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Circular Economy Model of Used Office Furniture

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Circular economy is a newly developed model that follows the principles of a “closed-loop” system. It functions as a perpetual machine which uses the energy it generates to fuel itself. Any element added to the circular system will remain there indefinitely, instead of being disposed of. In other words, products are reused and recycled for as long as possible. Such practice can negate a significant amount of resources, time and money due to its efficient consumption rate. This thesis focuses on the benefits of circular economy of reusing and recycling office waste, particularly furniture.

There are three major parts in this thesis: literary research, calculation and data, and furniture inventory. The location selected for furniture study is the Metropolia campus at Bulevardi 31. A set of common, used products designated for disposal was analyzed. Their measurements, origins and materials were identified as a part of environmental impact assessment in the laboratory. This process assists the final evaluation on the furniture’s final destination. The three main factors chosen for the assessment are carbon emission, energy consumption and financial cost. These factors cover a plethora of sub-factors, such as material extraction, manufacturing, and transportation. Finally, one of the three most suitable disposal approaches was chosen: reuse, recycle or waste to energy combustion. Obtained data and estimations are based on previous researches on furniture management.

The conclusion provides final calculations and data from each disposal solution. These results can be utilized in the future in the event any more furniture needs disposing. Taking advantage of the outcomes, the responsible department of Metropolia can devise an appropriate plan to relocate old furniture in the facility. It is important to note that estimations have been optimized to be as close to the desired results as possible. In practice, some unprecedented elements may arise and alter the output.

Keywords	circular economy, linear economy, recycle, reuse, waste to energy, greenhouse gas, global warming potential, carbon

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List of Abbreviations

BTU	British thermal unit
CO_{2e}	Carbon Dioxide Equivalent
GHG	Greenhouse Gas
GWP	Global warming potential
H	Height
HDP	Hot-dipped galvanized steel
L	Length
LCA	Life Cycle Assessment
MDF	Medium-density-fiberboard
NCV	Net calorific value
VOC	Volatile organic compounds
W	Width
WT	Weight
WTE	Waste to Energy

1 Introduction

Since the inception of industrial revolution, technological advancement has been able to push the boundaries of production, invention and consumption. The innovations achieved in the short span of industrial revolution are greater than the entire preceding human history. With the dawn of information era, the economy grew exponentially. Nowadays, millions of products are being constantly transferred and traded all around the globe, generating an astronomical amount of sales. If this development pace maintains, world economy will continue to flourish. However, that is not the reality we are facing.

1.1 Background

Furniture and household appliances are essential commodities in the daily life of any individual. Yet, not much thought is put into them when it comes to disposal. In most countries, used furniture is sorted with municipal waste and thrown into landfills to disintegrate with time. This practice causes great harm to the environment and is not economically efficient. Most furniture like chairs and desks, are quite durable and can last a long time. The materials used for their manufacturing still holds economic value, and can be recovered for later uses.

Moreover, a great amount of revenue was expended on facilities, infrastructure and manpower to mine, treat, synthesize raw materials used for manufacturing furniture and household appliances. An even greater amount is spent on marketing, researching, designing and distributing. Before being sold, furniture and household appliances have had to undergo long chains of complex and costly procedures. And when their design becomes obsolete, they are discarded with virtually no remaining value. This type of linear, one-way economy is immensely taxing on our planet in terms of resources and environmental impact. If this paradigm prolongs, it can cause serious consequences to global climate and future economy.

1.2 Goal and scope of the study

This thesis aims to study reusing and recycling office furniture. It consists of two parts: the literary and the application part. The literary part reviews researches on different approaches to circular economy. Each model is briefly outlined, and the collected data and knowledge are compared. The results will be applied in the disposal of old furniture in one of the Metropolia's campuses. Currently, there is an unidentified amount of used furniture at Bulevardi 31 building which is being commissioned for clearance. In addition, a number of new facilities are under renovation, which will lead to relocation of furniture and other appliances. Thus, this research was initiated with the purpose of finding the most suitable and logical solution. Compiled data provide an insight into climate change impact, energy consumption and cost of different methods. This creates a systematic framework for assessing scenarios and various options in regard to how old furniture can be dealt with. The emphasis is to avoid approaches that is inclined towards linear economy, such as landfill disposal or combustion.

