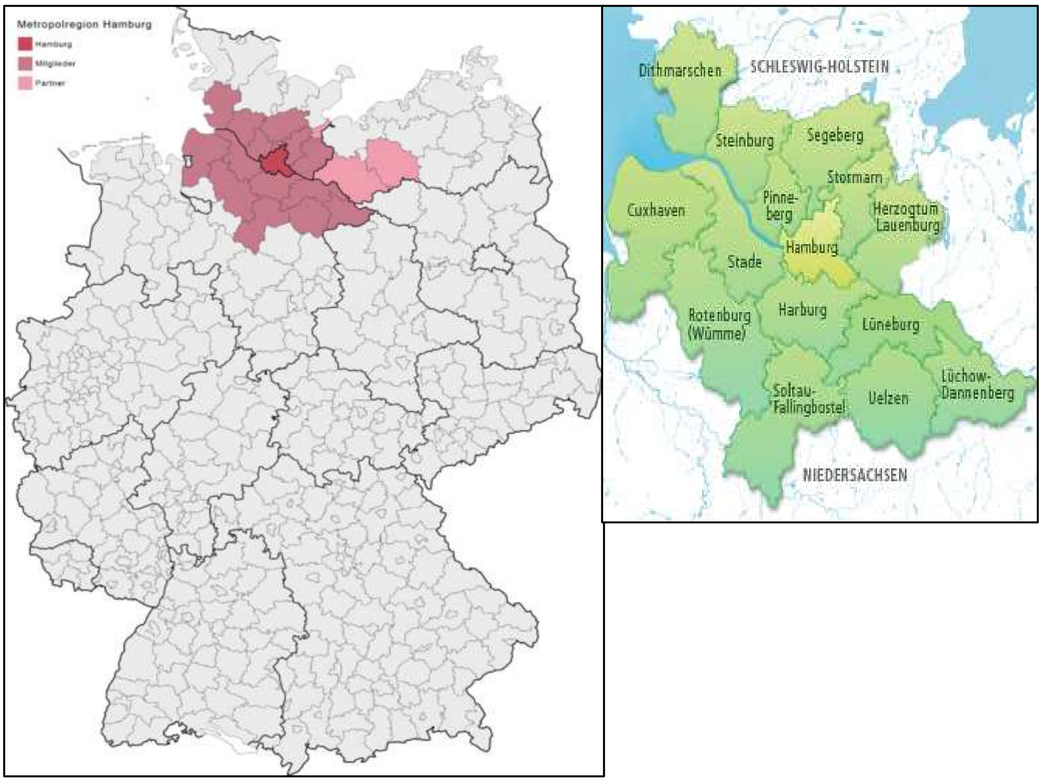


Figure 13 Map of Germany and Hamburg Metropolitan Area

The city of Hamburg occupies the area of 755 km² with the population of about 1,77 million citizens- Forecast up to 2040 (survey from Cologne University) the population of Hamburg will exceed 2 million, that of the metropolitan region will reach 4.412 million. Forecast up to 2040 (survey from Cologne University) the population of Hamburg will exceed 2 million, that of the metropolitan region will reach 4.412 million (Hamburg- Economy, 2009). Forecast for Hamburg until 2020: Population will grow to 1.84 million (Hamburg, 2009).

5. KEY STAKEHOLDERS

This chapter provides a short overview about the groups of stakeholders participating in aggregate provision as well as their responsibilities.

Identification of stakeholders in the studied regions was necessary for two purposes. Firstly, in order to collect data about the systems of aggregate provision in the studied regions. And secondly in order to understand who would be responsible for the achievement of sustainable aggregate provision.

5.1. Stakeholders responsibilities at different territorial levels

As it was described in Theoretical Framework, aggregate provision is managed on different territorial levels: international, national, regional, inter-regional (inter-municipal), municipal and individual projects.

The comparison of the systems of aggregate provision in this study was done on the regional level. Thus the share of responsibilities regarding aggregate provision on the regional level, as well as municipal and project levels is shown in the *Figure 14*. The figure shows general idea about the main critical issues of aggregate provision controlled on each level.

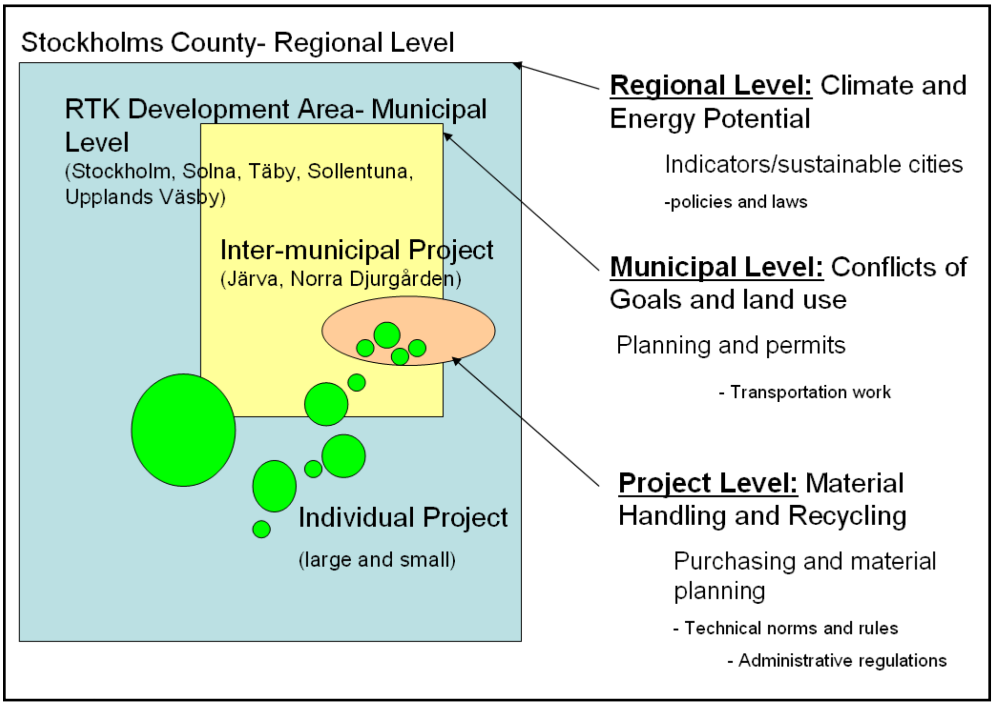


Figure 14 Geographic levels of aggregate provision (translated after Svedberg, 2009)

Stakeholders on the regional level are responsible for the implementation of the national and regional goals for material provision and establishment of policies and laws that secure aggregate supply for the whole region. They also contribute to the communal coordination in material provision and describe the need for the construction material (The County Administrative Board of Stockholm, 2000).

Planning and permits for the quarrying activities is done at the municipal level. The role of municipal authorities is to develop the plans for material provision; to take responsibility for coordination of material provision between communes; to provide the accessibility and good logistics to the aggregate reception stations and actively promote the use of secondary and recycled materials (The County Administrative Board of Stockholm, 2000).

Stakeholders at the project level take responsibility for the efficient use of natural gravel (it shouldn´t be used in the places where another material is also suitable); develop techniques for the minimized disturbance to the surrounding; promote reusing of the material; and develop cleaner and more resource efficient techniques for the extraction, processing and transportation of the material (The County Administrative Board of Stockholm, 2000). Stakeholders at the project level may be contractors, property owners, companies etc.

5.2. Groups of stakeholders

Based on the knowledge about the current system of aggregate provision in Stockholm County, there were identified the groups of stakeholders in each case-study.

Since the systems of aggregate provision are compared on the regional level, the main stakeholders interviewed were authorities on the regional and municipal level, as well as some companies.

The interviewed stakeholders in each region are shown in Appendix 3.

So the main stakeholder groups that participate in aggregate provision are as following**:**

Property owners, property developers (*byggherrar* in Swedish):

- Construction clients such as Railway, Road Administrations, municipalities, real estate owners etc.
- Branch organisations of construction clients (organisations that represent their interests). Examples in Sweden: Branch organisation of real state owners (*Fastighetsägare*); Branch organisation of construction clients (*Byggherrar*); Swedish Building Industry Association (*Byggmaterial Industrierna);* The Swedish Construction Federation (Sveriges byggindustries); Ecocycle Council-association of around 30 organizations within the Swedish building and real estate sector (Kretsloppsrådet) etc.

Transportation companies:

- E.g. the Swedish Association of Road Haulage Companies (Sveriges Åkeriföretag) - as the branch organisation of those companies in Sweden.

Aggregate supply companies:

- Individual aggregate supply companies, e.g. Jehander, Skanska, NCC Roads etc.;
- Branch organisations of aggregate supply companies, e.g. Swedish Aggregates Producers Association (Sveriges Bergmaterialindutri (SBMI)).

Waste management companies:

- E.g. Ragn Sells

Contractors (and other end-users of aggregates)

- E.g. Skanska, NCC- construction companies etc.

Consultants

- E.g. WSP, SWECO, Ramboll etc.

R&D

- E.g. Geological Survey, -Sveriges Geologiska Undersökning (The Geological Survey of Sweden); -Mining Inspectorate of Sweden; Swedish Geotechnical Institute (SGI); KTH, Ecoloop etc.

Authority (controllers, regulators, permission-givers):

- National Level, e.g. the Ministry of Environments, The Ministry of Enterprise Energy and Communication, Rail Administration (*Banverket*), National Board of Housing Building and Planning (*Boverket*), Road Administration (*Vägverket*), Environmental Protection Agency (*Naturvårdsverket*) etc.
- Regional Level, e.g. the County Administrative Board of Stockholm (*Länsstyrelsen*- in Swedish), County Council: the Regional and Planning Office (*Landstinget: Regionplane- och trafikkontoret (RTK))*
- Municipal Level, e.g. municipalities (kommun), *SKL*, *KSL* (branch organisations of communes),

It should be noted that some of the organisations (or companies) can belong to several groups of stakeholders. For example, Swedish Geological Survey belongs to the Research and Development group, but it also belongs to the authorities on the national level.

6. RESULTS

As it was previously explained in the section of Methods and Theoretical Framework, the DPSIR model was used as an analytical framework for assessing quantitative and qualitative data regarding aggregate provision (see *Figure 2*)

Table 4 shows the conceptual DPSIR framework proposed for analyzing general trends of aggregate provision. The indicators that were chosen for the study are shown in the column ¨accessible¨. The choice of these indicators was conditioned by data availability and comparability.

