CHALMERS

Evaluation of Recycling & Reuse of Building materials from Demolition: Cost feasibility and environmental impact assessment

A case study of Volvo Office building in Lundby, Gothenburg

Masters of Science Thesis in the Master's Degree Program Infrastructure and Environmental Engineering

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Examensarbete 2016:106/ Institutionen för bygg- och miljöteknik,
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ABSTRACT

The processes of building construction and demolition lead to the generation of unwanted material on site. These materials are commonly referred to as construction and demolition waste. Wastes have a potential negative effect to the environment in form of pollution of land, water and air. In Sweden the total amount of wastes landfilled in 2012 which includes mining and quarrying was 82.6%. From the total generated waste in Sweden, 4.9% is C&D waste where 1.1% of this is landfilled. The recycling rate of C&D wastes in Sweden was 50% in 2010 and the vision by the Swedish environmental protection Agency is to achieve a 70% recycling rate for all generated C&D waste by 2020.

Demolition of a building may be either conventional or selective in nature to attain the specified goal. In principle selective demolition should permit the recovery of a large volume of reusable and recyclable material unlike conventional demolition. It is therefore prudent to assess the environmental impact attributed to the two plans of building demolition as well as the costs involved. The environmental impact was assessed by considering a life cycle assessment perspective of building materials.

The functional unit for our life cycle assessment model involved the demolition of one office building owned by Volvo Trucks Headquarters in Lundby, Gothenburg. It is an eight floor level building with a total floor area of 19,500 m^2. The demolition that was done to remodel and renovate the existing office spaces generated concrete, scrap, wood and plastic materials.

The environmental impact results for the two well defined demolition plans obtained from SimaPro software for five different environmental indicators. The difference between the two demolition plans was showing the gained environmental benefit while choosing the plan with less emissions. By opting for selective demolition the overall result for the whole building was that, Global warming and Acidification had the highest avoided impact and Ozone layer depletion had the lowest avoided impact. In unit terms and with an analysis that is independent of material volume generated, plastic material results in the greatest avoided environmental load when demolished selectively. However concrete has the least environmental avoided impact compared to plastic, wood and steel. In the case of cost estimation for each demolition plan, labour and transportation costs were considered. The result showed that the cost for selective plan was almost double that of conventional demolition plan.

Overall the selective demolition plan is more environmentally friendly although it is the expensive option considering the outlined assumptions. The author also recommends to have a very clear material inventory before and after demolition to facilitate determination of materials suitable for reuse or recycle.

Key words

Sweden, Demolition, C&D waste, reuse & recycle, environmental impact, life cycle assessment

Utvärdering av återvinning och återanvändning av byggnadsmaterial från rivning:

Kostnads genomförbarhet och miljökonsekvensbeskrivning

Examensarbete inom mastersprogrammet, Infrastruktur och miljöteknik

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SAMMANFATTNING

Bygg- och rivningsprocesser leder till alstringen av oönskat material på plats. Dessa material betecknas vanligen som byggnads- och rivningsavfall. Avfall kan ha negativa effekter som kan orsaka på människors hälsa och på miljön, särskilt när det gäller förorening av mark, vatten och luft. Den totala uppkomna avfallsmängden som deponeras år 2012 i Sverige var 82,6%, av detta var mer än hälften någon form av mineralavfall. Från den totala genererade avfallet i Sverige, är 4,9% bygg- och rivningsavfall där 1,1% av detta deponeras. Återvinningsgraden av bygg- och rivningsavfall i Sverige var 50% under 2010 och etappmålet av den Naturvårdsverkets om byggnads- och rivningsavfall är att Insatserna så att återanvändning, materialåtervinning av byggnads- och rivningsavfall är minst 70% senast år 2020.

Rivningen av en byggnad kan utföras som selektiv rivning eller konventionell för att uppnå det angivna målet . I princip selektiv rivning innebär att montera ner byggnaden bit för bit för att möjliggöra återvinning av en stor volym av återanvändbara och återvinningsbart material till skillnad från konventionell rivning. Det är därför klokt att bedöma miljöpåverkan tillskrivas de båda rivningsplanerna samt kostnaderna. Miljöpåverkan bedömdes genom att miljövärderingar görs ur ett livscykelperspektiv.

Den funktionella enheten vi haft för vår livscykelanalys är rivning av en kontorsbyggnad som ägs av Volvo Lastvagnars huvudkontor i Lundby. Det är en åtta våningsplan byggnad med en total yta på 19.500 m2. Rivningen gjordes för att renovera de befintliga kontorsplanen och rapporten fokuserar på betong, skrot, trä och plast material som genererade av rivningsprojekten.

Miljöpåverkansresultat erhålls för båda rivningsplaner från SimaPro programvara för fem olika miljöindikatorer. Skillnaden mellan de två rivningsplanerna visar vunnit miljövinster vid valet av planen med mindre utsläpp. Genom att välja selektiv rivning över konventionella totalresultatet för byggnaden var att Global uppvärmning och försurning hade den högsta undvikas inverkan och uttunning av ozonskiktet hade den lägsta undvikas inverkan. En analys är gjordes oberoende av materielmängden på enhet sikt vilket visas plastmaterial resulterar i största undvikas miljöbelastningen när den revs selektivt. Resultaten från studien visar att betongen har det minst undvikas miljöbelastningen jämfört med andra l. Bedömningar om kostnad för både alternativ har gjorts där det arbets- och transportkostnader som övervägdes. Resultatet visade att kostnaden för selektiv plan var nästan dubbelt så vanlig rivningsplan.

Övergripande den selektiva rivningsplanen är mer miljövänligt även om det är det dyrt alternativ med tanke på de beskrivna antagandena. Författaren rekommenderar också att göra en fullständig materialinventering innan och efter rivning börjar för att underlätta bestämningen av material som är lämpliga för återanvändning eller recirkulering.

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List of abbreviations

LCA	Life Cycle Assessment
CFC	Chloro fluoro-carbon
C&D W	Construction and Demolition Waste
CO_2	Carbon dioxide
EPA	Environmental Protection Agency
EU	European Union
CML	Center of Environmental Science of Leiden University
BREEAM	Building Research Establishment Environmental Assessment Methodology
LEED	Leadership in Energy and Environmental Design
PO_4	Phosphate
Sb	Antimony
SO_2	Sulfur dioxide

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1 Introduction

There is large amount of construction and demolition waste which end up in landfills and energy recovery via incineration as the common treatment. According to Eurostat 2012, the total amount of wastes landfilled which includes mining and quarrying from Sweden, Denmark & Netherlands was 82.6%, 19.0% and 39.7% respectively. However, with regard to only C&D wastes there are more resource efficient ways that can be implemented to achieve the Swedish target of 70% weight recycling of C&D waste by 2020 from the estimated 50% in 2010 (EPA, 2012). Inadequacy of waste data at the present makes it hard to estimate precisely the amount of waste and in turn the potential environmental and economic benefits from reused and recycled material. Therefore, the Swedish Environment Protection Agency made strict objectives which should be achieved in the near future such as apt waste data management and zero landfill target in some waste generation areas. At such a point, it is important to evaluate the environmental impact and cost feasibility of secondary material as opposed to primary ones. The materials extracted from nature and used in a production process for the first time are referred to as primary materials. Secondary materials however, are materials that have been used before and are used again in a new production process. Therefore, replacing primary materials with secondary materials saves natural resources depletion (Eijk & Brouwers, 2002). The environmental effects of producing building materials from the cradle to the grave can be determined by life cycle assessment (LCA), which gives a complete overview on how different stages of production may affect the whole process. Where the prospect of recycling and reuse of building materials influences the design process and the circulation of materials, the role of waste products and the selected technology becomes important. Governments worldwide have responded to the need to reduce waste with regulation and legislation that have framed a market for building materials and products derived from the construction and demolition (C&D) waste stream (CIB, 2014). Efficient use of waste may make profits and also improve environmental outcomes by extracting valuable resources from the C&D waste stream which in turn responds to the challenges of environmental sustainability.

1.1Problem statement

Demolition is the process of tearing down a building to serve the necessary demands. Demolition of buildings and large infrastructures pose significant environmental concerns to property managers and the general public. Typically, demolition activities yield large volumes of waste and if this is poorly planned and managed, enormous volumes of waste end up at the lower steps in the waste hierarchy as shown in Fig. 1. Reduction of waste has the potential to reduce environmental impact, to improve social welfare and to cut costs related to waste handling. All these ensure the future generation's access to resources is protected. It is therefore imperative to study and develop better construction & demolition waste management schemes.

1.2Objectives

The main objective of the Master thesis is to evaluate the viability of recycling and reuse of demolished building materials with regard to their environmental impact and cost efficiency. The specific objectives of this study are;

- To establish which materials are suited for reuse or recycle.
- To determine the amount of recyclable and reusable waste from the demolition.
- Recommend best demolition practices for the future

1.3Scope of the study

This study focuses on demolition waste materials that were generated from the demolition due to renovation and makeover of an office building owned by Volvo Trucks Headquarters (VLH) in Lundby, Gothenburg, Sweden. The comparison of two demolition alternatives to assess the environmental impacts will be studied from a life cycle assessment perspective. Cost feasibility shall be assessed by considering unit rates for transportation, labour & equipment costs that were used during the demolition process.

2 Background

2.1 Waste

There are many definitions of waste in the world today. According to the Swedish Ordinance of waste (SFS 2011: 927), Waste is composed of combustible waste, hazardous waste and organic waste. Also, according to the Swedish Environmental Code (1998:808) chapter 15, Waste is referred to as "any object or substance that the holder discards or intends or is obliged to discard". Waste is usually unwanted material realized after a completion of a specific process. These may include packaging and excess material among other things.

2.1.1 Waste hierarchy

The EU Waste directive which came into play in 2008 aimed to achieve greater resource efficiency. A waste hierarchy (see Fig1) designed to help member states promote better resource utilization and in turn reduce environmental impact (EPA, 2012).