An inventory of some common items was constructed, detailing the characteristics of the products. Items were listed in volume, weight, quantity and material composition. This thesis also assessed the environmental impact of extracting, transporting and manufacturing raw materials. The main source of impact is greenhouse gas (GHG) emission, or more specifically, CO_2 gas. In addition, energy consumption was taken into consideration, since it is one of the main factors contributing to GHG emission. Subsequently, a brief study on logistical preparation was carried out to find the most economic way to relocate the used furniture. All this information could assist Metropolia school board in arrangement of their disposal. This can also enable a life cycle assessment (LCA) in the future.

2 Linear economy

2.1 Obsolescence of the linear economy

For the past 200 years, a large proportion of production chains are linear. The concept of this model is based on the principle of "take, make, consume, discard" (1). Materials after being extracted will be transferred into the factory for manufacturing, the resulting products then proceed into the consuming market. After its usability expires, the product is disposed of at the landfill, or sent to the incinerator. In developing countries like China, the disposal process is likely underdeveloped and unmonitored, causing an exceeding amount of pollutants (2). The constant mining and production also leads to an increase in greenhouse gas emission, which is the primary cause to global warming. The model can be visualized in Figure 1.

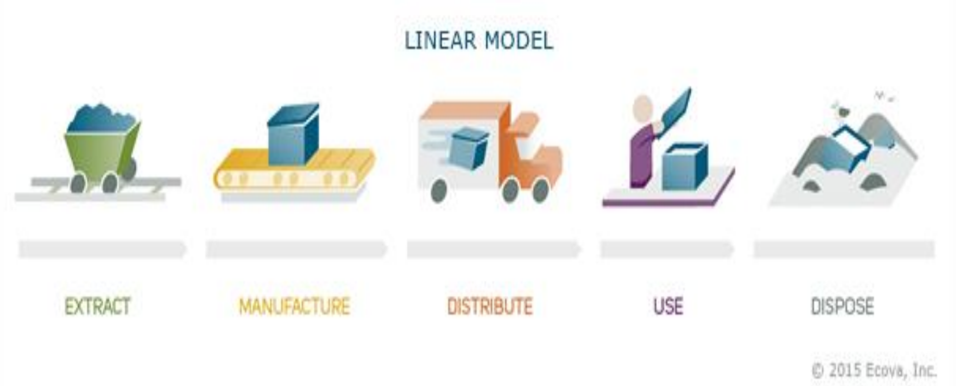

Figure 1 Generalized model of linear economy (3)

The major issue with this model of economy is its unsustainability. Earth is a finite planet with finite resources. Sustaining an economy model that only consumes and not produces is not plausible. A linear economy would gradually exploit all existing reserves without replacing the old ones. Additionally, the Earth population had boomed in the past two centuries: going from 1 billion people to nearly 7.4 billion (3). Human lifespan has been extended as well thanks to the advancement of medical technology. This exponential population growth naturally demands a larger market of consumption. More products are required to sustain our society as a result. Eventually, this would bring about a great shortage in future generations, where resources with economic values are all exhausted.

Furniture is one of the essential commodities nowadays, and it accounts for a large amount of resource consumption. According to a report by European Environmental Bureau (EEB), the EU region generates 10 million tons of discarded furniture annually. Overall remanufacturing amounts to less than 2 % of the turnover, and furniture recovery is still largely limited (4). The burgeoning size of landfills is a major contributor to soil and water degradation. Landfill sites are often rendered unusable for municipal purposes and inhospitable for wildlife after decommissioning, leading to a waste of land mass. After a certain period of time, organic wastes in landfills start to release methane, a gas 25 times more harmful than carbon dioxide. If the landfill also includes plastic, metal and chemicals used in wood treatment, there is a high risk of toxins being generated and leaching through the bottom layer. The liquid pollutants created in these sites are called leachates, and can infiltrate into soil and underground water (5). In the long term, this is not a viable solution to deal with accumulating wastes. To minimize their impacts, the Directive

1999/31/EC restricts a number of waste types from entering landfills, such as liquid waste, oxidizing waste, flammable substance and clinical waste (6). According to European Union waste management committee, landfill is the least preferable approach to treating wastes (7).