Table 4 DPSIR conceptual framework for assessing the general trends of aggregate provision (showing indicators selected for the study)

DPSIR	Proposed	Selected for the study (due to accessibility and comparability
Driving forces (economic sectors, natural factors)	Population, Population growth Need for infrastructure, housing Lifestyle (housing area/capita) Economical growth, Prices Geology	Pop 2008, Pop growth - Average living area/capita GDP *Prices of aggregates, prices of CDW landfilling, pricing of aggregate* *numbers of quarries and pits (sand and gravel)*
Pressures on the environment 1) human activities that are causing pressures;	Energy and natural resources use Production of waste (CDW, from quarrying activities) Production of noise Transportation	Aggregates use (natural/recycled) Landfilling of construction and demolition waste - Modes, distances
2) pressures on the environment (partly assessed by LCA approach)	Emissions to air, water and soil	CO2-emissions, Particles emissions
State (current situation of the environment)	Environmental quality (water, air, soil and biodiversity)	particles, CO2 emissions (total in the region)
Impact	Depletion of non-renewable resources	*Only qualitative assumptions on the proposed indicators*

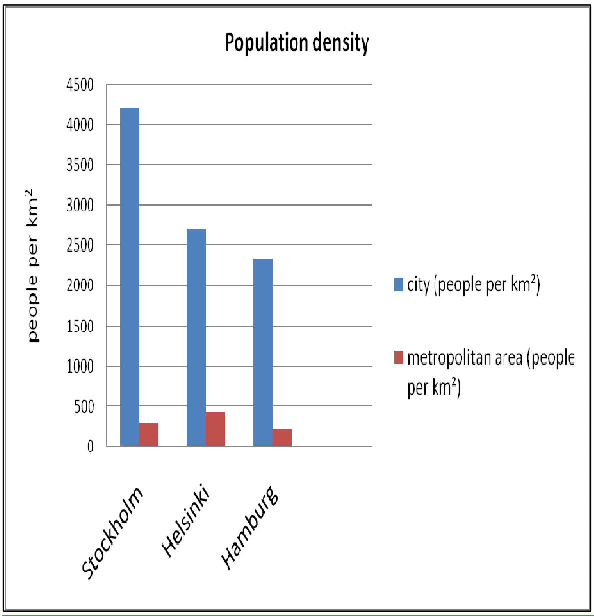
	Human health and safety (accidents) Cultural Heritage Landscape alterations Loss or damage to biodiversity Economy	
Responses	Environmental Policies and Targets Macroeconomic policy measures (pricing, taxes) Sector-specific policies (application of new technology, new standards etc.)	Environmental taxes and targets

The proposed DPSIR framework for aggregate provision and the results for selected indicators are described in the next chapters.

6.1. Driving forces

The chosen driving forces for the study are: population growth, population density, regional GDP, average living area; geology (numbers of quarries and pits located in the region) and pricing (prices for aggregates and landfilling) (as shown in the figures below). See the definitions of GDP and average living area on p. 9.

Demography, economy, lifestyle



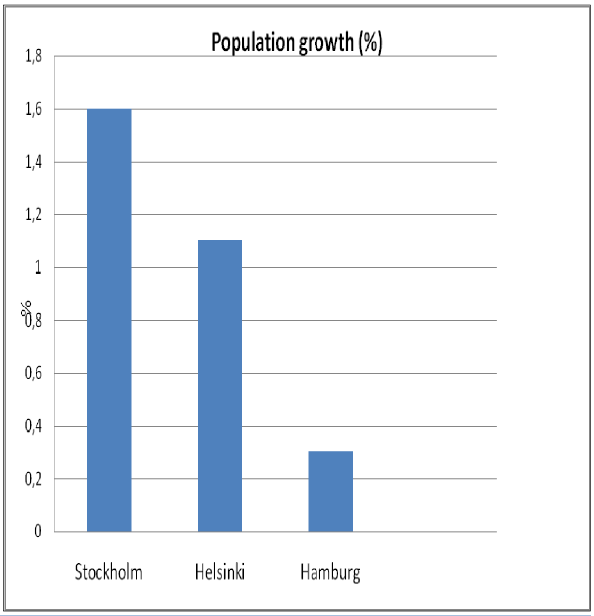


Figure 15 Demography in the studied regions (SCB, 2008; Population Register Center, 2007; Hamburg, 2009)

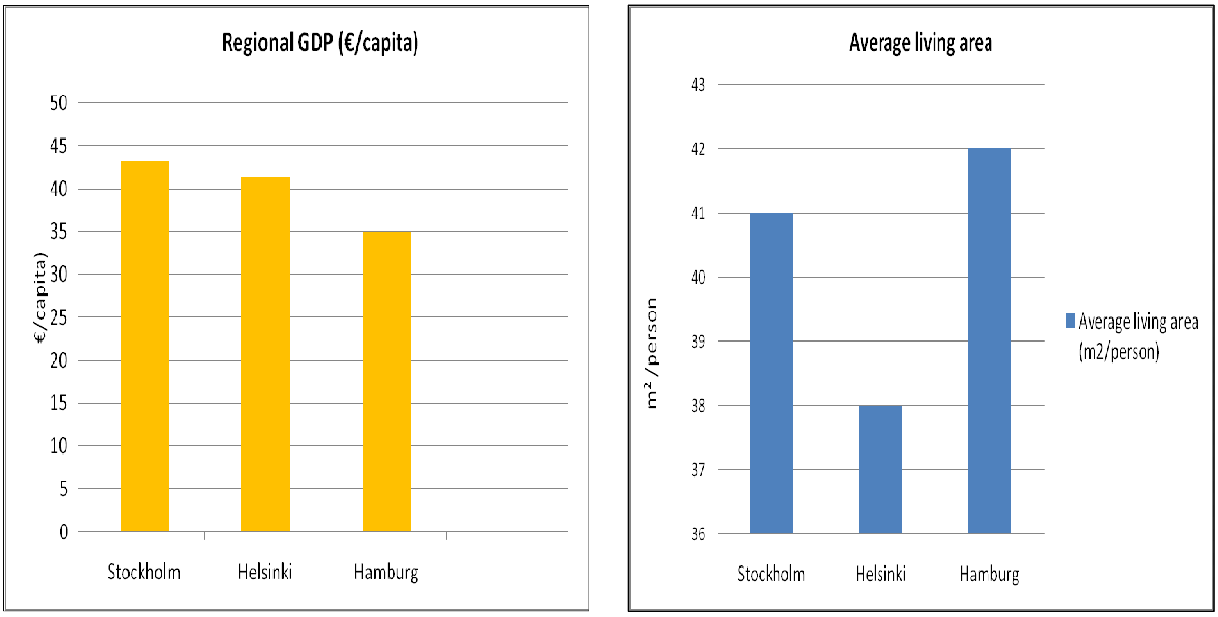


Figure 16 Economy and lifestyle in the studied cities (Urban Audit, 2004)

From the figures above, it may be assumed that Stockholm County, having the highest population growth, density, GDP and high living standards (that is measure by average living area), may require plenty of new construction and as the result, more aggregates.

Geology

The availability of natural aggregates in geological deposits can be represented by the numbers of quarries and pits located in the region. The difference between pit and quarry is that a pit contains loose sands and gravels that are directly excavated, screened, and transported. And on the contrary from pit all products from a quarry are crushed (APABC, 2009).

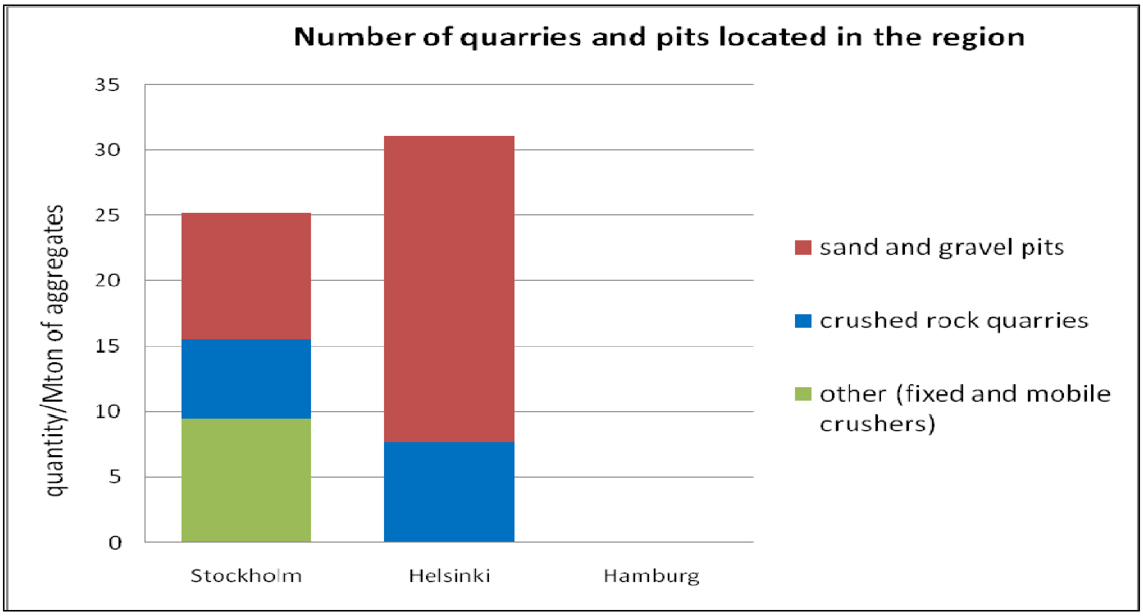


Figure 17 Numbers of quarries and pits located in the region (Länsstyrelsen i Stockholm, 2009; Uusimaa Regional Council, 2009; BSU, 2009)

It should be noted that *Figure 17* shows only the number of quarries that are registered in plans and have permissions. Unregistered quarries and pits (that are also located in the region) are not shown in this figure. Data for quarries in the Helsinki Metropolitan area is shown for the whole Uusimaa region (see *Figure 12*) that supplies aggregates for Helsinki Metropolitan Area. It can be also observed that the region of Stockholm has data on fixed and mobile crushers. These are the places for crushing activities that have no quarry permission (SGU, 2007).

The Federal State of Hamburg has only 1 quarry located in the region. 99% of aggregates are imported from other Federal States and countries.

Prices

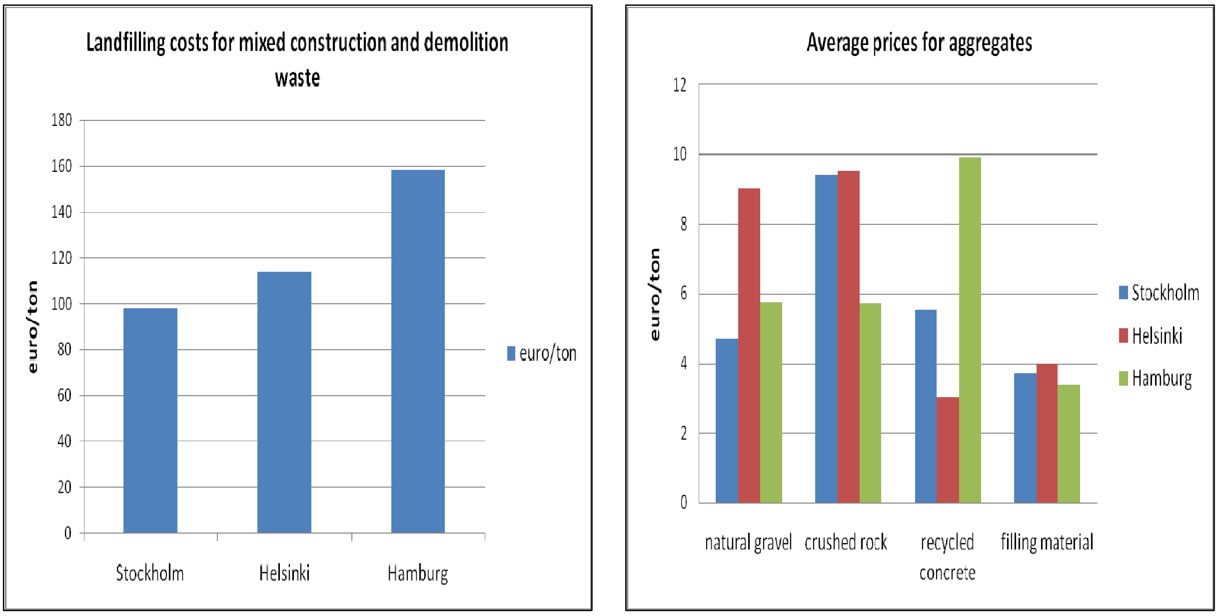


Figure 18 Prices for aggregates and waste disposal (COWAM, 2006; Sörab, 2009; YTV, 2008; SBMI, 2009; Rudus, 2009; Trade Association of Construction Materials in Hamburg, 2006)

Hamburg Federal State has the highest prices for disposal of mixed construction and demolition waste. The county of Stockholm, on the contrary, has the lowest price for disposal of mixed construction and demolition waste. This can be one of the factors explaining differences in the rates of aggregate recycling and reuse (see in the chapter of Pressures)

6.2. Pressures

Indicators selected for the study were subdivided into two groups: 1) human activities (use of primary aggregates, waste production, and transportation) and 2) pressures on the environment (emissions of CO_2 and particles emissions).