Reduce	1 Changing our behaviour
Reuse	2 Reusing material
Recycle	3 Recycling and reprocessing material
Recover	4 Recovering energy
Landfill	5 Targeting Zero Landfill

Figure 1: Waste hierarchy

According to Fig. 1, the best way for waste reduction is through behavior change and this may be achieved by the way we design and produce products. Purchasing is also an important step to consider when the aim is to reduce, setting the right requirement during procurement could influence the amount of waste to a large extent. Reuse is attributed to the use of specific manufactured material as second hand. Recycling of material means transforming waste into new products while recovery entails the use of waste to generate energy. The last stage is where disposal of completely non-recyclable waste into landfills.

2.1.2 Construction and demolition waste

Demolition waste is attained after pulling down an infrastructure project. The wrecked reinforced concrete, bricks, plaster, tiles, cardboards, timber sections etc. form an agglomeration what is referred to as demolition waste in this case. Construction waste on the other hand is surplus undesirable material resulting from completion of a construction activity. Excess mortar, broken tiles, broken formwork, wires, material packaging and many others fall in this category.

2.2 Recycling and Re-use

Recycling today is a solid waste management strategy that is in the same way valuable as both landfilling and incineration but more environmentally desirable (Lund, 2001). Recycling reduces pressure on land which is a big requirement for setting up of landfills. The energy required also for incineration is cut through recycling strategies. In these modern days where resource efficiency has taken root, recycling advancements help to promote the use of secondary materials while preserving the primary resource. Unlike recycling which requires reprocessing in a factory, reuse of material after demolition takes immediate effect and equitable reuse is affected by the method employed during demolition.

2.2.1 Drivers & barriers to increase recycling

Appropriate C&D waste recycling is generally influenced by many factors. Public perception and acceptance also varies a lot amongst the different stakeholders. For instance one of the barriers to recycling in Germany is the lack of laws that are related to reduction of landfilling of recyclable C&D waste (CIB, 2014). Table 1 further illustrates additional drivers and barriers to equitable recycling.

Table 1: Drivers & Barriers to increase recycling (Deloitte, 2014)

Factors	Drivers	Barriers
Legislations&EU recovery targets (source - ENCORT report (Arm et al., 2014)		The EU recovery targets prefer recycling of high density waste types while the largest impact to the environment might be caused by other wastes. They also do not consider the most sustainable recovery operations.
Resources allocated to CDW legislation enforcement		Resources needed for supervision by the authorities are limited.
Definitions and statistical data		Data on CDW generated for reuse is inadequate. Collection of CDW data is a challenge and new methods should be applied
Works contracts	Involvement of several stakeholders in the planning phase of works enables efficient recycling.	Having many stakeholders leads to challenges for waste prevention and also variations in waste streams make recycling hard in practice.
Recycling process and techniques	Effective logistics management enables cost	
Quality		Lack of quality control guidelines for CDW and data on technical properties of waste is lacking. New constructions also demand strict quality control standards. Hazardous substances in CDW also make recycling unfavorable.
Regional aspects		The quantity of waste in sparsely populated regions is usually not worthy for advanced recycling. On-site sorting in cities is difficult due to limited space.
Sorting	Landfill regulations on waste promotes sorting of waste. During recycling, it is cheaper to deal with pre- sorted waste as opposed to mixed waste.	Sorting costs much as compared to combustion (ref. SEPA 2015, Regeringsuppdrag). The restricted availability of offsite equipment makes onsite sorting more efficient.
Typology	The type of building defines the amount of waste to be	

2.3 Waste in Sweden

Waste management in Sweden functions relatively well (EPA, 2012). Regarding material and energy recovery, Sweden is one of the leading countries in the EU in recent decades. The EU's waste hierarchy is applied by Sweden to promote a sustainable development within waste management which will increase resource efficiency. As illustrated by the hierarchy (see Fig. 1), five preferred steps are in following order: waste prevention, preparation for reuse, recycling, other use e.g. energy recovery and landfill. By 2012 there were 184 landfills in operation in Sweden and of these 46 were for hazardous waste, 108 for non-hazardous waste and 30 were for inert waste. With regard to the Swedish EPA, the five areas that became prioritized for improvements in resource efficiency and environmental impacts are: construction and demolition sector, household waste, resource efficiency in the food-chain, waste treatment and illegal export of waste. A study in the Royal Institute of Technology shows considerable potential to increase recycling in the prioritized areas (Ambell C, 2010). The construction and demolition waste, household waste and resource efficiency in the food-chain are the most critical sectors that need to be considered in order to increase resource efficiency. The Swedish Environmental Research (IVL) assessment also shows that construction waste and household waste are the sectors which generate the largest greenhouse emissions in their different life cycle stages. Therefore, preventing, recycling and reuse of this sort of waste will increase the potential of environmental benefits (Sundqvist Jan-Olov, 2010).

2.3.1 CDW generation

In Sweden CDW data compiled by the Swedish EPA every even year. Data collected by this agency is realized from three major ways; 1. Waste factors which are attached to definite waste types as a function of the construction waste area, 2. Information from construction and demolition companies waste estimates and turn over number and 3. From environmental reports of waste recycling companies.

2.3.2 Hierarchical state of Waste today

Due to data deficiency on various categories of waste, an overview on waste treatment statistics should be clearly documented. The wastes which are known as recyclable waste and their concomitant Euro-base codes are as follow: ferrous metal waste (W061), non-ferrous metal waste (W062), mixed metal waste (W063), glass waste (W071), paper and cardboard waste (W072), rubber waste (W073), plastic waste (W074), wood waste (W075), textile waste (W076). In 2012, the summation of all type of wastes treated in Sweden reported some 151 million tones which includes imported/exported waste.

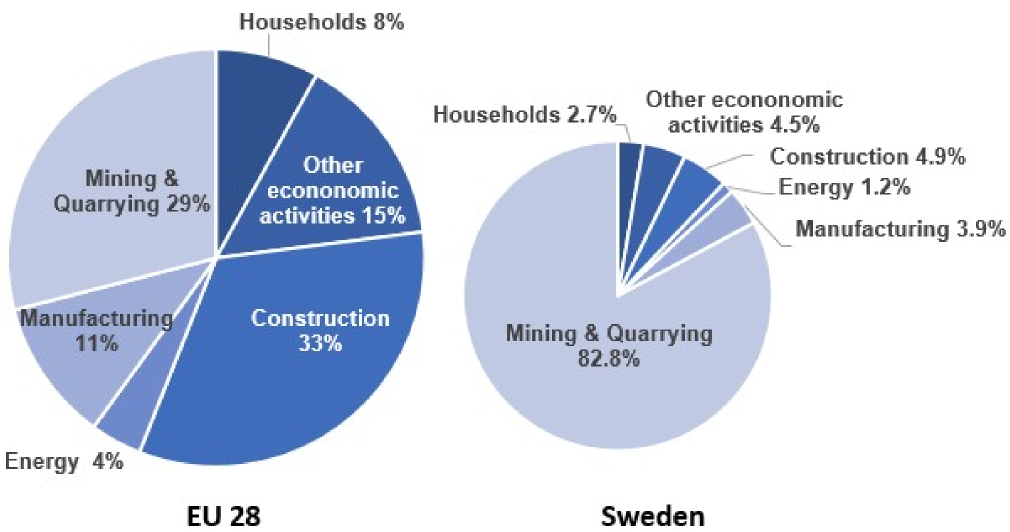

Figure 2: Total generated waste in EU-28 vs. Sweden (2012)

The annual percentages of the different types of waste treatment operations in Sweden employed were: 12.4% recycled, 4.4% energy recovered, 0.5% backfilling actions, 0.03% incinerated and 82.6% landfilled. However, it is not reasonable to generalize these statistics on applied C&D waste treatments since the type of wastes differ in various waste categories (eurostat, 2015).

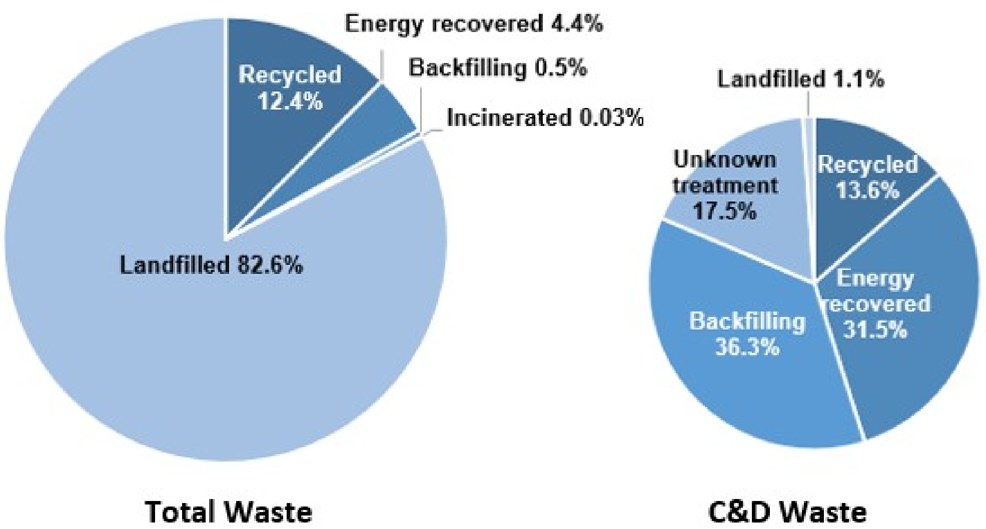

Figure 3: Waste treatment in Sweden

2.3.3 Concrete, Wood & Steel wastes

With the present technology, concrete cannot be made 100 percent by recycling old concrete. This is because new cement is always required for new concrete, as well the existing regulations and strict demand on physical properties for some structural concrete make this unpractical (WBCSD, 2009). It should also be noted that concrete is typically crushed to produce recycled concrete aggregate. In Sweden, it is estimated to realize 70% production of Recycled Concrete Aggregate by 2010. In turn it would be used as: 3% on the bound applications as aggregate for new concrete, 92% on the unbound applications below ground such as road base, backfill etc. and 5% to be used above ground for unbound uses such as road surface (Engelsen, 2005).Most of the used wooden material in the EU are used for energy recovery or used as virgin material in manufacturing primary materials. In Sweden, 90% of recovered wood is used for energy recovery while in France most of recovered wood is used as virgin material for processing new wooden products such as fiberboards (Muthu, 2015). There is no accurate data on wood waste fraction in C&D sector. According to the total market volume of wood, the recovery rate is estimated at 22.3% in the EUs which is 9.2% on material recovery and 12.1% on energy recovery (Mantau, 2012). With regard to steel however, typically the greatest amount of recovered materials and used as scrap in new steel production process. Krogh et al. (2001) states that in Sweden scrap steel are a base material in new concrete reinforcement bars production. The Green Building Council of Australia in 2010 reported a 90% recycling rate on steel scraps generated from C&D (Muthu, 2015).