To summarize, the persistence of linear economy should not be maintained any longer. This system has reached obsolescence, and is becoming increasingly unsustainable due to the environmental toll that our planet has taken. It is unfortunate that the mass populace is unaware of this reality and that the traditional "take-make-waste" culture has been ingrained into consumers' mind-set. In order to battle this convention, the model of economy must be re-established and innovated.

3 Circular economy

3.1 Overview

The alternative option to a linear economy is to recoup as much value as possible from expended and disposed products. The simplest and most effective way is to follow the "3R" method: reduce, reuse and recycle. For example, bottles and boxes can be used as containers, old clothes and fabric can be patched and sewn into new apparels, trinkets and ornaments can be turned into decoration pieces, and used products can be donated to charity organization. This seemingly trivial act is, in fact, a profoundly important step to initiate a more sustainable life cycle of products, a circular economy.

As the name implies, circular economy is a model with a closed loop. This concept was first introduced by two British economists David W. Pearce and R. Kerry Turner in 1989. They claimed that the traditional linear system is too wasteful and inefficient. Instead, we should replicate the cycle of nutrients in a living ecosystem (8). The "energy" deriving from living organisms is transmigrated in a harmonized cycle via consumption. To put it differently, the pattern runs undisrupted and no energy is lost outside of the loop. The only input comes from sunlight, which is practically infinite. Given our current technology, it is not all that unfeasible to replicate this cycle in the economy.

As illustrated in Figure 2, the circular economy follows three major principles (9):

- Improve natural capital by controlling finite stock of natural assets and renewable energy.

- Circulate products to maximize the efficiency of resources.
- Minimize systematic leakage by revealing design flaws in the economy.