A. Human activities

Aggregate consumption

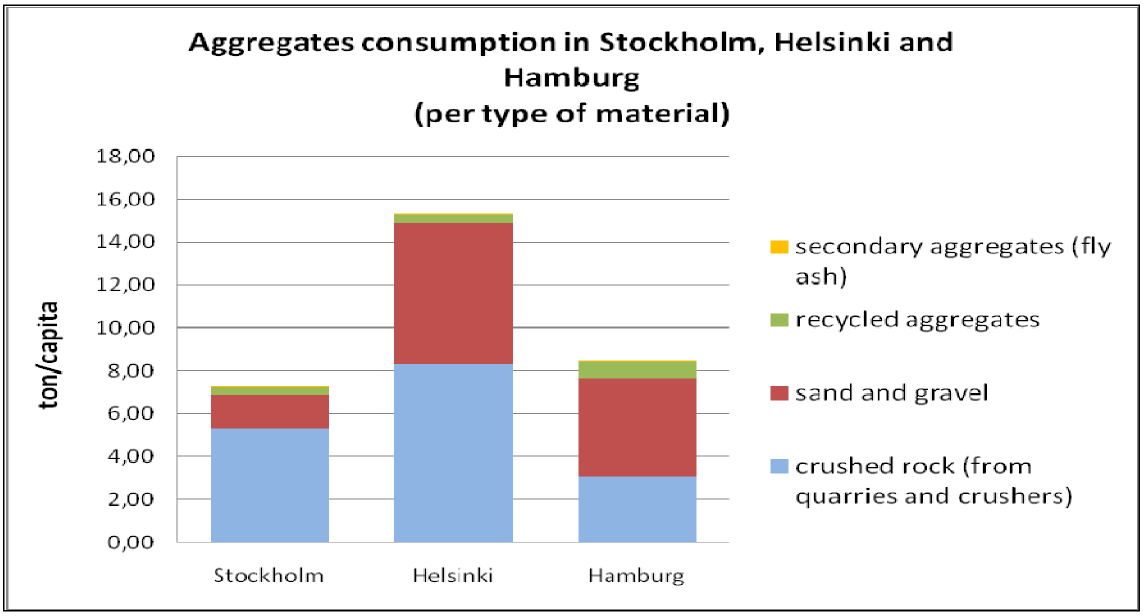


Figure 19 Aggregates consumption (NCC, 2009; Rudus, 2009; BSU, 2006)

Data on the volumes of secondary aggregates is shown only on the example of fly ash (due to the lack of data with regards to the volumes of other secondary aggregates used). Data about the use of recycled aggregates is taken only from the official statistics. However it should be emphasized that there are some unregistered numbers of recycled and reused aggregates (that is not included in this figure). In order to see the comparison of aggregates production and consumption on the national level, the data for the consumption of aggregates in the countries of the studied regions are shown in the *Figure 8*.

It may be observed that Helsinki uses the largest volumes of aggregates per capita. One of the reasons for this may be the fact that Helsinki is intensively expanding its infrastructure nowadays, while Stockholm and Hamburg have major part of infrastructure that was built in the past.

Waste disposal (CDW treatment)

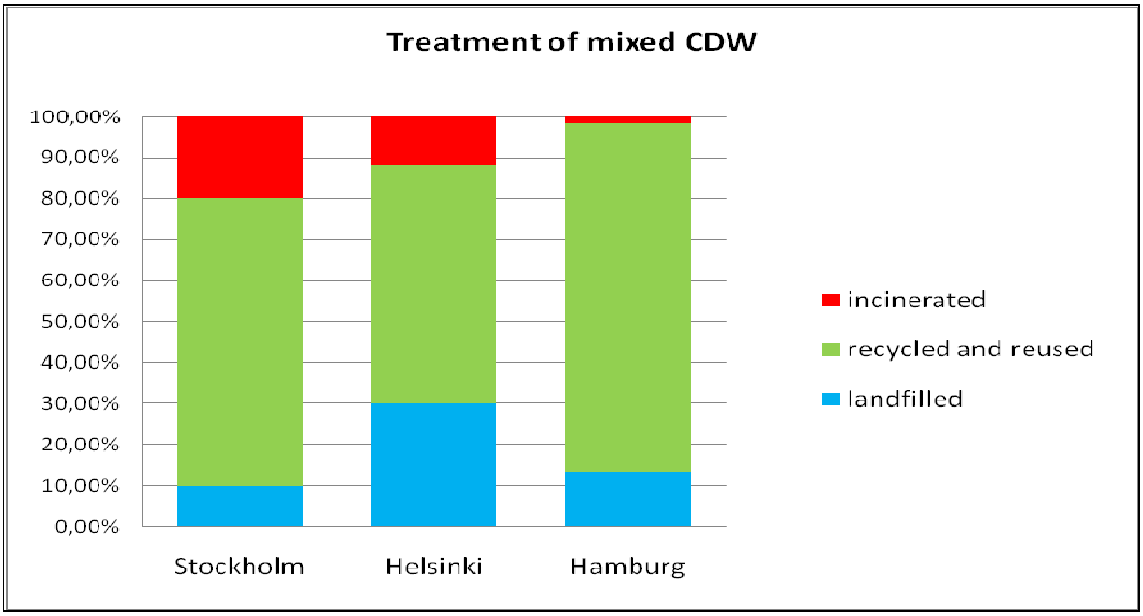


Figure 20 Construction and demolition waste treatment (YTV, 2006; Ragn Sells, 2009; BSU, 2006)

Fractions of construction and demolition waste in the studied cities are shown in Appendix 6, where it is possible to see that mineral material (bricks, concrete that may be used for recycled aggregates production) constitute for more than 60-70%.

Transportation (distances)

As it was written before, transportation causes the highest pressure on the environment.

It should be noted that due to the regional scale of comparison, only the average distances from the quarries (or pits) to the end-user (construction site) located in the region were taken for comparison.

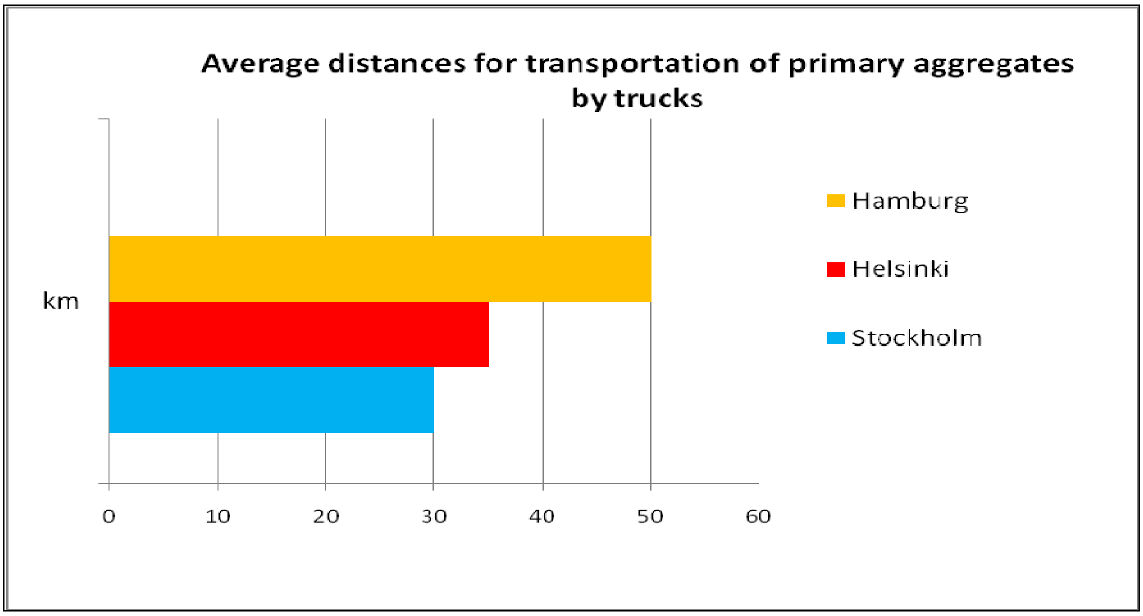


Figure 21 Primary aggregates transportation distances (Länsstyrelsen, 2009; Finnra, 2000; BSU, 2009)

It may be concluded from the figure that Hamburg has the longest transport distances. One of the reasons for this is the geological conditions in the Federal State of Hamburg, as explained further. Hamburg is importing nearly 100% of aggregates from other Federal States and countries (mostly from UK and Scandinavian countries) (BSU, 2009).

Modes of transport

Stockholm and Helsinki have very low volumes of aggregate transportation by water. Moreover the rate of aggregate transportation by water is continuously decreasing in Stockholm (due to the conflicts of land use when locating sea terminals) (Jehander, 2009). Hamburg has the highest volumes of aggregates transported by water transport. However, these aggregates are mostly transported from other countries and on large distances.