2.4 Stakeholders’ responsibilities

There is a serious risk of doubling the amount of waste over the next 20 years if strong waste management measures are not taken into account (Östlund, Naturvårdsverket, 2015). Both individuals and collectives are responsible to ensure that produced waste are handled according to the available regulations. For individuals, it is about sorting the waste and leaving it in the right place while the waste holder determines the treatment method except household waste where the municipalities take responsibility. The industry, producer, contractors, importer and similar stakeholders are responsible for establishing and operating a management system for their discarded products and a determined percentage of waste must be recycled. The manufacturers decide on product fees which also includes costs for collection and recycling the product. It is a mandatory responsibility of the producers of electronic goods, cars, packaging, newspaper and tyres to manage such waste that may result from them. Moreover, there are some voluntary agreements for office paper, building and demolition waste and farming plastics (Östlund, Swedish Environmental Protection Agency, 2011).

There are several organizations with different levels of responsibility and are categorized as below:

- Municipalities: they are responsible for drafting the management plan, collection and treatment of household waste which excludes producer waste. This is financed by property owners’ paid fees.
- County administrative board: county board gives permission for most operation and doing supervisory work. For instance, providing an exemption for the disposal of organic waste, monitoring the issue related to regional environment and facilities for biological treatment.

- Environmental courts: Issue permit for large landfilled and treatment plant, licensing of major businesses and cases related to hazardous activities.
- Environmental protection agency: It is the main environmental authority. Developing regulation and guidelines as well supporting the government in EU activities are part of their responsibility. In general, ensures that waste management is environmentally and socially acceptable.
- Industry and initiatives: Producers are responsible for handling their product waste on free market.

2.4.1 C&D waste management

The Swedish Environmental Protection Agency points towards preparation for reuse and recycling of construction and demolition waste by 2020 and must be at least 70 percent by weight (EPA, 2012).

Sweden generates about 156 million tons of waste every year according to EU's statistics in 2012.

After rock and other mine debris which has three quarters of total waste, the construction sector is second with the most generated waste (eurostat, 2015). These statistics show that EU's prioritization on preventing, preparing for reuse and recycling in construction and demolition sectors may possibly help gain considerable environmental benefits. In order to increase reuse and recycling of construction and demolition waste, well separation and sorting is essential. Therefore, a clear material inventory used in the construction of a building will play an important role in the demolition project. An improved building inventory (as may be illustrated from the building Typology & statistical data shown in Table 1) will facilitate identifying reusable and recyclable materials and also estimate the possible hazardous waste.

There is a conflict between total generated waste and treated waste statistics which might be due to inadequate data sets that means it is not possible to say precisely how far Sweden is from EU's reuse and recycling objectives.

Therefore, the Swedish Environmental Protection Agency is continuously working on improving statistics on construction and demolition waste, as well as working on developing cooperation between involved organization in this area such as property owner, developer and construction contractor, demolition enterprises, recycling industry, national board of housing and etc.

2.4.2 Green building concepts

According to the EPA (Environmental & Human Health, 2010) the concept of green building is a way of creating structures and using processes that are environmentally friendly and resource-efficient. It considers all aspects from, site selection, design, construction, operation, maintenance, renovation and deconstruction. All green building standards and systems enable the stakeholders and property managers to plan for resource reuse and recycling better.
BREEAM (BREEAM, 2015) and LEED (Environmental & Human Health, 2010)are the most broadly accepted environmental certification methods in the construction field (A. Rezaalla, 2014). Such tools enable designers to study environmental aspects in their considerations

during the design phase. It is usually at such a point in time that aspects of resource allocation, improved construction efficiency, future sustainable demolition and future reuse are taken into account.

The BASTA system comes in to regulate hazardous waste material to the environment. It is a system that leans more to sustainable buildings while controlling the use of harmful substances. Knowledge of the Chemical content in the construction materials is therefore important. According to the EU, there are more than 45,000 chemical substances used in construction across Europe and about 35% of these chemicals are regarded as dangerous to both human health & the environment (Gerth, 2006). The EU construction industry also employs about 11 million people and these are easily exposed to such dangerous substances. Such elements have gross effects which may be carcinogenic, bio-accumulative, mutagenic, and allergenic and many more implications. Therefore a known data base for buildings will ensure effective management of generate waste during construction and demolition.

2.5 Market for re-use and recycled material

Construction material accounts for more than 50% of all extracted virgin material worldwide. Recycling and re-using materials from demolished construction will make less waste and reduce the use of virgin material. But the trend to re-use in construction sectors is not high compared to other sectors (EU commission, 2014). Potential demand for recycled and re-use of material is determined by price and the quality of secondary material which differs in different applications of secondary material by time and location (Zhaoa, 2010).

In Sweden the construction sectors' waste was estimated to be 7.6 million tons during 2012 and of this 6.3 million tons is estimated to be excavated materials. The remaining 1.3 million tons of waste includes material such as, concrete, bricks, gypsum, wood, glass, metals, plastic, asbestos, etc. By improving the present rate of recycling and reuse of non-excavated construction waste from 50% to 70% by 2020, the need for analyzing market for secondary material is essential.

There some established companies in Sweden such as Kompanjonen (KOMPANJONEN, 2016) and Kretsloppsparken (Återbruket Begagnat bygmaterial, 2016)that deal with the selling of second hand construction materials for reuse.

2.5.1 Design disputes

In the case of re-use of building parts, it is not easy to say whether it is environmentally good or not even whether if it is competitive with the primary one in economic aspects. For instance, the toilets removed from a building in a developed country when sent to poor countries for re-use is not beneficial due to larger amount of water usage in each flush for such toilets as compared to new efficient ones that will be replaced in the modern country and also putting the water scarcity problems in the poor countries into context. So importing the secondary material and finding the market beyond the borders without a detailed environmental and cost assessment is not the best solution. Another example is when re-using building materials such as brick which needs high amount of labor resulting in high costs. It is therefore necessary to use an appropriate indicator to evaluate the environmental gain in contrast with the required costs.

2.5.2 Market challenges

The transport and landfill cost under the cover of environmental awareness is a strong driving force to improve utilization of generated waste. On the other hand, the quality criteria which requires the authorities' permit for re-use and recycling of waste have difficulties such as long waiting time to get response. Also, problems of handling waste during waiting time like that of lack of temporary storage facilities may lead to disposal even when the waste has re-use or recycling potential. With regard to price and quality, if the recycling technology does not fulfill the desired requirements to achieve better environmentally benefits, the use of secondary material will not have good market.

At present, there is no accurate statistics on generated construction and demolition waste and the potential supply of recycled and re-useable parts to have a good price estimation on the secondary material. It should also be noted that the abundant resource of high quality rock in Sweden creates a difficult market condition for secondary material with regard to quality of construction and demolition waste which may create environmental drawbacks due to recycling into low-grade applications instead of high-grade applications without effecting the indicated objectives by 2020 (SIMM-Center, 2014).

2.6 Life cycle assessment methodology

The notion of LCA is typically applied to a complete manufactured product. It entails the following up of a product from the cradle, where the raw materials are extracted from nature to its production, then to its eventual use and finally to its grave (disposal), (Tillman, 2004). Figure 4 clearly outlines key processes in environmental LCA that contribute on natural resource depletion and on pollutant emissions to the environment.

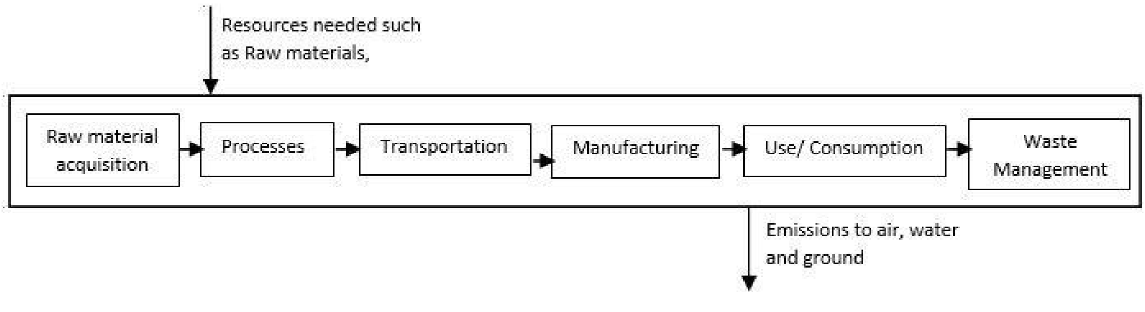

Figure 4: LCA model (Adapted from: (Tillman, 2004))

It must also be noted that the LCA model as described in Figure 4 is simplistic. LCA is described as a comprehensive procedure that sets out in detail how studies are done and interpreted (Tillman, 2004). As illustrated in Figure 5 the objective and scope definitions of the study must be known. Inventory analysis necessitates the computation of emissions produced and all the resources used throughout the life cycle. The impact assessment stage involves the categorization of emissions and resources to specific environmental setbacks and the last step is to weigh all the environmental impacts on a similar scale.