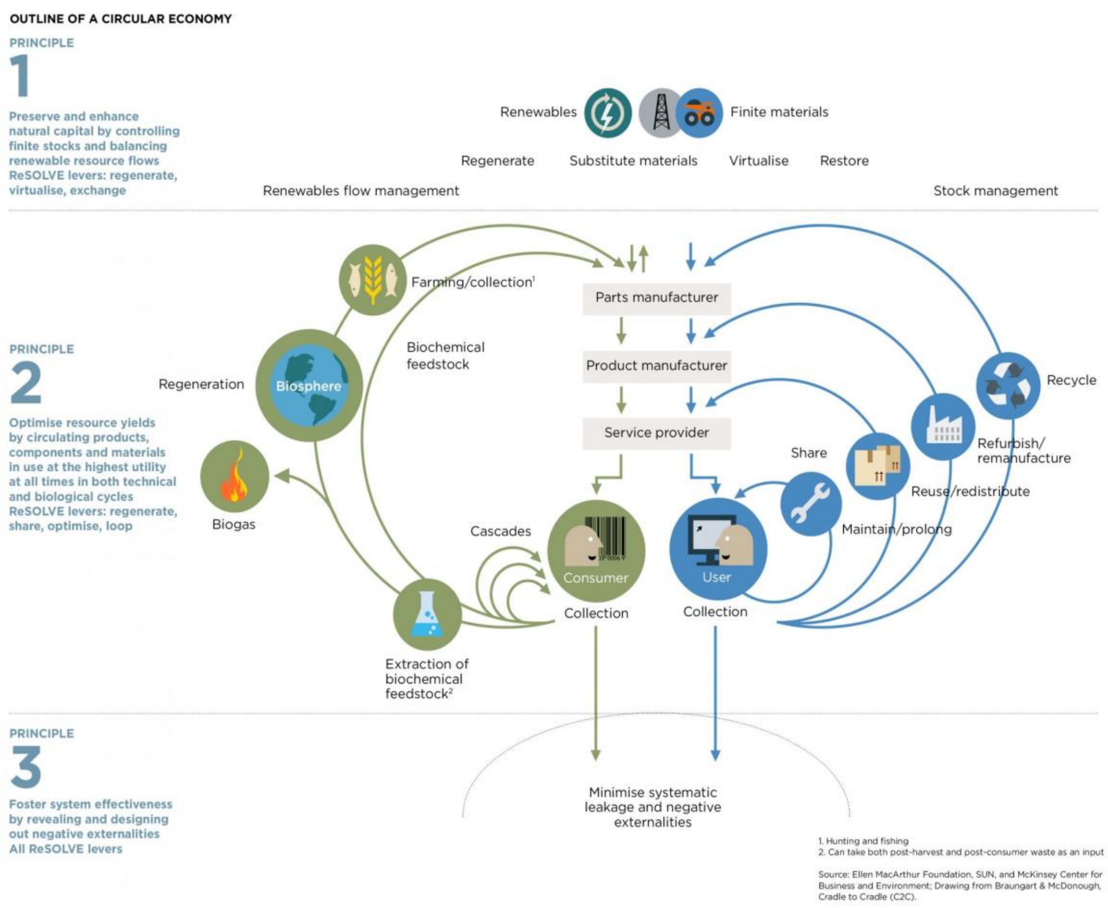

Figure 2 Outline of a circular economy model (9)

3.2 Sustainability of circular economy

Theoretically, in a circular economy, the input resources are not discarded after their usage, but will be recycled into new resources. In short, it is a “zero-waste” system. This will decrease exploitation and allow Earth to “regenerate” itself. Although it is not possible to conceive a completely closed cycle, we can minimize the leakage, waste and emission from production and consumption. Disposed products commonly hold a fair amount of value even after being used. Furniture especially so, since those types of products have high durability and do not usually undergo significant deterioration during their lifetimes.

The problem is, in many cases, perfectly usable furniture is replaced because of its outdated model and design. Sometimes, the reason for replacement is purely aesthetic. Moreover, furniture is composed of primarily wood, metal and plastic materials, all of which are fairly efficient to recycle or reuse. By innovating the way household products are manufactured and circulated on the market, we can lessen the impact of linear economy. In other words, there is no such thing as waste in the circular economy. Products are designed to be optimized for “a cycle of disassembly and reuse” (10). The process of recycling and reusing materials of products will lower their wasted potential. This system is capable of providing and replenishing itself, without requiring a large amount of new output resources. In the long run, such methods will recover substantial economic value.

3.3 Positive impact on environment

Circular economy is a fundamental factor in transitioning to a lower carbon emission economy. Reusing and recycling a product consumes notably less energy than production. Not only that, but exploitation of new materials is not needed to create new products. Both of those changes will dramatically reduce the strain on environment and natural resources. As an example, let us consider the impact of circular economy on Scotland. Figure 3 illustrates the projection of environmental impact based on carbon footprint and material consumption in Scotland by Zero Waste Scotland organization:

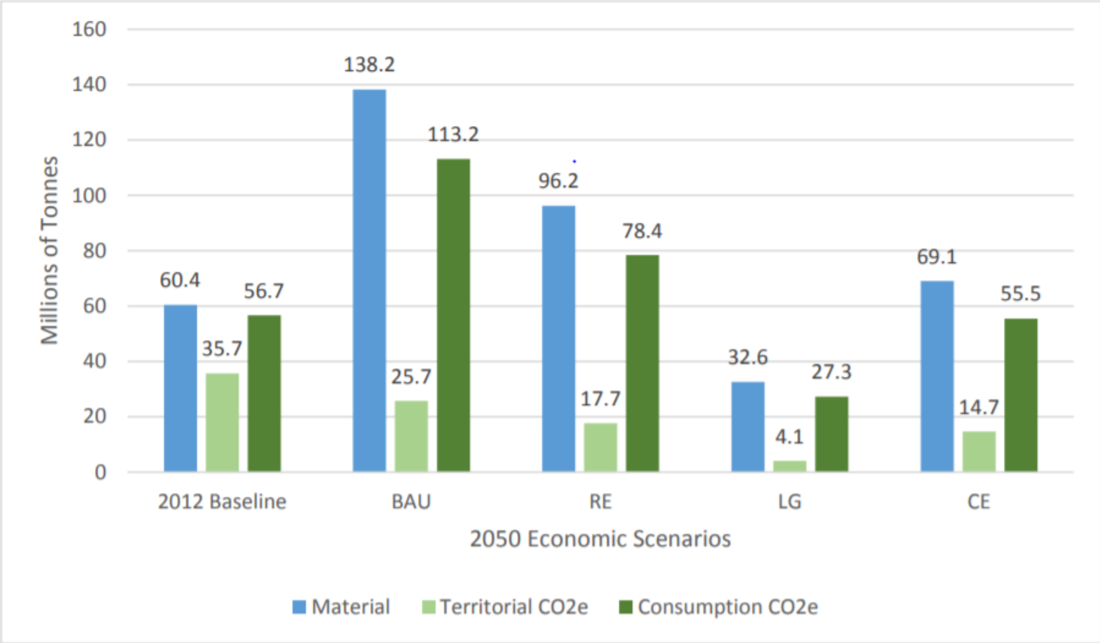

Figure 3 Territorial and consumption carbon impacts for 2012 and the 2050 scenarios for material consumption in Scotland (million tons) (11)

In Zero Waste Scotland's report, the statistics were predicted for four different scenarios in 2050. The baseline used for comparison is the carbon footprint in 2012. The second set of columns in this graph represent a business as usual (BAU) model. BAU, in other words, is a scenario where no changes are made to the current trend. Production and consumption continue to remain at high levels. As illustrated in Figure 3, both material consumption and CO_2 emission rise by over twofold. The third, fourth and fifth sets designate resource efficiency (RE), limited growth (LG) and circular economy (CE) respectively. RE layout follows the assumption that resource saving policies will be applied. However, it does not adopt long term plans to reuse, recycle or prolonging products' lifespans, hence the significant environmental impact (11). LG scenario presents the lowest amount of CO_2 emission and material consumption. Nevertheless, this comes in tandem with poor economic growth and profit by drastically hindering consumption. Finally, the scenario involving a CE model shows only a slight increase in material consumption without sacrificing much economic growth. CO_2 emission is also slightly lower than in 2012. When taking the economy to environmental impact ratio into account, CE is the most efficient out of four scenarios (11).

The positive environmental influence can also be observed in the data outcomes devised by WRAP. In UK, 200,000 desks and 295,000 chairs are reused every year, weighing a total of 8500 tons. Most reused items are resold in second-hand shops or donated to charity. A large number of old products have successfully negated the purchase of brand new ones (12). This act of reusing reduces 15,600 tons of CO_2 per year. For every ton of desk reused and recycled, 0.2 to 0.4 tons of CO_2 emission are mitigated when compared to landfill solution. For every ton of chair, we can decrease from 1 to 3 tons of CO_2 (12). This is a substantial amount of mitigated environmental impact, even when considering data from a single country. If all other nations collectively shift to circular economy system, it is possible to notice dramatic improvement in terms of economy and ecology in a foreseeable future.

3.4 Economic benefits of circular economy

In addition to the environmental sustainability, a circular economy would also generate great revenue. Ellen MacArthur Foundation is a British organization founded in 2010 with the purpose of educating and propagating environmental awareness and innovative thinking. Their main goal is to assist the transition of circular economy on a global scale and advocate sustainability (13). According to their estimates, the value of material used for fast-moving goods accumulate to 3.2 trillion USD. 20 percent of which is recovered through cascading of waste and by-products. That leaves 2.6 trillion USD that has the potential to be recovered (10) .