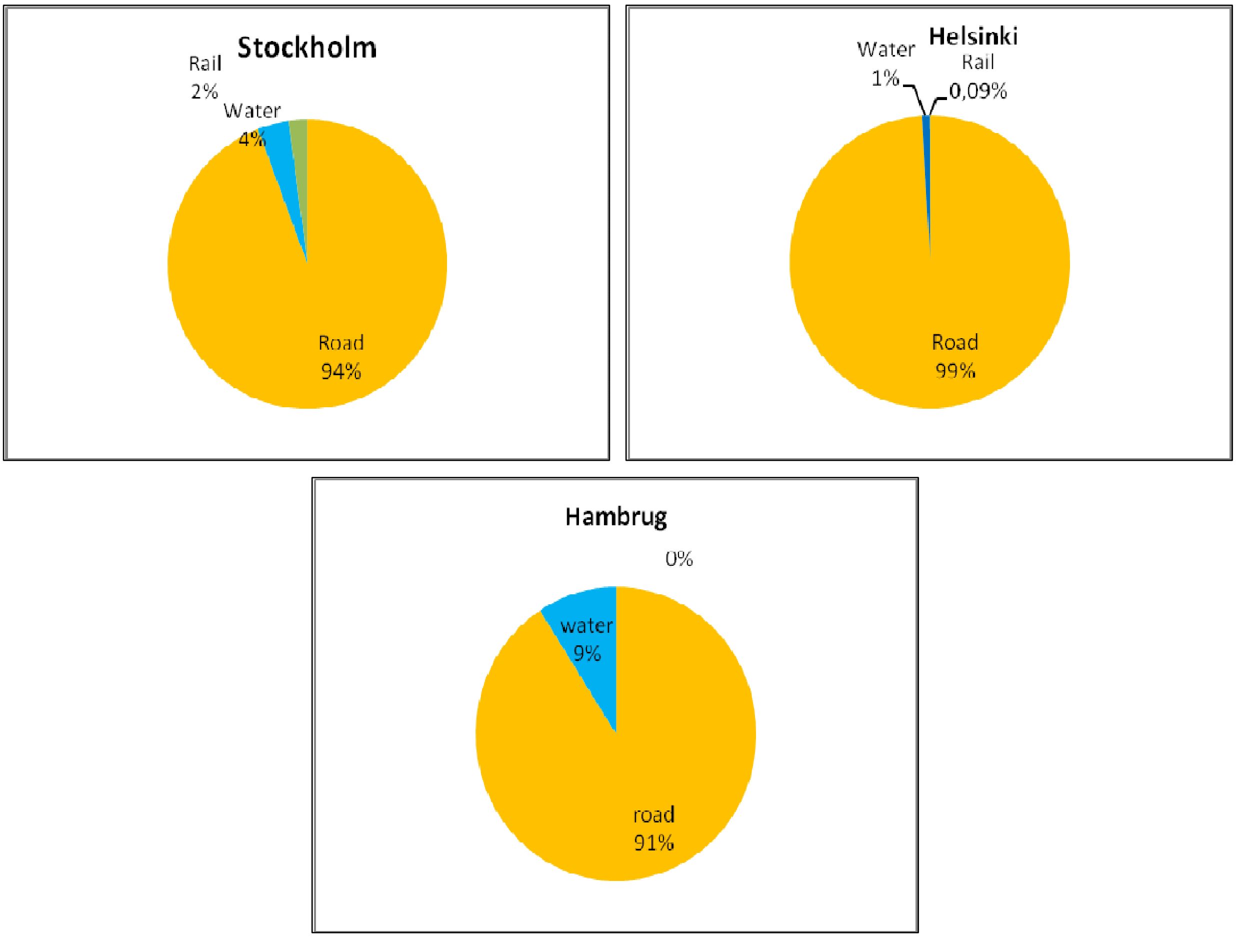


Figure 22 Modes of aggregate transportation (Jehander, 2009; Railway Administration in Finland, 2009; Rudus, 2009; Port of Hamburg, 2008)

B. Pressures on the environment

Calculated emissions

1) CO_2 equivalents emissions

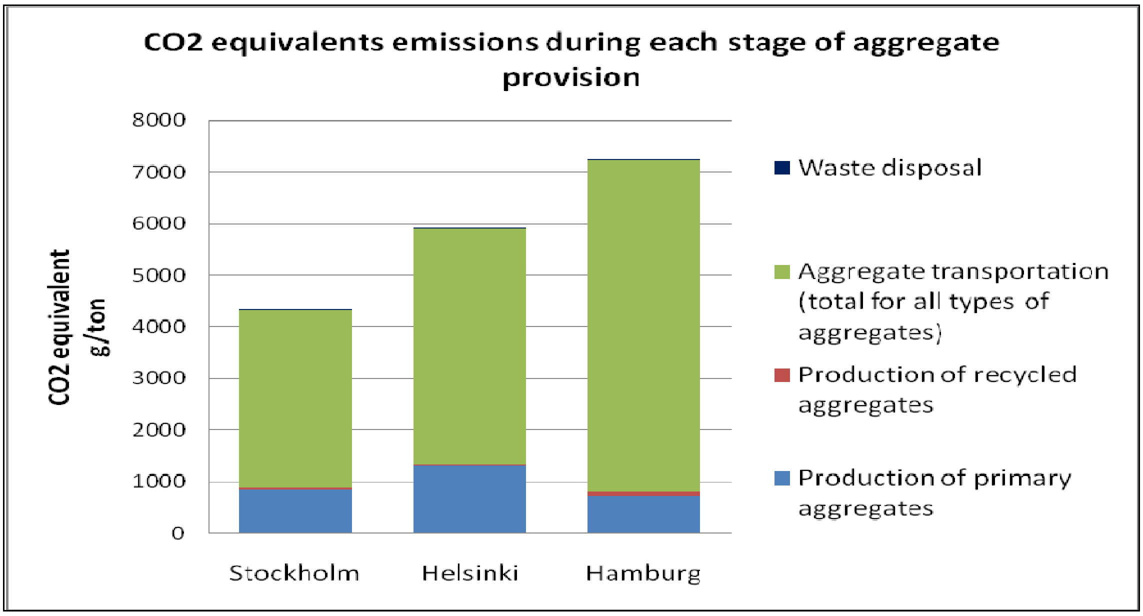


Figure 23 CO_2 eq emissions during each stage of aggregate provision

2) Particles emissions

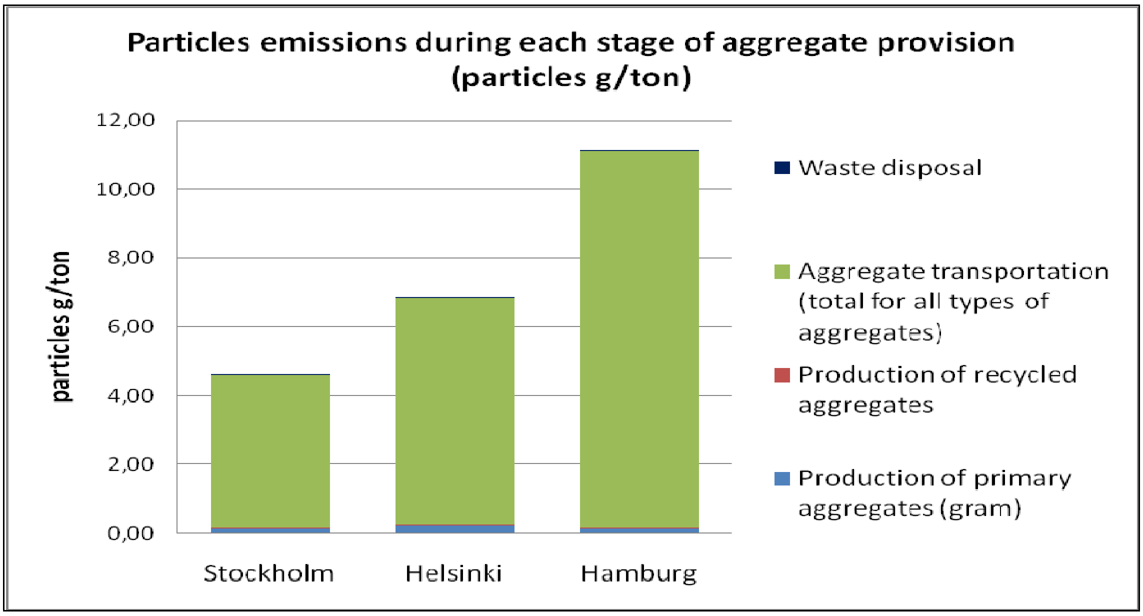


Figure 24 Particles emissions during each stage of aggregate provision

Figure 23 and *Figure 24* show that Hamburg has the highest level of greenhouse gas emissions and particles emissions during the stage of aggregate transportation. This can be explained due to the fact that Hamburg imports aggregates from other Federal States and countries. On the other hand, Hamburg has the lowest level of CO_2 and particles emissions during the stage of aggregate production and processing (due to its high level of recycling).

Concluding it may be observed that the largest emissions of CO_2 equivalents and particles in the studied regions are derived from aggregate transportation.

Comparison of the proposed scenarios

In order to see possibilities to decrease the impact from aggregate transportation it was decided to propose some potential measures (such as change in transport distances or change in modes of transports) and compare those scenarios in the studied regions (as described further).

The scenarios regarding the potential ways of aggregate transportation were proposed as following:

Scenario 1- situation nowadays (that corresponds to the findings shown in the previous sections):

- Stockholm:
    - average distances of aggregate transportation- 25 km (30 km for sand and gravel; 25 km for crushed rock);
    - the share of modes of transport: 94% of aggregates are transported by trucks, 2 %- by rail, 4%- by water transport.
- Helsinki:
    - average distances for transportation of primary aggregates - 30 km (40 km for sand and gravel, 15 km for crushed rock);
    - the share of modes of transport: 99% of aggregates are transported by trucks; 0,09%- by rail, 1%- by water.
- Hamburg:
    - average distances for transportation of primary aggregates- 50 km (not specified per type of material);
    - the share of modes of transport: 91% of aggregates are transported by trucks, 9% of aggregates are transported by water transport for large distances, no data were found about aggregate transportation by railway.

Scenario 2- Average transport distances for the transportation of primary aggregates are decreased by 10 km in the studied regions:

- Stockholm: the average distance is changed from 25 km to 15 km.
- Helsinki: the average distance is changed from 30 km to 20 km.
- Hamburg: the average distance for primary aggregates transportation is changed from 50 km to 40 km.

Note, that Stockholm and Helsinki have more possibilities to decrease transport distances by 10 km as in Scenario 2 (by prioritizing the location of quarries and pits in land use planning, for instance). However in the case of Hamburg it would be more difficult, due to the fact that Hamburg cannot control the location of quarries and pits, as it imports most of the aggregates.

Scenario 3- 20% of primary aggregates (natural sand and gravel, crushed rock) are transported by boat

Stockholm: the rate of primary aggregates transportation by boat is changed from 4% to 20%.

Scenario 4- 20% of primary aggregates (natural sand and gravel, crushed rock) are transported by railway

- Stockholm: the rate of primary aggregates transportation by railway is changed from 2% to 20%

Only Stockholm was taken for comparison of the Scenario 3 and Scenario 4 (due to similar tendencies of the impact decrease when transport modes are changed). Comparison of scenario 3 and scenario 4 is shown only for CO_2 eq emissions, because of the lack of data regarding particles emissions during aggregate transportation by railway.

Comparison of the proposed scenarios is shown in the figures below (*Figure 25*, *Figure 26* and *Figure 27*).