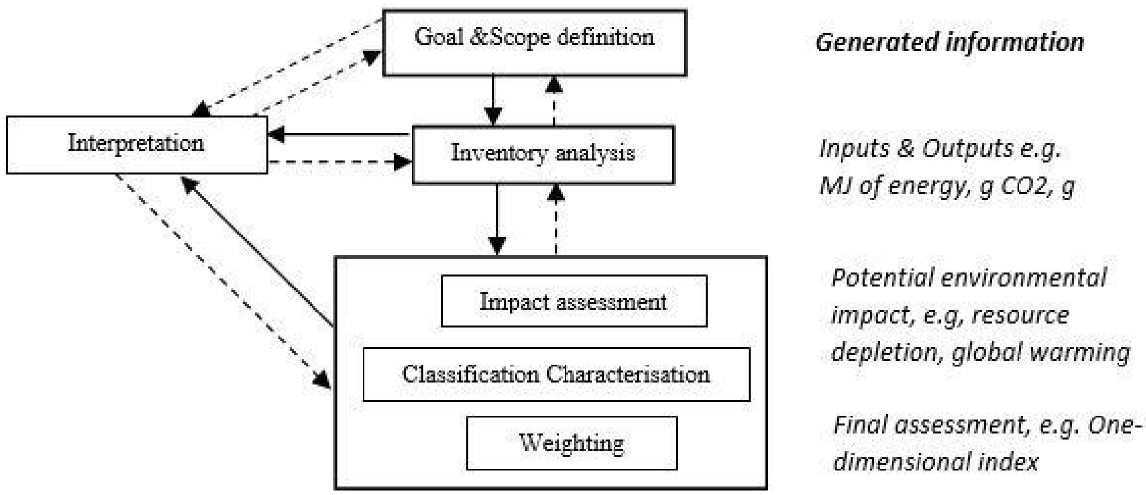

Figure 5: The LCA Procedure (Adapted from (Tillman, 2004))

2.7 Environmental impact indicators

The following environmental impact categories are addressed by the LCA model from the Center of Environmental Science of Leiden University (CML). Abiotic depletion, global warming, ozone layer depletion, human toxicity, fresh water aquatic Eco-toxicity, marine aquatic Eco-toxicity, terrestrial eco-toxicity, photochemical oxidant, acidification and eutrophication. The availability of data sets in each category and direct effect of them to the environment lead to choose following indicator to focus on which will give a better understanding of the direct impacts on the environment and health issues in demolition projects:

- Abiotic depletion
- Global warming
- Ozone layer depletion
- Acidification
- Eutrophication

3 Demolition scenarios

Buildings are usually demolished by either selective or conventional demolition plans. In this study the demolition of the building is studied from a life cycle perspective considering these two alternatives.

Table 2: Comparison of the two alternatives

Demolition option	Implementation	Materials generated
Alternative 1: **Selective Demolition**	• Less energy resources – *More specialized equipment needed* • More labour – *Increased costs* • Onsite sorting • May require more transportation trips • More time needed • Needs more space for different bins • Need more project planning, training and information • Need specific competence	• Re-usable & Recyclable materials
Alternative 2: **Conventional Demolition**	• Extensive Energy resources – *Cranes, Explosives, Loaders etc.* • Less Labour • Less demolition time required • Limited onsite sorting • Less transportation trips • More landfilling	• Recyclable materials • Combustible materials • Waste

3.1 System boundaries

In the production of demolition waste, the major factors that directly contribute to environmental impacts and cost are demolition energy & transportation. Labour cost shall be applied in the cost estimation. The LCA methodology typically considers assessment of products from the cradle to the grave but in our case we assumed that the materials are already available at the demolition site. In this case the product cycle analysis shall be conducted from the demolition site to user as described in sections 3.1 and 3.2 and also represented in Figure 6 and 7 below.

3.2 Scenario 1 - Selective method

Selective demolition involves deconstructing the building to salvage of re-usable materials as much as possible and recycling the materials that are not profitable to be re-used (see, Table 2). This leads to a decrease in landfilling which is a waste hierarchy's strategy. The following deconstruction steps in practice for a selective demolition as demonstrated by Chini and Bruenig (2003) shall be applied.

1. Put out doors & windows frames
2. Remove kitchen fittings, pipe materials, windows and doors
3. Take off floor and wall plaster, wiring and pipes
4. Put down the roof
5. Teardown the walls and floors, story by story

The building materials that can be re-used in selective demolition as identified in Section 5.3, which were carefully dismantled without breaking are sold off to retailers. After selective removal of reusable products, this building is demolished and treated in the same way as in the conventional alternative.

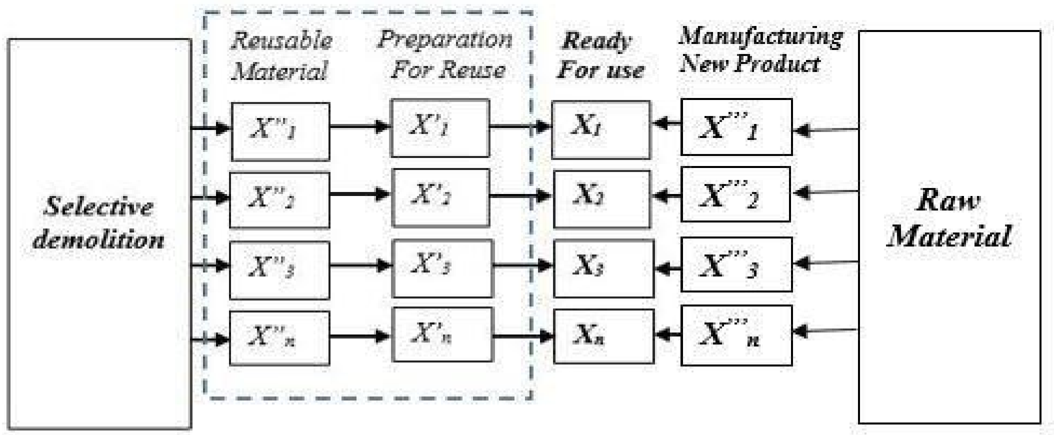

Figure 6: Selective demolition plan

From Right to Left we show and highlight the production of primary materials through manufacturing processes (Cradle to use). From the Left however we illustrate the scenario for production of secondary materials. The processes that will be described in the model shall consider production of ready to use materials as shown from Left to Right (Demolition to use). In this scenario reusable materials are carefully dismantled during the demolition process and transported to the user. The demolition energy needed to tear down the building is in form of materials/fuel or electricity/heat that is used to take out and prepare products for reuse. The transportation mode or distribution to the next site for reuse is as well considered.

3.3 Scenario 2 – Conventional method

In the conventional method, heavy equipment, hand tools, explosion, etc. are used to bring down the building (see, Table 2). At the demolition site mostly without prior disassembly, materials are sorted in different fractions such as wood, steel and inert material for recycling, energy recovery and landfilling.

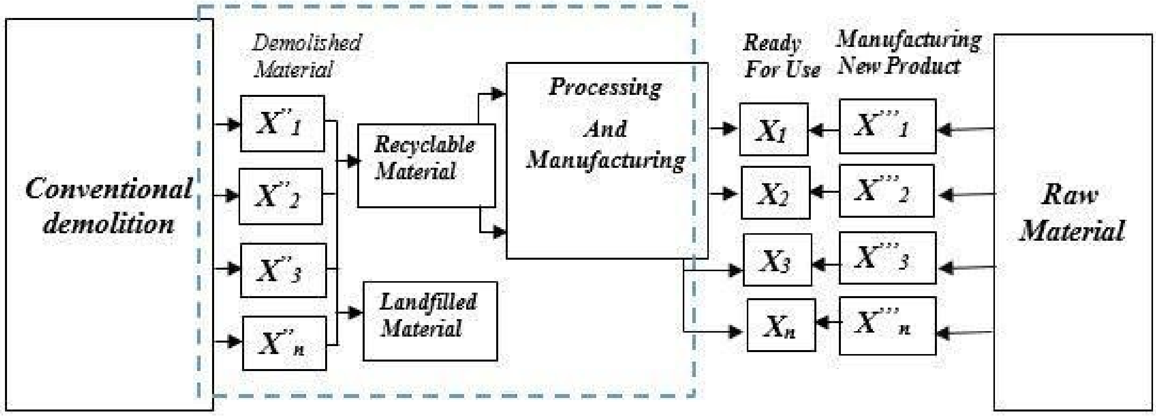

Figure 7: Conventional demolition plan

In this case demolition energy is needed to bring down the building. Collected materials are sorted and the recyclable materials transported to recycling plant for processing to produce new products (Demolition to Recycling to Use).In the case where the recycling process does not provide the same product the model will be adjusted to the production of primary product (Left to Right). For instance, wooden waste material is assumed to have no possibility to be recycled into the very product it has been before demolition. In this situation the production of the new wooden product will be modeled from raw material to estimate avoided environmental impact that is gained from reuse

4 Methods

In this chapter the method that will be used to assess the environmental impacts and cost feasibility is described.

4.1 Environmental impact assessment

The SIMA Pro model shall be uses to assess the environmental impacts from the two proposed demolition scenarios. The software uses Ecoinvent database for the Life cycle inventory data and the characterization method that will be used is CML-IA baseline version 3.02 (EU25). SIMA Pro seeks to interpret data by clearly defining the goal, scope and the inventory. Inputs and outputs are used to build the model by choosing relevant processes and product stages to simulate to real situation. In this case selective and conventional demolition plans of specific materials are analyzed. The inputs are in two main categories which are from nature (resources) and from the technosphere and these are inform of materials/fuels and heat/electricity. The outputs however are emissions to air, water and soil (see Fig. 8). The eventual effect of these emissions in form of Abiotic depletion, Global warming, Ozone layer depletion, Acidification, Eutrophication is studied

.