The EU estimated that approximately 340 to 630 billion USD is saved on material cost, which is equivalent to 3.9% of the regional GDP. It is reported that approximately 500,000 jobs can be generated after adopting the new strategy (10). The model also advocates changes such as efficiency, innovation, the shift from quality over quantity and increased skill labor. Another impact the circular economy has, is reducing the effect of downstream demand on upstream demand. In other words, this harmonizes the price volatility on the market (10).

However, the process of recouping does encounter numerous problems, such as collection and lack of public attention. Adopting circular economy will be profitable not only for companies and manufacturers, but for the consumers as well. Transforming an economy model is not a short sight matter. Furthermore, reusing and recycling mitigates GHG emission and raw material consumption. Considering that linear economy has dominated the industrial scene and consumption market for the past two centuries (1), it will take tremendous effort to revert the pre-existing perception of the public, the government, as well as corporations.

3.5 Waste circulation in EU and Finland

Globally, furniture market is on the rise. Furniture consumption increased from 226 billion euros in 2003 to 347 billion euros in 2012. Europe amounts to 20 % of total furniture usage globally, with Finland being the 5th highest. Similar to most countries, furniture is one of the essential consumption goods in Finland. Their revenue in furniture is approximated to be 1.3 billion euros, amounting to 1.6 % of EU total share (14). European Federation of Furniture Manufacturers claimed that 4 % of municipal solid waste is furniture, which amounts to an annual of 10.78 million tons. Among those figures, 80-90% of furniture waste is sent to landfills, and only 10 % are recovered (4). The limited circular economy in EU might direct from multiple economic and regulatory challenges, paint reduced export and tariffs from foreign trades, labor cost and increased demands for affordable products (4).

In recent years, Finland has been advancing the reusing and recycling of materials from municipal waste. As of 2016, merely 3 % of total waste was disposed into landfills, the remaining 97 % was successfully recovered. Moreover, waste wood has become an important source of biofuel for energy production (15). Over 93 % of waste wood receives the energy recovery treatment, and 7 % were recycled. On the contrary, 100 % of metallic waste is recycled. This is due to municipal wastes consisting of metals that are poor in flammability. General data in Figure 4 illustrates a positive trend in material recovery in Finland (15).

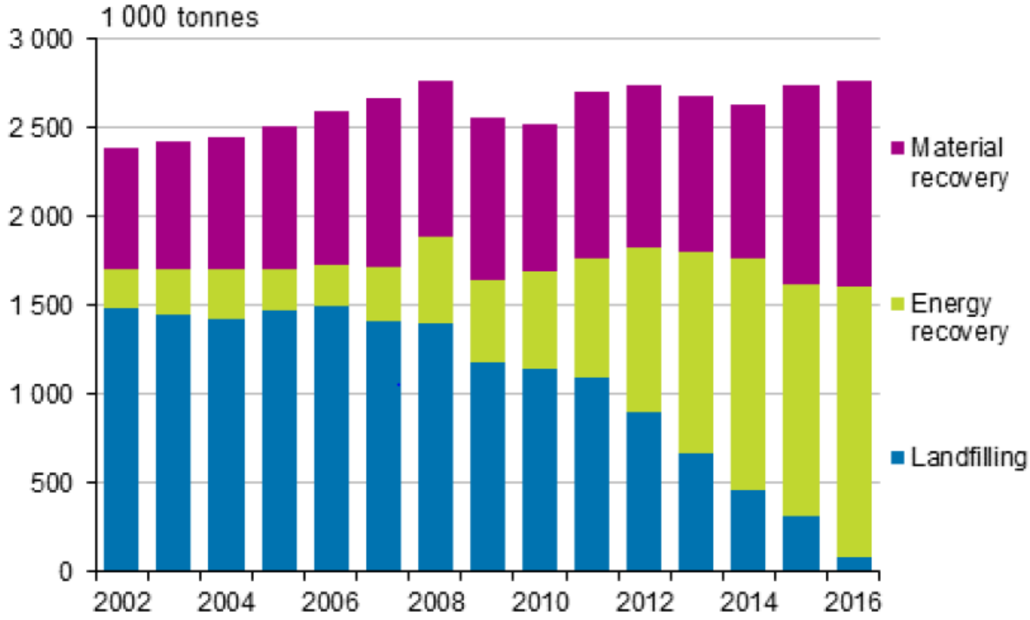

Figure 4 Waste treatment in Finland from 2002 to 2016 (15)