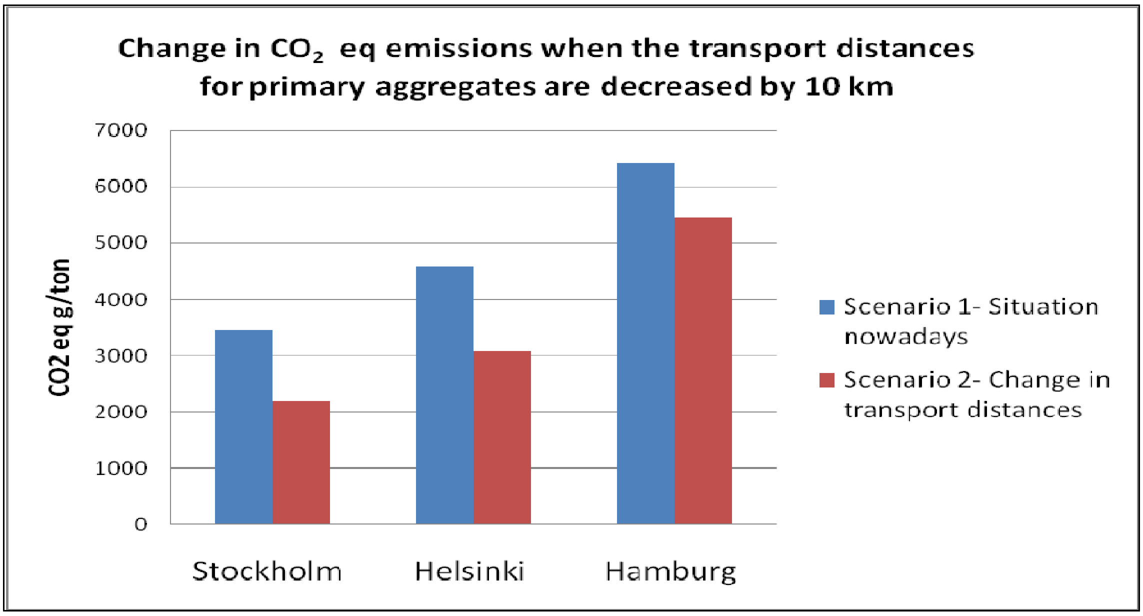


Figure 25 Change in CO_2 eq emissions when the transport distances are decreased by 10 km

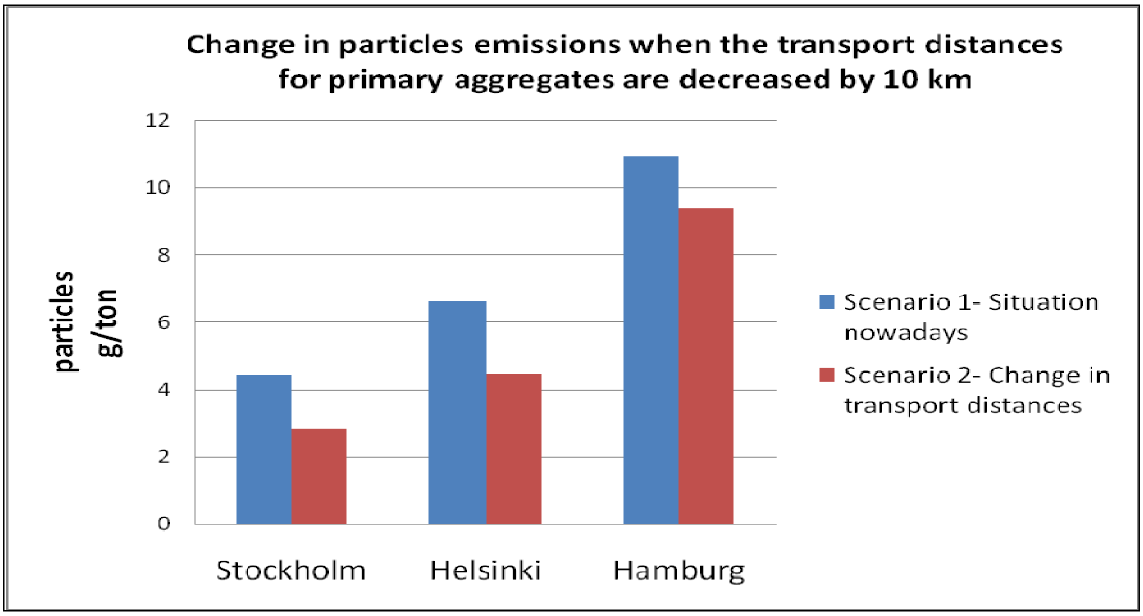


Figure 26 Change in particles emissions when the transport distances are decreased by 10 km

Figure 25 and *Figure 26* show that the decrease in transport distances by 10 km reduces the emissions of CO_2 equivalents by approximately 1300 g per ton of delivered material and particles emissions by approximately 1.6 g per ton of delivered material (in the case of Stockholm).

Figure 27 shows that when increasing the volumes of primary aggregates transported by boat from 4% to 20% the emissions of CO_2 equivalents are decreased by 450 g/ton of delivered material (or in other words, CO_2 emissions would decrease by 6300 ton/year).

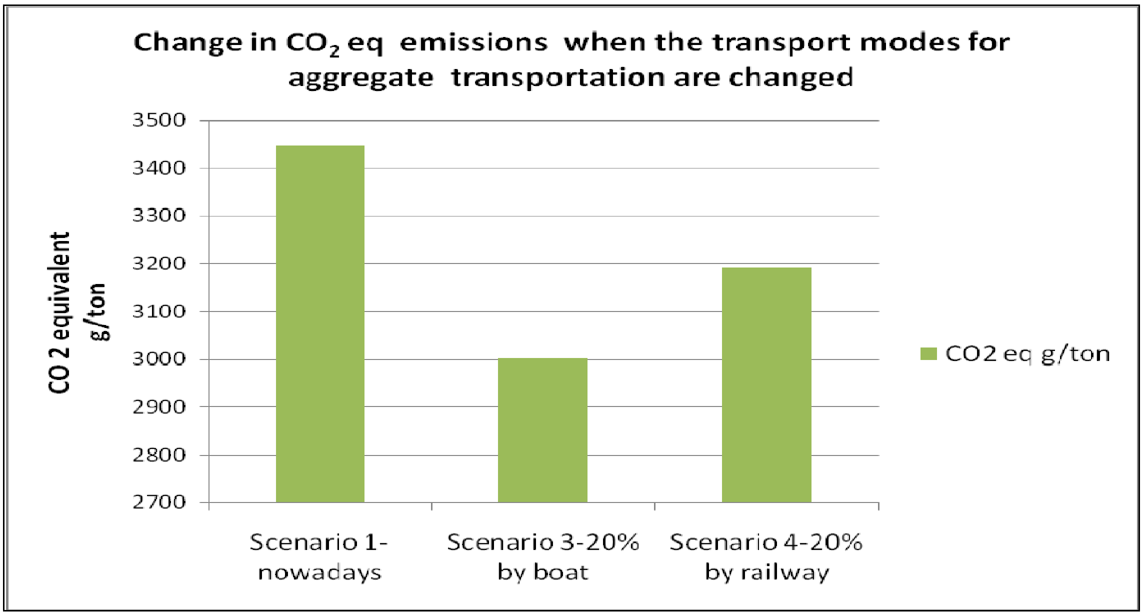


Figure 27 Change in CO_2 eq emissions when the transport modes for aggregate transportation are changed

Concluding, the figures above proved that there is a huge potential of mitigating the pressures derived from aggregate transportation by decreasing distances and changing the modes of transport.

6.3. State

The mentioned above pressures may change the current state of environment (water, air, soil and biodiversity). As it was mentioned before, one of the largest pressures from aggregate provision is emissions to air caused by transportation. Thus it was decided to compare the state of air and greenhouse gas emissions in the studied cities (using such indicators as concentrations of PM10 and CO_2 emissions).

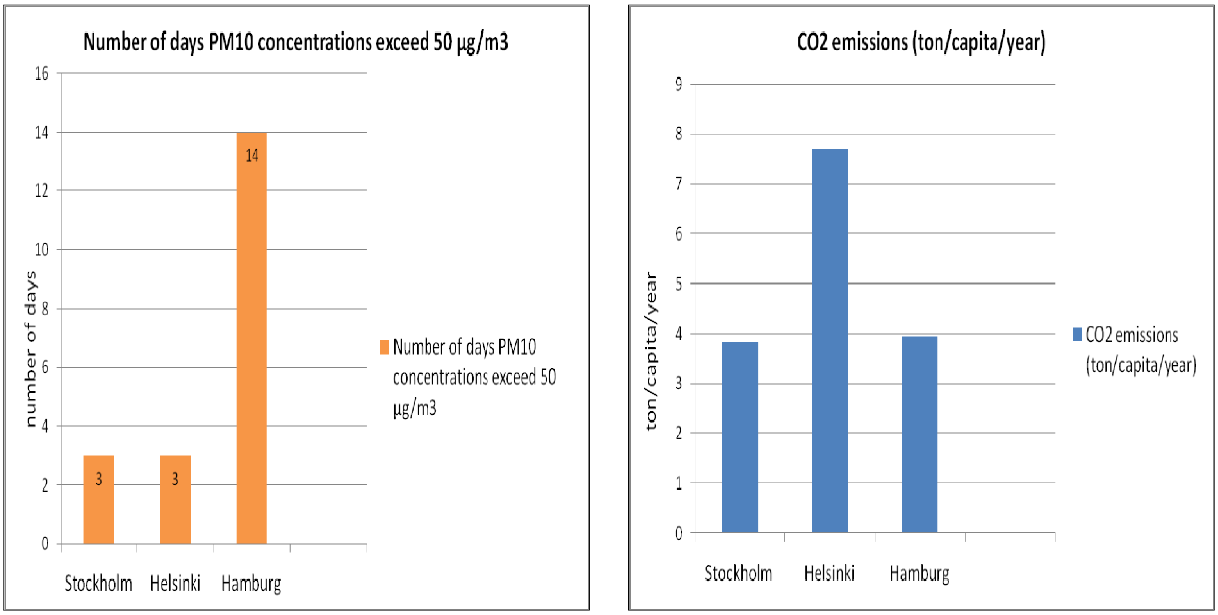


Figure 28 PM10 and CO2 emissions in the studied cities

When comparing the state of environment in the studied regions it was observed that Hamburg has the highest level of PM10 concentrations in the region and Helsinki has the highest level of CO_2 emissions per capita.

However since aggregate provision is not the only industry that generates PM10 and CO_2 emissions it is hard to draw conclusions that this is the main cause of such volumes. Thus it may be assumed that together with vehicles, power plants and other industrial processes, aggregate provision has a certain share in air pollution and CO_2 emissions (as it was proved in the chapter of pressures, p 48).

6.4. Impact

It may be concluded that the previously described pressures from aggregate provision may lead to the following main impacts (both on the local and global scales) in the studied regions:

- local impacts (direct and indirect) :
    1) depletion of non-renewable natural resources (natural gravel, soil, water etc.), caused by the extraction of primary aggregates, aggregates transportation as well as waste disposal);
    2) loss or damage to biodiversity (during all the stages of aggregate provision)
    3) landscape alterations (especially during aggregates extraction)
- global impacts (indirect):
    1) global warming potential (mostly during aggregate transportation).

Moreover aggregate provision may lead to a set of negative social impacts (e.g. impact on human health and safety mainly caused by truck traffic and aggregates extraction) and economic impacts (e.g. through the consumption of water and energy) (WRAP, 2007).

6.5. Responses

Transportation

Most of the interviewed actors concluded that authorities on the regional and local level should be responsible for the issues regarding aggregate transportation. That is why most of the measures are expected to be done from the part of the regional government (Länsstyrelsen in case of the Stockholm County) and municipalities. Some interviewees also expressed opinion that this issue is more the question for planners than for environmentalists.

Interviewing stakeholders in Hamburg it was observed that aggregate transportation was not a high priority for them, probably because they import most of the aggregates and they cannot control the location of quarries.

Stockholm and Helsinki, on the other hand, raised a high awareness about this issue. The respondents in those regions expressed several opinions about which measures should be done by the regional government in order to optimize aggregate transportation. They are as following:

- Aggregates should be prioritized in the land use planning (in order to locate strategic areas for storage places and areas with good transportation connections) (SBMI, Finnra etc.);
- Need for more terminals for sea transportation and railways connected to quarries (Länsstyrelsen);

Analyzing the current responses of the regional governments in the studied cities, it was observed that Stockholm and Helsinki have the targets set on the regional level for the decrease of transportation distances and use of other modes of transport. No targets regarding aggregate transportation on the regional level were set in Hamburg (according to the literature review). However German states have formulated a national goal for minimizing transportation of building materials (Meulen et al, 2003).