Figure 8: LCA Conceptual model in SIMAPro

4.2 Cost assessment

Unit rates for demolition equipment costs, labour costs & transportation of materials shall be used to compare the costs incurred with the two scenarios. The calculations will be done in Excel.

Table 3: Considered factors for cost analysis

	Scenario 1- Selective	**Scenario 2 - Conventional**
Demolition equipment	Loader Hydraulic drill Hand	Loader Hydraulic drill
Labour	Skilled worker Unskilled	Skilled worker Unskilled
Transport	Transport to User	Transport to recycling plant

5 Case study

The case study is an office building owned by Volvo Trucks Headquarters (VLH). It is a high rise eight (8) level building with a total area of 19,500 square meters located in Lundby, Gothenburg, Sweden. It was constructed from 1982 to 1987. The structure is supported by concrete columns, beams and slabs with inner wall partitioning. The purpose of the demolition was to remodel the existing office space to suit the new use of accommodating Volvo Group Headquarters' staff.

Figure 9: VLH Office building

5.1 Goal & Functional unit

The function unit is demolition of interior fixtures & partitions of one office building. The goal is to compare the environmental and cost benefits of demolition by either selective or conventional demolition.

5.2 Material inventory

Table 4 shows the materials that were generated during the demolition process which were adapted from a demolition inventory received on 7 March 2016.

Table 4: Demolished material inventory

No.	Material	Amount
1	Mixed waste (Concrete, wood, plastic)	733.63 Ton
2	Wood	28.78 Ton
3	Combustibles (Plastic, paper & softwood)	12.65 Ton
4	Scrap (Steel)	138.82 Ton
5	Fluorescent	725 kg
6	Bulbs	59 kg
7	Smoke detectors	23 kg

These materials were demolished from the floor, ceiling and partitioning elements of the building. However it is important to identify the type of material that the interior part is made of to locate the specific categories they belonged for consideration in our classification and to facilitate simulation in the software. Floor materials for example comprised of timber floors, cement tiles, Plastic (Vinyl) floors and Linoleum floor.

5.3 Material Reuse potential

It was assumed that since the case study building was more than 30 years old at the time of demolition and yet still functioning, it must have undergone a series of periodic maintenance. Therefore the recovered materials from the demolition had some potential for reuse as a result of this. From the received demolished building material inventory data, there were materials that are beneficial for immediate reuse while some others can be recycled and put to some other use. The prevailing condition of the product, method employed for the demolition and market availability greatly affect the reuse potential of demolished building products. For instance, since it is difficult to reuse wood and plastic materials after conventional demolition the best option is to recycle such materials for the production of other materials.

- **Fluorescent tubes & Bulbs**

There were 725 kilograms of fluorescent tubes and 59 kilograms of bulbs recovered from the demolition site. Considering that all were in good condition and if carefully dismantled selectively all these can be reused on another site or sold off to a new user.

- **Fluorescent fittings and Lamp holders**

All fluorescent fittings and lamp holders if there are in good condition do not need to go to waste. These at the time of demolition can be selectively removed and reused. It must be noted that such fittings are typically changed from time to time during periodic building maintenances to meet the prevailing market demands. Identifying market for these fittings would generate extra revenue for the owner.

- **Wood floors & Painted wood partitions**

This fraction of material included 28.78 tons of wood recovered. Most of this came from wooden flooring and wall partitioning. Reuse of wood floors is not an option considering the age of the building. It may also not be possible to dismantle timber wall partitions and be able to reuse them. These materials may however be recycled to produce new wood based materials such as fiberboards & panel boards.

- **Soft boards and paper**

Most of these were generated from acoustic ceiling materials. This is fraction 40% of the combustibles bringing the weight to 5.1 tons. When in good condition these ceiling boards may be reused but may be considered for energy recovery in heat generation plants.

- **Plastic and Linoleum flooring materials**

81 tons of plastics were recovered from mixed waste and combustibles. Plastic materials were generated from floor materials and most specifically from plastic mats & Vinyl floors. Recycling of plastic materials may also be undertaken to produce different plastic materials. Incineration for production of energy may not be the best option since such synthetics give off harm full toxins to the environment.

Linoleum flooring formed the largest part of flooring materials with over 80 % of the floor material. It may also be reused as flooring in smaller house projects. Energy may be obtained from incinerating these materials.

- **Scrap Recycled to Other steel products**

About 138 tons of steel overall were recovered. Scrap metal products were recovered from different fixtures points in the building. Some we recovered from ceilings, stairways, doors and balustrades. Reuse of steel parts is possible with selective demolition but for a case of conventional demolition steel is treated as scrap and may be recycled to produce the same desired materials.

- **Concrete & Gypsum Recycled to backfilling materials & aggregates**

From 733.63 tons of mixed waste, over 90% belonged to this category. This resulted into 660.3 tons of concrete material. These materials were produced from demolition of partitioning walls, work tops, staircases and screed material. Much of this may be used as backfilling material. Careful recycling of this material may result in the production of both fine and course aggregates.

6 Data Analysis and Results

6.1 Introduction

Accurate data input in the software plays a significant role for the purpose of obtaining reasonable results. During the demolition phase, demolition work encountered was in form of the demolition equipment used. The amount demolished is given in volume, area or linear meters and this calls for the conversion of these units to weight units.
In the case where a process or production step required a specific energy input during the analysis, the required energy demand was assumed as shown in Table 5 below. For instance the production of 1 ton of steel from scrap required 2800kWh of electricity.
Table 5 shows the amount of energy required for the Production of 1 kg new materials. (LowTech-Magazine, 2016)

Table 5: Production energy for new materials

Material	Energy required	Energy required (KWh)[1MJ = 277.77 Wh]
Wood (from standing Timber)	5	1.4
Steel from Iron	35	9.7
Steel (from Recycled Steel)	10	2.8

**Plastics production 1kg requires1.3kwh* (Nobuhiko Narita, 2002)

6.1.2 Concrete

In the selective plan, it is assumed that concrete is carefully demolished and applied for other use while in the conventional plan it is assumed that the same amount of concrete is demolished and 50% of it is used to produce new concrete aggregates. The remaining half of the required aggregates is produced from virgin material.

6.1.3 Steel

In the selective plan, all dismantled steel products are carefully assembles and reused. In the conventional plan however, recovered scrap materials are recycled in a steel processing plant for the production of new materials.

6.1.4 Wood

The demolished wood in the selective plan is assumed to be demolished carefully with electric hand tools and directly transported to be reused. While in the conventional plan, in the production of a new product we assume that 50% of the material comes from recycled demolished material and the other 50% from virgin material.

6.1.5 Plastics

In the selective plan it is assumed that the plastic materials are carefully deconstructed and transported to be reused. While in the conventional plan it is assumed that all recovered plastic material are recycled to produce new material.

6.2 Data Input in SimaPro

Allocated data sets for each material in the two Scenarios are shown in Appendix 1. In the demolition phase for selective plan it is assumed to use electric hand tools which is not applied in the conventional plan. Also the production stages for different materials depend on their reuse and recycling potential. Materials may be reused or recycled into products for similar applications. Where a production processes required virgin materials from nature, an extra transportation process was incorporated in the cycle. Transportation of demolished material for selective plan was assumed to be located within a 20 km radius from the demolition site while that for the conventional demolition plan was assumed to be 30km. The unit for transportation in the software was tone*kilometer and these assumed distances where used together with the weight of each material to determine the suitable inputs for transportation.

6.3 Results for Environmental impact

In this section the total environmental impact loads within a defined system boundary for both, selective and conventional plan are illustrated. Also the result obtained for environmental indicators according to the CML-IA baseline version 3.02 (EU25) for each studied material is described. In both scenarios the released environmental impacts from demolition work in form of equipment used to demolish, transports to reuse or recycle and also production of material from wastes or raw material are considered. Impacts from unit mass of each material as well as the overall impacts from the total mass from the case study is described.

6.3.1 Unit impact

A unit weight of 1 ton and a transportation distance of 1 ton*km was considered for each material. In such a case the environmental impact from selective and conventional scenarios is calculated to find out the influence of the different materials on each indicator (Table 6).

Table 6: Impact for each material in Unit terms

Impact category	C1	C2	P1	P2	S1	S2	W1	W2
Abiotic depletion *kg Sb eq*	2.8×10^{-5}	2.1×10^{-4}	1.0×10^{-5}	3.6×10^{-3}	4.0×10^{-5}	8.9×10^{-4}	9.5×10^{-6}	5.8×10^{-4}
Global warming (GWP100a) *kg CO2 eq*	7.8	105.4	2.3	2.4×10^{3}	4.7	164.3	2.2	215.3
Ozone layer depletion (ODP) *kg CFC-11 eq*	6.1×10^{-6}	7.6×10^{-6}	8.8×10^{-7}	1.3×10^{-4}	3.2×10^{-6}	1.5×10^{-4}	7.9×10^{-7}	9.1×10^{-5}
Acidification *kg SO2 eq*	0.039	0.367	0.013	8.297	0.026	1.037	0.012	1.097
Eutrophication *kg PO4 eq*	0.048	0.111	0.007	2.400	0.028	1.179	0.004	1.137

Figure 10 below further highlights the potential difference between the two scenarios for the four considered materials.

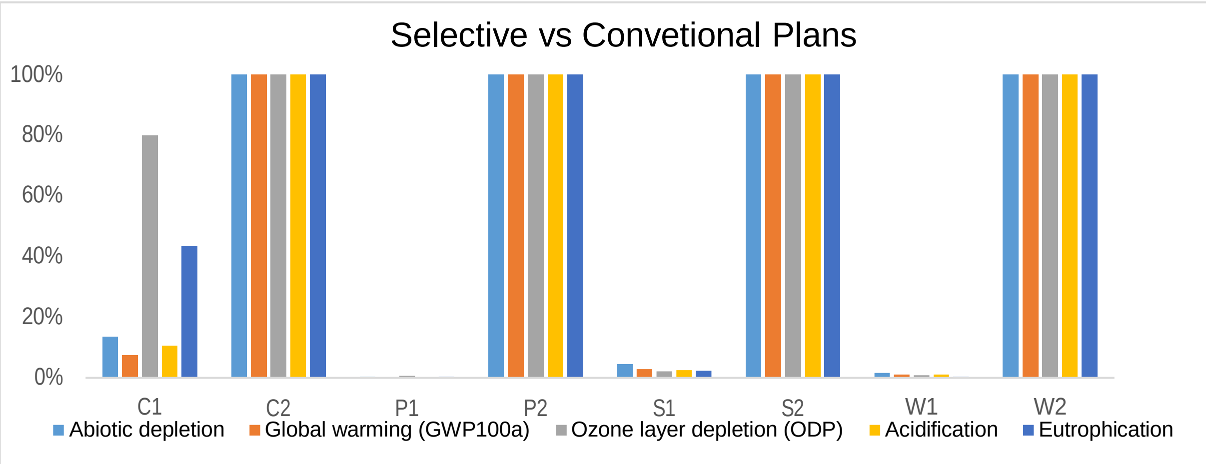

Figure 10: Comparison of selective and conventional plans

Of the materials evaluated in 1 ton*km unit, plastic materials result in the greatest avoided environmental load when demolished selectively. The avoided impacts (difference) are rather high which is due to high value realized from the conventional plan compared to wood, steel and concrete. This could be explained by the chemical nature of plastic material. Therefore by reusing plastic instead of recycling or producing from raw material a considerable environmental avoided impact will be gained.

For wood, the gained environmental benefit is not as high as plastic but still it is rather big compared to steel and concrete. This could be caused by the approach that is applied in Scenario 2 for wood material where it is assumed that to produce 50% of the product from raw material and the other 50% from already demolished wooden material which makes higher values in scenario 2 and therefore higher difference from scenario 1.

Concrete has the least environmental avoided impact compared to plastic, wood and steel, despite that production of cement from limestone being a primary ingredient in making concrete has a high potential of giving off large emissions due to the extreme heat needed to produce it. This could be explained by the applied approach in Scenario 2 for concrete where it is assumed that the raw material such as limestone and cement which would be required to produce 50% of the product are already taken from nature and the energy intensive cement manufacturing machine is not needed. The 50% of demolished concrete material has been assigned to be recycled which in turn makes the conventional plan (scenario 2) less environmental damaging and gives smaller differentiation between the two scenarios.

6.3.2 Total Impact

The total environmental impact from selective and conventional demolition for the office building is shown in Table 7. The difference between the two scenarios is the amount of avoided environmental impacts when the demolition plan with the less environmental impact is applied. It is evident that the conventional demolition plan has a greater impact than the selective plan from all the studied materials. The difference is the gain that would result from opting for the selective demolition option.

Table 7: Total effect of all material

Impact category	*C1*	*C2*	*P1*	*P2*	*S1*	*S2*	*W1*	*W2*	*Total 1*	*Total 2*	*Difference*
Abiotic depletion *[kg Sb eq]*	0.05	0.16	0.005	0.30	0.01	0.13	0.002	0.02	0.07	0.61	0.54
Global warming (GWP100a) *[kg CO2 eq]*	1.2×10^4	7.7×10^4	991.1	1.9×10^5	2.0×10^3	2.4×10^4	351.2	6.5×10^3	1.5×10^4	3.0×10^5	28.5×10^4
Ozone layer depletion *[kg CFC-11 eq]*	0.005	0.006	0.2×10^{-3}	0.011	0.001	0.022	1.0×10^{-4}	0.003	0.006	0.041	0.04
Acidification *[kg SO2 eq]*	43.4	261.5	3.2	674.7	7.4	148.5	1.1	32.4	55.1	1.1×10^3	1040
Eutrophication *[kg PO4 eq]*	35.9	77.5	1.1	195	4.7	164.7	0.3	32.9	42.1	470.2	428

Figure 11 shows the overall comparison of the effects from the two scenarios. By opting for selective demolition, Global warming and Acidification have the highest avoided impact and Ozone layer depletion (ODP) has the lowest avoided impact.

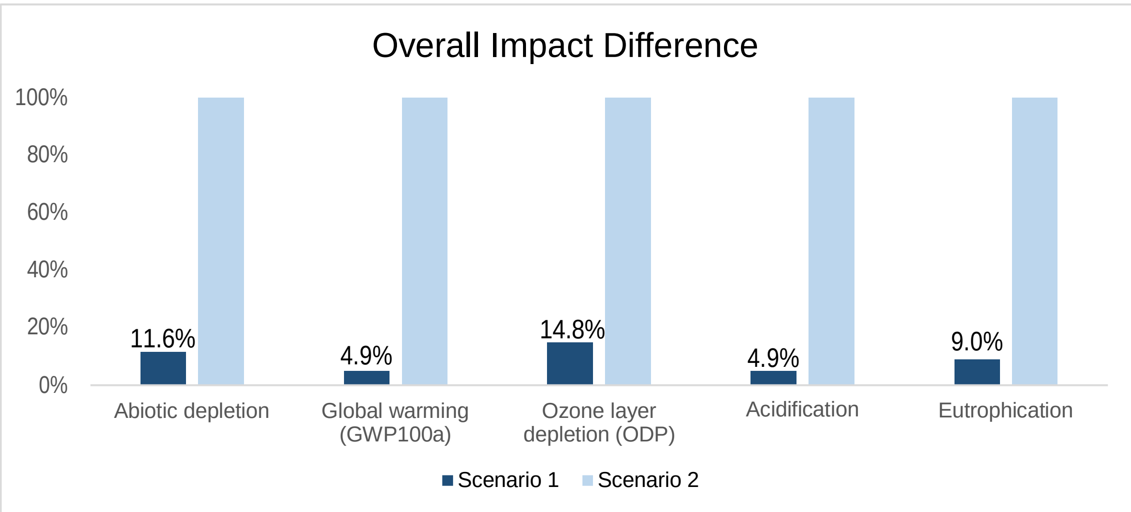

Figure 11: Overall comparison of the two scenarios

6.3.3 Contribution of different material in each indicator

In scenario 1, concrete has the most contributing impact followed by steel, plastic and wood. This could be explained due to large amount of concrete from the demolished building. In selective demolition of, eutrophication for concrete, Abiotic depletion for wood, steel and plastics are the most dominating impacts. The dominating indicators during scenario 2 for concrete is Abiotic depletion while Global warming is the most dominant for plastic, Ozone layer depletion for steel and Eutrophication for wood (Figure 12). It is also evident that the contribution of the different indicators in a given scenario and material cycle do not differ so much but the effect varies from material to material. For instance, in scenario 1 for concrete all the indicators have rather equal effect ranging between 73% - 85% while for steel values fall between 11% - 17%. In scenario 2, this trend is also valid for concrete and wood. The high contribution of steel to ozone layer depletion which is measured in CFC-11 equivalents in scenario 2 may be attributed to the scrap steel input in the software which may have elements that may cause this result.

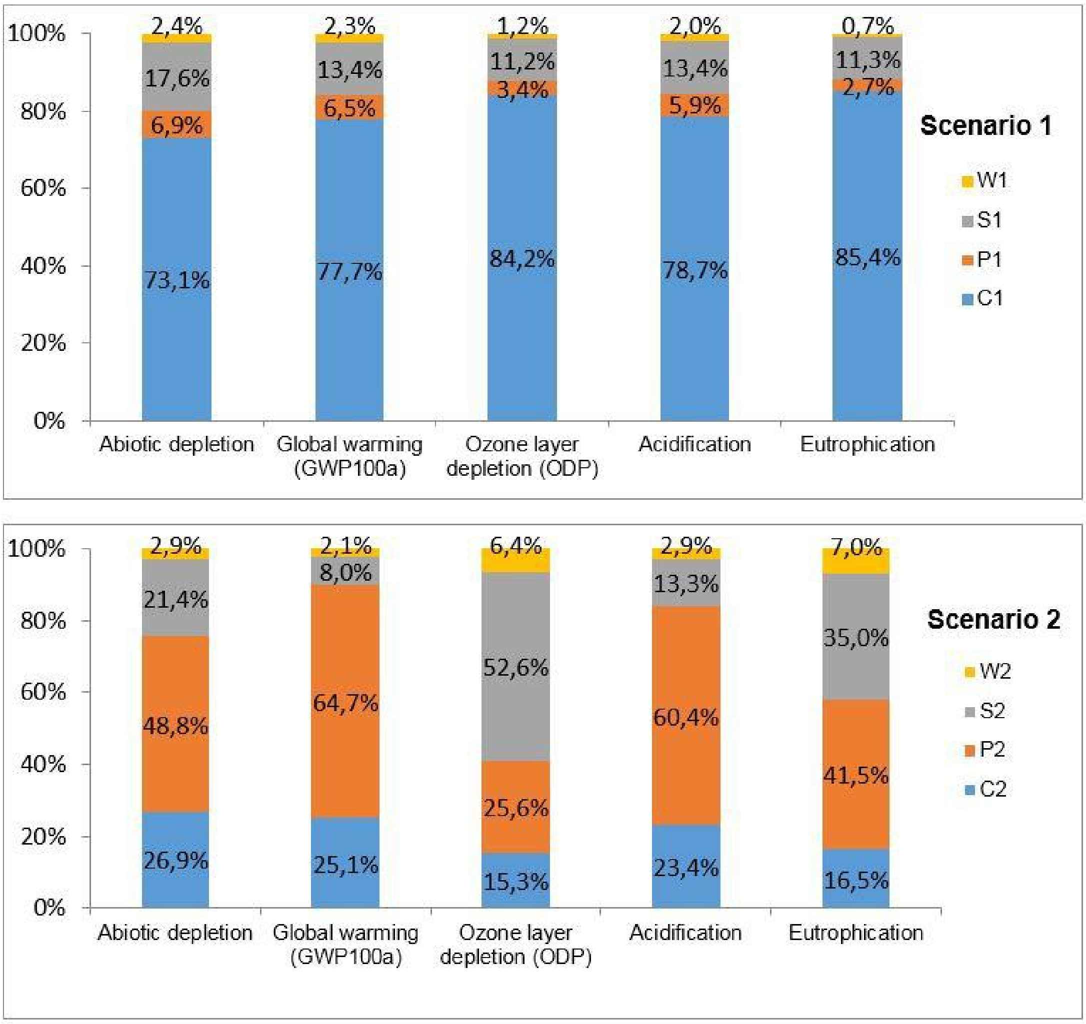

Figure 12: Contribution from different indicators

6.4 Results for Cost feasibility

In this section, the total cost, transportation and labour costs will explained in detail. Equipment costs were not considered in this study. We assumed the demolition contractor had the requisite equipment for the project. Cost estimation for hand tool as the main set of equipment used in the projects was difficult to establish. With regard to labour costs, it was assumed that a demolition site worker earned 22,333 SEK/month (139.6 SEK/hr) on average in Sweden (Lönestatistik, 2015).Transport costs were assumed to be 195 SEK per 10 Veh-Km (Vti, 2008)