Use of primary aggregates

Most of the stakeholders agreed that the main responses of the government that can reduce the use of primary aggregates should be done on the national level. No current or possible responses on the regional, local or project level regarding material use were discussed.

So the proposed responses on the national level are as following:

- Policy instruments such as environmental taxes on the use of natural raw materials (see the definition of environmental tax in the Glossary), that could lead to the increasing prices for primary aggregates
- Development of an accounting system on aggregate flow including primary, secondary, recycled and reused aggregates (that would provide better statistical data)

Comparing Germany, Finland and Sweden it may be concluded that Sweden has the most developed system of environmental taxation for natural raw materials (mainly, the use of gravel).

According to the findings in literature review, Germany has no environmental taxation for gravel extraction.

The Swedish gravel tax is EUR 1.38 (or SEK 13) per tonne (that makes up 12% of the final aggregate price) (EEA, 2008). This tax turned out to be an efficient tool for decreasing the volumes of natural gravel extraction. It may be also seen on *Figure 19* that Stockholm has the lowest volumes of natural gravel extraction (in comparison with Helsinki and Hamburg). Thus it is also important to recognize that there have been other contributory factors that have supported this trend, such as a change in road building policy and tightening of permit regime (EEA, 2008).

Finland has also implemented the fee for gravel abstraction. No data were found about the exact sum of this fee. However, it can be assumed that this fee is not an effective policy tool for the reduction of natural gravel extraction as it can be seen on the example of the region of Helsinki that uses the highest volumes of natural gravel (in comparison with Hamburg and Stockholm).

Finland, on the other hand, has developed another approach to the sustainable use of primary materials- by developing an accounting system that provides online information on aggregate resources and substitute materials that is accessible to all stakeholders (Räisänen, 2005). This system has just recently been implemented. But it is expected to be an important step towards achievement of sustainable aggregate provision.

Aggregates recycling and reuse

All the studied regions have the targets set for the increased level of aggregates recycling and reuse but these measures are still in the process of development.

According to the answers received from the interviews the best measures that promote the increased use of recycled aggregates on the national level are as following:

- Tax for waste disposal
- Establishment of standards that could guarantee good quality of secondary and recycled aggregates, and consequently reduce the need for primary aggregates

Stockholm for example has significantly decreased the rate of landfilling (from 40% several years ago to 10 %) and increased the rate of CDW recycling (see *Figure 20* with the current situation). And this trend can be partially explained by the introduction of waste tax in 2000, that made it more expensive to landfill the waste (with the current price of 435 SEK per ton of landfilled material) (Avfall Sverige, 2009).

Hamburg shows the best results in terms of government's responses towards the promotion of aggregates recycling. The city (as well as the whole Germany) has an efficient and successful construction and demolition system. Landfilling costs for construction and demolition waste are very high in Hamburg (see *Figure 18*), that provides an economic incentive for recycling. Moreover Germany established the standards that guarantee good quality of recycled products (LAGA and RAL standards) that are the keys to facilitating recycling (COWAM, 2006).

7. DISCUSSION

The overall aim of this master thesis was to analyze the general trends of aggregate provision from environmental point of view in selected regions around the Baltic Sea (on the example of Stockholm, Helsinki and Hamburg). The study also aimed to learn from the experiences of other regions and to find out ideas that could be used for the achievement of sustainable aggregate provision in the region of Stockholm.

Some of the main trends of aggregate provision in the studied regions and problems that were aroused during the performance of the study are discussed in this chapter. The Discussion starts with comparing the general trends of aggregate provision in terms of aggregate use, transportation, and reuse and recycling in the studied regions. Other important issues that were discussed are the data quality and methodology of the study. And, finally the ideas for the future research are proposed.

7.1. Comparison of the studied regions

Transportation

The study showed that Stockholm County and Helsinki Metropolitan Area have sufficient quantity of deposits for primary aggregates (sand and gravel and crushed rock) within the region. That is the main reason why the transport distances for primary aggregates are shorter in those regions than in Hamburg. However, it was pointed out by most of the interviewees in Helsinki and Stockholm that land use conflicts (and mainly ¨not-in-my-backyard¨ problem) lead to increasing transport distances. Hamburg, on the other hand, is importing most of the aggregates from other Federal States and even countries. That is why the localisation of quarries in Hamburg is beyond the regional scope.

It was also observed that the use of alternative modes of transport (such as water and railway transport) is not very popular in the studied regions (especially Stockholm and Helsinki). This tendency may be also explained by the fact that aggregates provision is not given a high priority among the planners and that is why it is becoming more difficult to localise water terminals in strategic places.

Hamburg has larger percentage of aggregates transportation by water. But most of these aggregates are transported from other countries on large distances. And unfortunately it was impossible to track how those aggregates were transported in the countries of their origin.

Use of primary aggregates

As explained in the chapter of Responses, Stockholm and Helsinki have set the targets for decreased use of natural gravel. The reason for this is the protection of water areas. It may be observed that Stockholm County has managed to start decreasing the volumes of natural gravel extraction. This region uses the least volumes of natural gravel per capita in comparison with Hamburg and Helsinki. However some of the interviewees emphasized that increasing use of crushed rock would mean larger consumption of energy, and consequently more CO_2 emissions. Thus a careful analysis should be made of the trade-offs between water protection areas and energy use.

Aggregates reuse and recycling

Hamburg shows the best results in terms of aggregates recycling. The main factor that influences this trend is the lack of natural resources for primary aggregates and efficient policy tools set by the government (see Responses) in terms of landfill taxes and standardisation.

Stockholm and Helsinki have smaller percentages of the recycling of construction and demolition waste. However it was observed during the literature review that the volumes of recycled aggregates used in Stockholm and Helsinki are increasing with every year (see *Figure 19* and *Figure 20* showing the current state).

7.2. Data analysis

Data gaps

As described in the chapter of Results, some assumptions and estimations were made during the analysis of impact throughout the life cycle of aggregates. The reason for that were certain data gaps in the statistics on aggregate provision in the studied regions.

Stockholm County, for example, has incomplete statistics regarding the volumes of reused aggregates and construction and demolition waste on the regional level. But on the other hand, it has good statistics regarding the volumes of primary aggregates and the numbers of quarries with permissions.

The federal State of Hamburg has well-organized statistics and lots of information regarding recycling of aggregates, as well as construction and demolition waste. However, there is a lack of data regarding the use of primary aggregates and transport distances. This could be explained by the fact that the Federal State of Hamburg does not have its own resources of primary aggregates.

Helsinki, in general, showed the best well accessible statistics regarding the environmental state in the city in general and aggregate provision in particular. However, it was difficult to find data regarding the reuse of aggregates (as in the case of Stockholm and Hamburg).

There have also been some data gaps in inventory results when calculating the impacts of aggregate provision. Moreover the existing emissions data are quite old- from 1990s (see Appendix 5). But on the other hand it was noted that for example emissions data for aggregate transportation are almost the same when comparing new data proposed by EC in Fry (2007) and the old ones given by Tillman et al (1994).

Unfortunately, no new emission data were found for such stages as aggregate extraction and processing. During the literature review it was found that even the most recent scientific works based their calculations for aggregate processing and extraction on the old emission data (dating back to 10 year ago). And since the technology and methods for aggregates extraction and processing are changing very fast, there is a strong need for finding new emission data for these stages of aggregate flow.

It should be noted that the same emission data were taken for all three case studies. And as the result specific technologies (for example for aggregate extraction and processing, or mitigation measures) used in each region separately were not considered. That is why the conclusions that can be drawn from these calculations can only show the general idea about the major impacts of aggregate provision, but they cannot be used for the comparison of the technology used in the studied regions.

Data uncertainties

Even though it was attempted to identify similar aggregate flows in the studied regions and make as much accurate analysis as possible, it should be admitted that data uncertainties are unavoidable when comparing such complex systems as aggregate provision among the regions of different countries. The following main factors could cause data uncertainties:

- Different definitions in the studied countries:

For example, the definition of waste is one of the most unclear issues that may create problems for statistics and institutional practices even inside of the region. Thus, when collecting statistics on construction and demolition waste it was noticed that many stakeholders even inside of one region have different perceptions of waste (especially in the sphere of building industry).

- Currency conversance:

Hamburg and Helsinki are in the euro zone, but Stockholm has another type of currency (krona). So in order to compare the prices for aggregates and waste landfilling, Swedish krona was converted to euro according to the currency rate of year 2009 (as the prices for Stockholm were found for the year 2009). But since the currency rate is changing every day this could lead to some uncertainties when comparing the prices.

- Different statistics in the studied countries:

Some of the data for comparison was taken from the national or regional statistics. However, it may be assumed that each country has different methods and approaches to the collection of data. Moreover, the year of data collection can also play a vital role in the final results.

- Language problems (risk for misunderstanding during translation of data)

Interviewing was performed in English in most of the cases (that was not the native language for none of the stakeholders). Even though the definitions and terms used were internationally recognized and known, there must be accepted the slightest risk for misunderstanding.

7.3. Methodology

DPSIR framework

DPSIR model was used as an analytical framework for assessing quantitative and qualitative data. However the choice of indicators and the way they were grouped is an important subject for discussion.

As it was explained before, the choice of indicators used for comparison was based on data availability and comparability. That is why DPSIR framework analyzed in this study is not as complete as proposed in the table 5. Such indicators as geological conditions in the studied regions, future need of aggregates for construction purposes, land use, noise production and others were omitted from the study due to lack of data or time limitations. However these data could be very valuable for understanding the whole picture of aggregate provision.

Certain difficulties were also encountered when grouping the data into drivers, pressures and state. Since aggregate provision is a very complex issue with many actors and processes involved, the boundaries between those categories sometimes seemed unclear. For example, ¨aggregate transportation¨ was grouped as a pressure, as it causes high pressure on the environment. But on the other hand it could also be grouped as a driver (since it is a human activity that causes pressures, see in the definition of DPSIR methodology, p 17).

Another issue that should not be overlooked when analyzing the DPSIR framework is the links between all its elements. As Kristensen (2004) states that it is also important to understand the links between all the elements of DPSIR. For example, relationship between drivers and pressures depends on the eco-efficiency of the technology. Fewer pressures are produced from drivers, when eco-efficiency is high.

As far as aggregate provision is concerned, drivers (such as population and economic growth that cause larger need for aggregates) will not necessarily cause high pressures on the environment in case the methods of aggregates use and provision are eco-efficient. And in order to achieve the eco-efficiency of aggregate use and provision, such responses of the government as policies and targets should be set.

LCA approach

When using life cycle approach for assessing the impacts of aggregate provision in the studied regions, it should be realised that the final results strongly depend on the choice of system boundaries. Thus it is important to point out the importance of some stages that were delimited from the system boundaries analyzed in this study.

The stage of aggregates use in construction was not taken into account when analysing the impacts of aggregate provision. However considering this stage could have significant impact on the final results. Analyzing the use of aggregates for construction purposes could point out the main environmental impacts from the use of primary, recycled and secondary aggregates, as well as find out the main differences between them.

Another important stage in aggregate provision that was delimited is land recovery after aggregate extraction. Analyzing this stage could point out such impact categories as land use, biodiversity and social aspects (such as the impact on the local population etc.).