6.4.1 Total cost

Table 11 shows estimated total cost for each scenario (also refer to Table 12 and 13). The result shows that cost for selective is almost double that of conventional demolition. This outcome did not consider equipment costs and operational cost.

Table 8: Total cost of demolition

Scenarios	Estimated Transport	Estimated Labour costs	Total Cost (SEK)
Selective	118,170	1,339,980	**1,458,150**
Conventional	106,318	669,990	**788,160**

6.4.2 Labour costs

This cost estimate was developed from a general assumption that selective demolition needs more time and human force than conventional demolition to carefully deconstruct the building and recover reusable material. In this case it was assumed that selective demolition required a total of 15 workers while conventional demolition require 10 workers. Also it would require 1h to demolish 4 m^2 of floor area conventionally (Coelho & deBrito, 2010) . It was assumed that to do the same job selectively it would require double the time (1hr for 2m^2). It would therefore take 60 days considering an 8 hours day Job to demolish 19500 m^2 of building with the conventional method .Selectively it would take 80 days. Table 12 shows a summary of the labour costs for both scenarios.

Table 9: Estimated labour costs

	Scenario	No. workers	days	Time (hr)	Rate/hr	Total amount (SEK)
1	Selective	15	80	640	139.6	**1,339,980**
2	Conventional	10	60	480	136.6	**669,990**

6.4.3 Transportation cost

Different types of waste categories may have had different destinations for treatment or reuse. It was assumed that material for reuse (scenario 1-selective demolition) were delivered to sites or store near the demolition site while material from conventional demolition was delivered to sites far away from the city center for treatment. Transportation of demolished material for selective plan was assumed to be located within a 20 km radius from the demolition site while transport distances for conventional demolition plan was assumed to be located within a 30km radius from the demolition site. Table 13 show the estimated cost comparison for both scenarios.

Table 10: Estimated transportation costs

Scenario	Material	Qty (tons)	No. trips (6 ton/trip)	Trip Length (Km)	Rate (SEK/10km)	Total costs (SEK)
Selective	Concrete	660.3	110.1	40	195	85,878
	Wood	28.8	4.8	40	195	3,744
	Steel	138.8	23.1	40	195	18,018
	Plastics	80.8	13.5	40	195	10,530
						118,170
Scenario	Material	Qty (tons)	No. trips (10 ton/trip)	Trip Length (Km)	Rate (SEK/10km)	Total costs**(SEK)**
Conventional	Concrete	660.3	66.03	60	195	77,255
	Wood & Plastics	109.6	10.96	60	195	12,823
	Steel	138.8	13.88	60	195	16,240
						106,318

7 Discussion

The materials analyzed were divided into four major categories which were concrete, wood, steel and plastics. These formed the bulk of the demolished materials although they came from different building elements. Plastics mainly arose from flooring. Wood mainly from flooring and partitions, Steel from ceiling and fixtures while concrete was from stair ways, work tops and wall portions. This categorization was made since the data received did not exactly specify the exact volumes of each materials present in the generated wastes.

Selective demolition seems to be more environmental friendly than conventional one. But cost estimation analysis shows that the selective demolition costs twice more than conventional demolition. However revenue from selling off reusable material from demolition was not considered in our study which could compensate for some of the demolition expenses. The main building material for the studied case is concrete which has the greatest environmental impact between all waste categories in scenario 1 with eutrophication as its dominant environmental indicator. The dominance of concrete in this scenario may be attributed to the fact that it formed the biggest volume of the demolished material thus obtaining the highest value of transport distance in ton*km. This is also evident for steel, plastic and wood in this scenario. In scenario 2 however, plastics dominate the contribution of environmental loads in all environmental indicator categories. Recycling of plastics would possibly lead to giving off of high emissions. On the other hand, this scenarios assumed the use of half waste concrete which the software considers as an environmental benefit. This therefore gave plastics a very high environmental impact over concrete in this scenario.

The overall environmental benefit of opting for selective plan over conventional one considering the global warming indicator was 28.5×10^{4} Kg CO2 eq. To get a comprehensive image, this total avoidance would permit the use of 908 passenger cars in one year. This is obtained from the assumption that by 2015, the target for new passenger cars would be to emit 130 g CO2/km taking into consideration that each car travels 2414 km/year (Söderman, 2011).

It is hard to conclude that moving to higher steps in the EU waste hierarchy is more environmental friendly since landfilling and energy recovery which fall in the lower stages of the waste hierarchy are not considered in this study. However, reusing material has less environmental impact than recycling due to the cut off of transportation and energy consumption in the recycling plant. Age and type of building has an effect on selecting the demolition plan. In case that building is in its end of functional life where deconstructed material cannot be reused after applying various types of demolition equipment, then maybe conventional plan is a better choice. For instance, in a case where that building is a low rise as well as buildings that have almost equal contribution of materials that would generate a variety of waste material categories which in turn would need using different demolition equipment for deconstruction, a diversity of transport modes with different destination which cannot use peak capacity due to the small amount of waste in each category. In such a case the selective demolition plan would potentially not be the best practical choice.

With regard to the assumptions made and accuracy of the results obtained, the software is very sensitive to the choice of inputs alternatives from the database than the amount of energy required for the different process. For instance the energy required for low voltage hand tools has no significant effect on the result by choosing different energy values. Cost estimation was limited to only labour and transportation cost. Unit rates for the equipment that were assumed for the demolition were hard to be determined because the specific equipment used for the demolition were not stated in the demolition inventory and this would possibly affect the reliability of the estimation. The lack of a detail list for the demolition equipment used on the project affects both environmental impact and cost estimation.

8 Conclusion and recommendations

Conventional demolition given the outlined assumption in the study gives the largest environmental impact. It allows for limited material recovery for reuse and also gives complex sorting challenges hence allowing little recovery of recyclable materials. From a life cycle assessment perspective the failure to recover a product from demolition renders such materials going to waste and if reused it would field a negative impact to the environment by avoiding the effects that arise from the production on new material. Reuse of building materials needs be adopted by Volvo Group Real Estate as a more environmentally friendly scheme. Resale of these demolished material may help to pay off demolition costs, land fill cost and other related costs. This assertion matches a study carried out in Vietnam that C&D waste management creates numerous benefits such as revenue from reuse & recycling as well as company image improvement (Lockrey Simon et .al, 2016).

The authors recommend the need to have a clear material inventory after construction and after periodic maintenance work to keep track of the existing materials. At the time of demolition specifics are important in addition to the investigation for environmental impact assessment and cost viability of demolition methods would offer independent results for particular recoverable materials.

Adopt more steel and wood as building materials since recycling of these warrants justifiable environmental effects unlike concrete and plastics as depicted from the results section. Recycling of plastics yields a large mass of CO_2 emissions and therefore its re-use should be targeted. Designs that warrant selective demolition should also be embraced. By this, the labour costs and energy required at the time of demolition would possibly reduce. Building products with resale or re-use capacities need also to be considered during the design phase as an option for environmental protection.

9 Future studies

In this study conventional and selective demolition methods have been compared with the aim of evaluating the environmental impact from a life cycle assessment perspective. Cost assessment of the two alternatives was also performed. Four major materials were analyzed in a general form and the first proposal for future work should be to analyze building materials in a more specific way. The second study which would also be vital to the first proposal is to seek better building inventory information before and after a demolition exercise. A comprehensive study needs to be carried out to look into the accuracy and specifics of demolition information. Thirdly, Volvo needs to study and evaluate its reediness and shift to the green building management schemes such as LEED & BREEAM. Lastly the authors suggest that future researchers need to compare the environmental impacts that arise from recycling of material and incineration of combustible materials for heat production.

References

A. Rezaalla, C. B. (2014). LEED and BREEAM; Comparison between policies, assessment . *Conference: BSA 2012 – Proceedings of the 1st International Conference on Building Sustainability Assessment.* Porto: Green Lines Institute & ResearchGate.

Ambell C, B. A. (2010). *Potential för ökad materialåtervinning av hushållsavfall och industriavfall.* Stockholm: KTH Samhällsplanering och miljö.

Återbruket Begagnat bygmaterial. (2016). Retrieved from Blocket: http://www.blocket.se/aterbruket

BREEAM. (2015). *BREEAM*. Retrieved from http://www.breeam.com/

CIB. (2014). *Barriers for Deconstruction and Reuse/Recycling of Construction Materials:Publication 397.* Rotterdam: International Council for Research and Innovation in Building and Construction (CIB).

Coelho, A., & deBrito, J. (2010). Economic analysis of conventional vs selective demolition - A case study. *ELSEVIER*.

Deloitte. (2014). *Construction and Demolition Waste in Sweden.* Deloitte Touche Tohmatsu Limited. Retrieved from Sweden-Europa: http://ec.europa.eu/environment/waste/studies/deliverables/CDW_Sweden_Factsheet_Final.pdf

Eijk, R. v., & Brouwers, H. (2002). STIMULATING THE USE OF SECONDARY MATERIALS IN THE CONSTRUCTION INDUSTRY: THE ROLE OF CERTIFICATION. *International Journal for Construction Marketing (IJCM)*, 43-50. Retrieved from University of Twente.

Engelsen, C. J. (2005). *Carbon dioxide uptake in demolished and crushed concrete.* Oslo: norwegian building research inistitue.

Environmental & Human Health, I. (2010). *LEED Certifacation: Where Energy Efficiency Collides with Human Health.* North Haven: West Hartford.

EPA, S. (2012). *Swedish Environmental protection Agency.* Retrieved from http://www.naturvardsverket.se/Documents/publikationer6400/978-91-620-6560-7.pdf

EU commission. (2014). *Horizon 2020*. Retrieved from The EU Framework Programme for Research and Innovation: https://ec.europa.eu/programmes/horizon2020/en/news/demolish-re-use-recycle-and-rebuild

Eurostat. (2015). Retrieved from eurostat Statistic Explained: http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Labour_costs_per_hour_in_EUR,_2004-2015_whole_economy_excluding_agriculture_and_public_administration.png

eurostat. (2015). *Eurostat Statistics Explained*. Retrieved from File:Waste generation by economic activity and households, 2012 (1000 tonnes).png: http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Waste_generation_by_economic_activity_and_households,_2012_(1000_tonnes).png

Gerth, G. (2006). *Basta - Phasing Out Very Dangerous Substances from the Construction Industry.* Stockholm: Best Life Environment Projects & NCC Construction Sverige AB.

KOMPANJONEN. (2016). Retrieved from http://www.kompanjonen.se/

Lockrey Simon et .al. (2016). Recycling the Construction and Demolition Waste in Vietnam: Opotunities and Challenges in Practice. *Cleaner Production*.

Lönestatistik. (2015). Retrieved from http://www.lonestatistik.se/loner.asp/yrke/Rivningsarbetare-1433

LowTech-Magazine. (2016). Retrieved from Low-Tech Magazine: http://www.lowtechmagazine.com/what-is-the-embodied-energy-of-materials.html

Lund, H. F. (2001). *The McGraw Hill Recycling Handbook*. New York: McGraw Hill .

Mantau, U. (2012). Wood Flows in EU27. Celle.

Muthu, S. S. (2015). *Carbon footprint handbook*. Boca Raton, London, New York: CRC press, Tylor & Fracis group.

Nobuhiko Narita, M. S. (2002). Life Cycle Inventory Analysis of CO 2 Emissions: Manufacturing Commodity Plastics in Japan. *LCA case studies*.

Östlund, C. (2011). *Swedish Environmental Protection Agency*. Retrieved from Swedish Waste Management: http://www.recobaltic21.net/downloads/Public/Conferences/Emerging%20trends%20and%20investment%20needs%20in%20waste%20management%202011/catarina_ostlund.pdf

Östlund, C. (2015). *Naturvårdsverket*. Retrieved from Vem gör vad i avfallshanteringen : http://www.naturvardsverket.se/Miljoarbete-i-samhallet/Miljoarbete-i-Sverige/Uppdelat-efter-omrade/Avfall/Vem-gor-vad/

SIMM-Center. (2014). *MARKET SUMMARY AND DEVELOPMENT OPPORTUNITIES.* Stockholm: INNOVATION expess.

Söderman, L. (2011). *Förebygga avfall med kretsloppsparker Analys av miljöpåverkan*. IVL.

Sundqvist Jan-Olov, P. D. (2010). *Miliöpåverakan från avfall. Uderlagg för avfallsprevention och förbätrad avfallshanterning*. Stockholm: IVL Svenska Miljöninstitute AB.

Thormark, C. (2002). *Handling and recycling building and counstruction waste*. Stockholm: Nordic Council of Ministers.

Tillman, B. &. (2004). *The Hitch Hiker's Guide to LCA: An Orientation in Life Cycle Assessment Methodology and Applications* . Lund: Studentlitteratur.

Vti. (2008). *The effects of long and heavy trucks on the*. Retrieved from Vti: https://www.vti.se/en/publications/pdf/the-effects-of-long-and-heavy-trucks-on-the-transport-system--report-on-a-government-assignment.pdf

WBCSD. (2009). *World Business Council for Sustainable Development*. Retrieved from The Cement Sustainability Initiative: http://www.wbcsdcement.org/pdf/CSI-RecyclingConcrete-Summary.pdf

Zhaoa, W. e. (2010). Evaluation of the economic feasibility for the recycling of construction and demolition waste in China—The case of Chongqing. *ELSEVIER*.

APPENDIX 1

NO.	**Scenario 1- Selective**	**Scenario 2 – Conventional**
Concrete	**Process:** Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {GLO}| market for | Alloc Def, U **CONCRETE 1 demolition** Input from technosphere (material/fuel)**:** Excavation, skid-steer loader {GLO}| market for | Alloc Def, U 1 m3 Building machine {GLO}| market for | Alloc Def, U 1 p Input from technosphere (electricity/ heat)**:** Electricity, low voltage {SE}| electricity voltage transformation from medium to low voltage | Alloc Def, U 100 kWh	**Process:** Transport, freight, lorry 7.5-16 metric ton, EURO6 {GLO}| market for | Alloc Def, U Transport, freight, lorry 16-32 metric ton, EURO6 {GLO}| market for | Alloc Def, U **CONCETE2** Input from nature(resources)**:** Limestone 0,15 Ton Sand and gravel 0,35 Ton Water, lake 0,1 m3 Input from technosphere (material/fuel)**:** Concrete block {GLO}| market for | Alloc Def, U 0,5 Ton Machine operation, diesel, < 18.64 kW, generators {GLO}| market for | Alloc Def, U 0,5 hr **CONCRETE2 demolition** Input from technosphere (material/fuel)**:** Excavation, skid-steer loader {GLO}| market for | Alloc Def, U 1 m3 Waste concrete, not reinforced {GLO}| market for | Alloc Def, U 0,5 Ton
Steel	**Process:** Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {GLO}| market for | Alloc Def, U **STEEL 1 demolition** Input from technosphere (material/fuel)**:** Excavation, hydraulic digger {GLO}| market for | Alloc Def, U 0,75 m3 Excavation, skid-steer loader {GLO}| market for | Alloc Def, U 0,75 m3 Input from technosphere (electricity/ heat)**:** Electricity, low voltage {SE}| market for | Alloc Def, U 50 kWh	**Process:** Transport, freight, lorry 7.5-16 metric ton, EURO6 {GLO}| market for | Alloc Def, U Transport, freight, lorry 7.5-16 metric ton, EURO6 {GLO}| market for | Alloc Def, U **STEEL2** Input from technosphere (material/fuel)**:** Iron scrap, sorted, pressed {GLO}| market for | Alloc Rec, U 1 ton Input from technosphere (electricity/ heat): Electricity, high voltage {SE}| production mix | Alloc Def, U 2800kWh **STEEL 2 Demolition** Input from technosphere (material/fuel)**:** Excavation, skid-steer loader {RoW}| processing | Alloc Rec, U 1,5 m3 Input from technosphere (electricity/ heat): Electricity, low voltage {SE}| market for | Alloc Def, U 50 kWh
Wood	**Process:** Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {GLO}| market for | Alloc Def, U **WOOD 1 demolition** Input from technosphere (material/fuel)**:** Excavation, skid-steer loader {RoW}| processing | Alloc Def, U 2m3 Input from technosphere (electricity/ heat)**:** Electricity, low voltage {SE}| market for | Alloc Rec, U 10 kWh	**Process:** Transport, freight, lorry 7.5-16 metric ton, EURO6 {GLO}| market for | Alloc Def, U Transport, freight, lorry 16-32 metric ton, EURO6 {GLO}| market for | Alloc Def, U **WOOD 2** Input from nature(resources)**:** Wood, primary forest, standing 1 m3 Input from technosphere (material/fuel)**:** Fibreboard, soft {GLO}| market for | Alloc Def, U Input from technosphere (electricity/ heat)**:** Electricity, medium voltage {SE}| market for | Alloc Def, U 1400kWh **WOOD 2 demolition** Input from technosphere (material/fuel)**:** Excavation, skid-steer loader {GLO}| market for | Alloc Def, U 2 m3 Waste fibreboard {GLO}| market for | Alloc Def, U 0,5 Ton
Plastic	**Process:** Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {GLO}| market for | Alloc Def, U **PLASTIC 1 demolition** Input from technosphere (material/fuel)**:** Excavation, skid-steer loader {RER}| processing | Alloc Def, U 2 m3 Input from technosphere (electricity/ heat)**:** Electricity, low voltage {SE}| market for | Alloc Def, U 10 kWh	**Process:** Transport, freight, lorry 7.5-16 metric ton, EURO6 {GLO}| market for | Alloc Def, U Transport, freight, lorry 7.5-16 metric ton, EURO6 {GLO}| market for | Alloc Def, U **PLASTIC 2** Input from technosphere (material/fuel)**:** Ethylene vinyl acetate copolymer {GLO}| market for | Alloc Def, U 0,5 ton Polyvinylchloride, emulsion polymerised {GLO}| market for | Alloc Def, U 0,5 ton Electricity, high voltage {SE}| production mix | Alloc Def, U 1300kWh **PLASTIC 2 demolition** Input from technosphere (material/fuel)**:** Excavation, skid-steer loader {GLO}| market for | Alloc Def, U 2 m3