It should be also noted that only some of the environmental aspects were considered in this study. That is why the final conclusions regarding the impacts of aggregate provision in the studied regions should be drawn carefully. There is a need to analyze such important issues as social impacts (accidents, employment, health etc.), economical impacts (expenses for road maintenance, traffic congestions, turnover etc.) and other environmental impacts not included in the study (acidification, biodiversity, land use, water depletion, mineral resource depletion, noise etc.).

7.4. Proposal for the future research

Based on the literature review and interviews, some of the interesting issues regarding aggregate provision that could be developed further were identified. They are as following:

- Finding out new solutions for the localization of storage places and new logistic solutions for aggregate transportation on order to decrease the distances and times for aggregate transportation and storage.
- Performing a complete LCA of aggregate provision (including all impact categories and important life cycle stages) in order to understand and realize all negative impacts of aggregate provision on the environment.
- Evaluate social and economical impact of aggregate provision, using for example such tool as cost benefit analysis in order to include other than environmental aspects of sustainability.
- Performing of the strategic environmental assessments (SEAs- assessments of policies, plans and programmes) regarding policies in aggregate provision in the studied regions. This could be done in order to analyze how the policies regarding aggregate provision (for example the policy promoting increased rate of recycling) would influence on the environmental, social and economical state of the region in general.
- Performing international comparisons of the standards for the use of recycled and secondary aggregates in construction in order to improve existing standards.
- International comparisons of the quality for construction and demolition waste management in order to find out new possibilities for the improvement with regards to CDW management
- Investigation of the new emissions data during all stages of aggregate provision to be able to evaluate the actual impacts of aggregate provision that exist nowadays.
- Collecting more data on aggregate flow on different territorial levels in order to identify possible strategies for improvement of aggregate provision.
- Suggesting common regulations for all EU countries.

8. CONCLUSIONS AND RECOMMENDATION

Having performed the study, it may be concluded that the regions of Stockholm, Helsinki and Hamburg have certain similarities and differences regarding aggregate provision on the regional level. Geological conditions (mostly, access to primary resources) and policy instruments are the main factors influencing the current systems of aggregate provision in the studied regions. That is one of the main reasons why the differences in aggregate provision occur depending on the region.

The Federal State of Hamburg shows the best examples regarding the use of recycled aggregates and management of construction and demolition waste. The Metropolitan Area of Helsinki shows the best example regarding the data accessibility on material flows (and aggregates flow in particular) and the environmental state of the city in general. Stockholm County shows the best examples regarding the use of primary aggregates and decreased use of natural gravel.

As far as similarities are concerned, most of the aggregates in the studied regions are transported by trucks. And consequently aggregates transportation causes the highest levels of CO_2 and particles emissions in comparison with other stages of aggregate provision (excluding the use of aggregates, where emissions were not calculated) in the three case studies. Thus there is a huge potential in decreasing the negative impact from aggregate provision by decreasing the distances for transportation and changing the modes of transport (as shown in the scenarios 2, 3, 4, see p 50- 51).

Planners (especially on the regional and municipality level) and property developers (in Swedish *byggherrar*) are the most important actors in terms of aggregate transportation, since they make final decisions regarding the location of quarries, terminals and the use of different modes of transport. Authorities on the national level provide guidelines and policy instruments regarding the use of material and waste disposal. Other important groups of stakeholders include: aggregate supply companies, transportation companies, waste management companies, contractors, consultants and R&D institutions.

This study proved that aggregate provision is a very complex process including many environmental, social and economical issues as well as many actors involved. Thus the main recommendations drawn from the study are as following:

- Aggregates should be prioritized in the land use planning (providing strategic areas for localisation of quarries, pits and terminals for transportation) in order to decrease the transport distances. Key stakeholders: *authorities on the regional and municipality level.*
- Need for more transport regulations and increased use of water and rail transport. Key stakeholders: *Authorities on the regional level, property developers, as well as aggregate supply companies.*
- More knowledge is needed on how to manage construction and demolition waste. Key stakeholders: *all stakeholder groups involved in aggregate provision (see p38).*
- Need for standardizations on recycled and secondary aggregates. Key stakeholders: *R&D, authorities on the national level, property developers.*
- Need for better statistics and accounting of aggregate flow in order to enable identification of strategies for the improvement of aggregate provision in the future. Key stakeholders: *authorities on the national, regional and municipal level, property developers.*

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PERSONAL INTERVIEWS

Stockholm

- Jan Bida
  SBMI (Swedish Aggregates Producers Association)
  April-May, 2009

- Björn Frostell
  KTH
  February, 2009

- Erik Karlstrand
  Ragn Sells
  July, 2009

- Per Murén
  NCC Roads (Sweden)
  May, 2009

- Olov Sabell
  Jehander
  May, 2009

- Harald Svensson
  Fortum
  May, 2009

- Lars Åkerblad
  Stockholm Länsstyrelsen (The County Administrative Board of Stockholm)
  April, 2009

Helsinki

- Soile Atos
  GTK (Geological Survey of Finland)
  June, 2009

- Martti Kärkkäinen
  Rudus (Finland)
  May, 2009

- Pia Rämö
  Aggregates Department (INFRA)
  May, 2009

- Kari Ruohonen
  Finnish Rail Administration
  May, 2009

- Hannu Siitonen
  Uusimaa Regional Council (Finland)
  May, 2009

- Juha Uuksulainen
  YTV (Helsinki Metropolitan Area Council)
  May, 2009

Hamburg

- Sebastian Doderer
  Port of Hamburg
  May, 2009

- Bernt Matthes
  Minisrty of Urban Development and Environment
  May-June, 2009

- Thomas Prenzer
  Trade Association of Construction Material in North-West Germany
  May, 2009

- Renate Taugs
  Hamburg Ministry of Urban Development and Environment, Geological Survey of Hamburg
  May, 2009

APPENDICES

Appendix 1

Classification of the construction materials (McNally, 1998)

Cut and broken rock:
- Dimension stone (structural and cladding);
- Breakwater armourstone and rock core;
- Dam rip-rap, embankment slope protection blocks;
- Pitching and beaching stone;
- Ruble, dam rockfill;
- Rock slag.

Coarse crushed rock:
- Course aggregate for concrete and asphaltic concrete;
- Surfacing aggregate (¨chippings¨);
- Railway ballast, macadam pavements and gabion stone;
- Free-draining sub-base, drainage layers;
- Recycled concrete aggregate (RCA) and recycles asphalt (RAP)

Fine crushed rock:
- Prepared road-base and sub-base;
- Processed granular filters;
- Bedding material, grit, crusher dust.

Sand and gravel:
- Crushed and screened river gravel;
- Washed fine aggregate and sand filters;
- Mortar sand (¨fat¨ sand), plastering sand;
- Sand fill, stabilizing grit;
- Granulated slag

Soil materials:
- Brick, tile and pipe clay;
- Natural road-base;
- Stabilized soils;
- Common fill;
- Select fill, sub-ballast; capping layers;
- Pulverized fly ash (PFA) and furnace bottom ash (FBA).

Appendix 2

Chosen indicators for each stage of aggregates flow (grouped by DPSIR framework)

Indicators	Units	DPSIR typology
Material extraction from geological deposits and Quarrying/Processing		
Number of sites granted for aggregate extraction and processing	[number of sites]	P
Export/ import of aggregates from (to) other regions (countries)	[ton]	D
Aggregates price	[SEK/ton]	R/P
Turnover of the aggregate supply industry sector	[SEK/year]	P/S
3. Material use in construction		
Volumes of material used	[Mton]	P
4. Transportation and storage		
Quantity of transported aggregates per mode of transport	[ton/year]	P
Average distances of aggregate transportation (from the quarry to the end-user or landfill)	[km]	R/P
Average distances of aggregate transportation from the quarry to the end-user or landfill by lorries (specified by type of material)	[km]	R/P
Cost of aggregate transportation per mode of transport	[SEK/ton/km]	R/D
5. End-of-life (landfilling, reuse and recycling)		
Landfill cost for inert waste	[SEK/ton]	R/D
Landfill cost for mixed Construction and Demolition Waste (CDW)		R/D
Volumes of the mentioned below types of CDW that is landfilled	[ton/year]	P/R
Volumes of the following types of CDW that is recycled or reused	[ton/year]	R/P
Total volume of produced CDW		P
Total volume of CDW that is landfilled		P/R
Total volume of CDW that is recycled or reused		R/P

Appendix 3

Groups of stakeholders interviewed

Stakeholder	Stockholm	Helsinki	Hamburg
Property owners, Property developers	Kretsloppsrådet	Rudus Oy	
Material suppliers	SBMI (Sveriges byggmaterialindustrier) NCC Roads, Jehander	Aggregates Department; Rudus	Trade association of construction materials
Authorities (building, land and environment)			
National	SGU	GTK (Geological Survey of Sweden) Finnish Rail Administration	Geological Survey of Hamburg
Regional		Uusimaa Regional Council	
County	Länsstyrelsen i Stockholms län		Ministry of Urban Development and Environment in Hamburg
Municipal		Helsinki Metropolitan Area Council	
Transportation companies and organisations	Jehander		Port of Hamburg
Waste management companies	Ragn Sells		

Appendix 4

Inventory data for LCA

Stockholm

	Data	**Data sources, comments**
PRIMARY AGGREGATES		
Extraction from the quarry (processing):		
crushed rock (ton)	5100000	Länsstyrelsen (2009)
natural gravel and sand (ton)	3100000	Länsstyrelsen (2009)
Transportation to the end-user by truck		
Average distances (km):		
sand and gravel	30	Länsstyrelsen (2009)
crushed rock	25	Länsstyrelsen (2009)
Average all types of material (average distance):	25	NCC (2009), SBMI (2009)
Volumes of aggregates transported (ton):	12600000	Own calculations from the received data
Transportation to the end-user by sea		
Average distances (km):	35	Jehander (2009)
Volumes of material (ton):	500 000	Jehander (2009)
Transportation by rail-way		
Average distances (km):	50	*NCC Roads (2009)*
Volumes of material (ton):	300000	*NCC Roads (2009)*
RECYCLED AND OTHER TYPES OF AGGREGATES		
Volumes of recycled aggregates (mainly recycled concrete) (ton):	600 000	Estimated on the basis of NCC (2009)
Other types of aggregates (for instance, after rock blasting during large construction projects or excavation waste)	5 200 000	Länsstyrelsen (2009) and SGU (2007)
Average distances for transportation (km)	25	(Länsstyrelsen, 2009)
END-OF-USE		
Volumes of CDW landfilled (ton)	325 054	SWECO (2008)
Distances for transportation to the landfill (km)	30	*Estimated from finding the average distances to the largest landfills near Stockholm*

Helsinki

	Data	Data sources, comments
PRIMARY AGGREGATES		
Extraction from the quarry (processing):		
crushed rock (ton)	11500000	Kärkkäinen (2009)
natural gravel and sand (ton)	9200000	Kärkkäinen (2009)
Transportation to the end-user by truck		
Average distances (km):		
sand and gravel	40	Mroueh (2000)
crushed rock	15	Kärkkäinen (2009)
All types of primary aggregates (average distance):	30	estimated
Volumes of aggregates transported (ton):	22760000	Own calculations from the data received
Transportation to the end-user by sea		
Average distances (km):	50	Mroueh (2000)
Volumes of material (ton):	200000	Estimated after Kärkkäinen (2009)
Transportation by rail-way		
Average distances (km):	15	Railway Administration (2009)
Volumes of material (ton):	40000	Railway Administration (2009)
RECYCLED AGGREGATES		
Volumes of recycled aggregates	500 000	estimated
Average distances for transportation to the end-user (km)	10	Kärkkäinen (2009)
END-OF-USE		
Volumes of CDW landfilled (ton)	234 936	YTV (2006)
Transportation to the landfill or incineration plant		
distances (km)	30	*Estimated from finding the average distances to the largest landfills near Helsinki*

Hamburg

	Data	**Data sources, comments**
PRIMARY AGGREGATES		
Extraction from the quarry (processing):		
crushed rock (ton)	5400000	Matthes (2006)
natural gravel and sand (ton)	8100000	Matthes (2006)
Transportation to the end-user by truck		
Average distances (km):		
sand and gravel	50	Estimated, based on Geological Survey of Hamburg (2009)
crushed rock	50	
All types of primary aggregates (average distance):	50	
Volumes of material (ton):	12264276	estimated
Transportation to the end-user by sea		
Average distances (km):	700	Estimated from finding the distances to the countries aggregates are imported from (UK, Scandinavia)
Volumes of aggregates transported (ton):	1235724	The Port of Hamburg (2007)
Transportation by rail-way		
Volumes of material (ton):	No data	Assumed, that none aggregates are transported by railway
RECYCLED AND OTHER TYPES OF AGGREGATES		
Volumes of recycled aggregates	1 400 000	Matthes (2006)
Volumes of material refilled (material used for gravel pits backfilling)	2 600 000	Matthes (2006)
Average distances for transportation to the end-user (km)	25	assumed
END-OF-USE		
Volumes of CDW landfilled (ton)	400 000	Matthes (2006)
Transportation to the landfill or incineration plant		
distances (km)	30	estimated

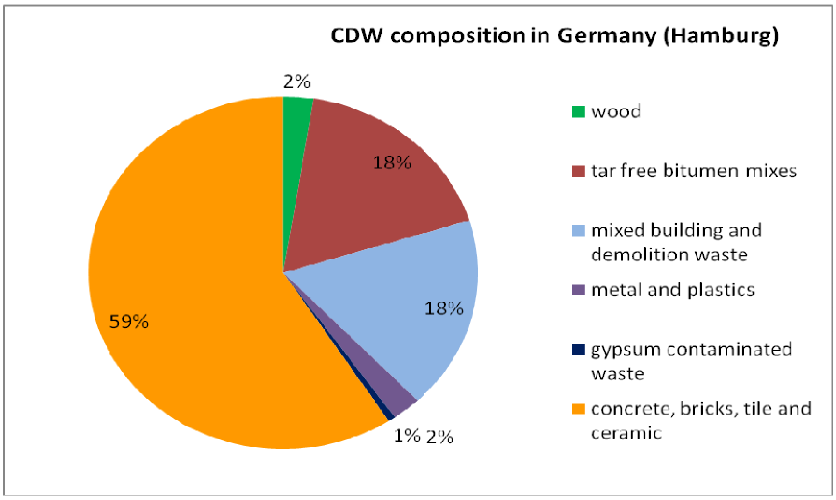
Appendix 5

LCI data

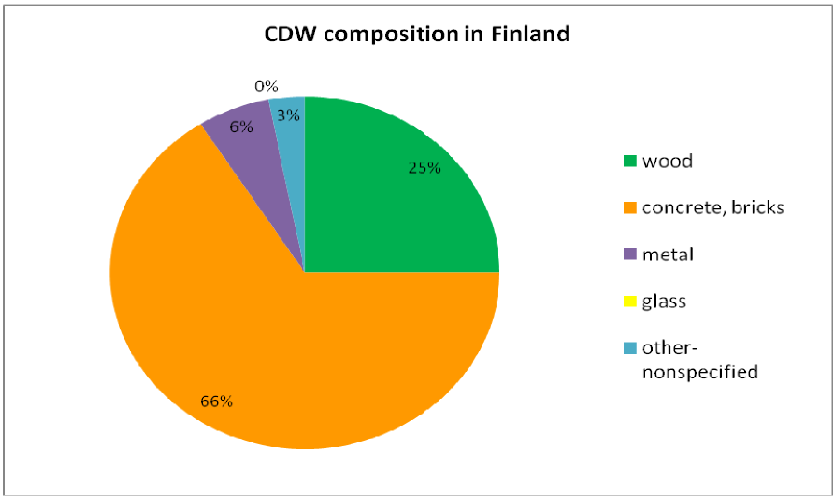
	CO2 eq	Particles	Reference
Extraction from the quarry (processing):			
production of 1 ton of gravel (g/ton)	129,5576	0,0231	Stripple, 1995
production of 1ton of crushed rock (g/ton)	2325,08	0,477	Stripple, 1995
Transportation by truck			
Transportation of all types of aggregates (average value) (g/tonkm)	139,1	0,22	Tillman, 1994 and Fry (2007)
Transportation by sea			
Transportation of all types of aggregates (average value) (g/tonkm)	21,868	0,05	Tillman, 1994 and Fry (2007)
Transportation by rail-way			
Transportation of all types of aggregates (average value) (g/tonkm)	41	*No data*	Fry (2007)
RECYCLED AGGREGATES			
Processing (g/ton)	1118	0,24	Estimated after Iwabuchi, 1996 and Stripple, 1995
END-OF-USE			
Landfilling (g/ton)	355,3846154	0,05075	Estimated after Olsson et al, 2008

Appendix 6

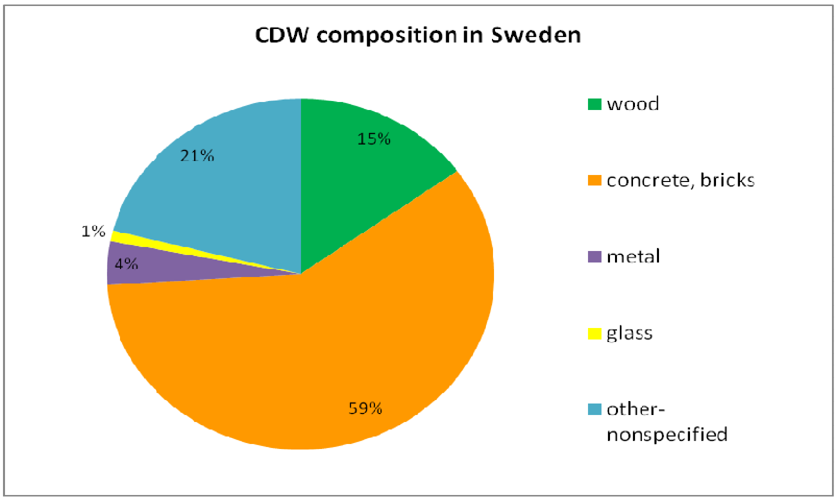
CDW composition and aggregate consumption in Germany, Sweden and Finland



Source: COWAM (2006)



Source: Thormark (2002)



Source: Thormark (2002)

Appendix 7

Questionnaire

A – QUESTIONS ABOUT THE INTERVIEWEE

Organisation_______________________________

Name_____________________________________

Address___________________________________

Title______________________________________

Years of working experience__________________

Tel____

e-mail_____________________________________

Please mark the stakeholder group you belong to.

Please mark the stakeholder group you belong to.

Stakeholder group	Mark the field
Property owners (property developers)	
Authorities	
Material supply company	
Transportation company	
Transport organization	
Contractors	
Consultants	
R&D	
Other, Which?_________________	

B- GENERAL QUESTIONS TO ALL STAKEHOLDERS

1. Which group of stakeholders plays an important role in aggregates provision in your region (respectively each strategic issue)? Give a grade from 1 to 5 (with 5- as the most important)

Stakeholder group	**Land use**	**Transportation**	**Material use (including reuse and recycling)**
Property owners, property developers (byggherrar)			
Authority (controllers, regulators, permission-givers):			
National Level			
County Level			
Municipal Level			
Transportation companies (åkerier)			
Aggregate supply companies			
Contractors (and other end-users of aggregates)			
Consultants			
R&D			
Other?_____________________			

2. Are there any targets set for the decrease of material transportation or the use of other modes of transport in your region?
   a) No
   b) If yes, which ones?____

3. Is aggregate transportation considered in the strategic planning of the city?
   a) No
   b) Yes
   c) Comments:____

C- REGIONAL INDICATOR QUESTIONS

Please answer the questions that are relevant to your field of work.

1. Material extraction from the source (geological deposits, other industrial processes or construction activities)

Indicators	Units	Answer
Area of land granted for aggregate extraction and processing	[ha/capita], [ha/ton]	
Cost of land	[SEK/ha]	
Number of sites granted for aggregate extraction and processing	[number of sites]]	
Export/ import of aggregates from (to) other regions (countries)	[ton]	

2. Quarrying/ Processing

Indicators	Units	Answer
Aggregates price:	[SEK/ton]	
1) natural gravel (0-8 mm)		
2) crushed rock (2-8 mm)		
3) filling material		
4) fly ash from coal powered station		
5) recycled concrete		
Turnover of the aggregate supply industry sector	[SEK/year]	

3. Material use in construction

Indicators	Units	Answer
Volumes of material used	[Mton]	
1) natural gravel and sand		
2) crushed rock		
3) filling material		
4) fly ash from coal powered station		
5) recycled concrete		

4. Transportation and storage

Indicators	**Units**	**Answer**
Quantity of transported aggregates per mode of transport	[ton/year], [%]	
1) lorries:		
a) primary aggregates		
b) secondary and recycled aggregates		
2) sea		
3) rail		
Average distances of aggregate transportation (from the quarry to the end-user or landfill)	[km]	
a) by lorries		
b) by sea		
c) by railways		
Average distances of aggregate transportation from the quarry to the end-user or landfill by lorries (specified by type of material)	[km]	
a) natural sand and gravel		
b) crushed rock		
c) fly ash from coal powered station		
d) recycled concrete		
Cost of aggregate transportation per mode of transport:	[SEK/ton/km]	
1) lorries		
2) sea transport		
3) railway		

5. End-of-life (landfilling, reuse and recycling)

Indicators	**Units**	**Answer**
Landfill cost for inert waste	[SEK/ton]	
Landfill cost for non-hazardous waste	[SEK/ton]	
Landfill cost for hazardous waste		
Landfill cost for mixed Construction and Demolition Waste (CDW)		
Volumes of fly ash from coal powered station that is landfilled	[ton/year]	

Volumes of the mentioned below types of CDW that is landfilled:	[ton/year]	
1) concrete		
2) gravel		
3) masonry		
4) asphalt		
5) other?:_______________		
Volumes of the following types of CDW that is recycled or reused:	[ton/year]	
1) concrete		
2) gravel		
3) masonry		
4) asphalt		
5) other?:_______________		
Total volume of CDW that is landfilled		
Total volume of CDW that is recycled or reused		

D- OPEN QUESTIONS

1. If possible, propose other indicators (not included in the list above) that could measure the sustainability of material supply in your region

i. ____
____
____

ii. ____
____
____

iii. ____
____
____

2. Which problems in your opinion obstruct sustainable material provision in your region?

iv. ____
____
____

v. ____
____
____

vi. ____
____
____

3. Other comments-

____
____
____
____
____