4 Metropolia old furniture inventory

4.1 Overview

Currently, Metropolia University is undergoing renovation and construction of additional facilities. The project includes replacing a significant amount of old office furniture. This chapter will focus on item listing and inventory management. It is important to know the specific properties of the items for more efficient logistical instructions. A number of furniture can be folded or disassembled to reduce their volumes. This helps conserve cost of transport, at the exchange of time and manpower invested to do the labor. Certain items cannot undergo recycling due to the properties of their material.

In general, the priority plan is to reuse the furniture, either by sending them to a different facility or donating to an organization. This is the most economically and time efficient solution due to the exclusion of extra infrastructure capital. There is no need for a third-party recycling factory, incinerating plant or landfill site. In other words, only transportation and retail services are required. According to the waste hierarchy by European Environmental Bureau, reusing the second preferable option to dealing with waste generation (16). If reusing is not feasible due to reasons like finance, the next option on the waste treatment hierarchy will be considered. The last two options: obtaining energy and disposal via landfill are not desirable choices, since they have a high impact on environment as stated in chapter 1. Therefore, it is best to minimize the amount of furniture receiving those treatments (16). The hierarchy is detailed in Figure 5:

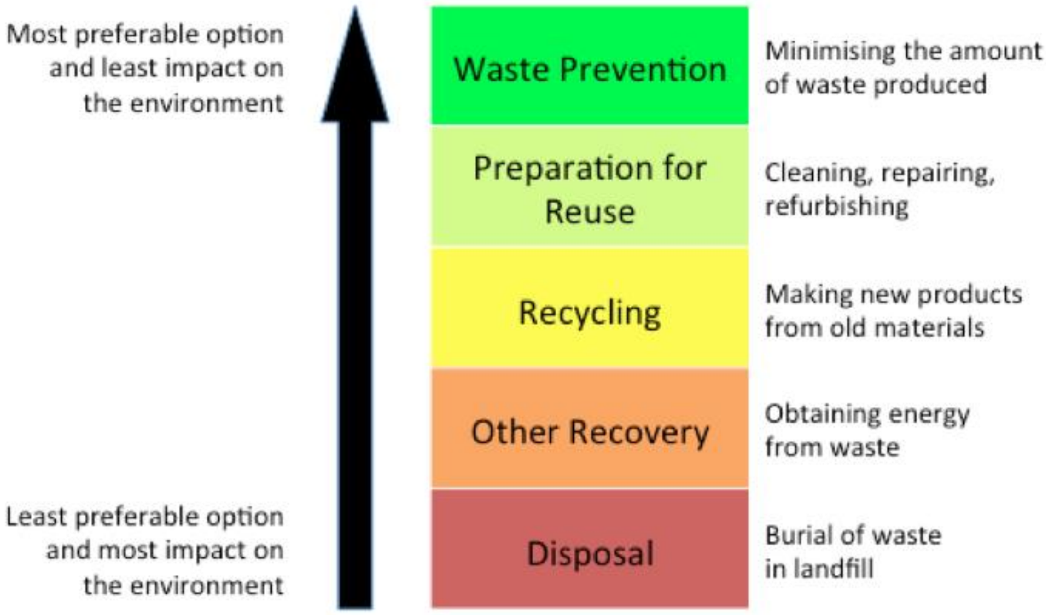

Figure 5 Waste hierarchy by European Environmental Bureau (16)

4.2 Methodology

Due to the large amount of furniture variety and lack of personnel, it was not possible to analyze every furniture type in Bulevardi. Instead, five most common desk and chair types are selected for assessment and calculation. The assessment criteria for the furniture are as follows:

- Volume and weight of the product.
- Volume and weight of each material in the product.
- Assembly, disassembly time.

Most furniture comprises of more than one material. Therefore, to fully interpret the property of an object, it was necessary to completely dismantle and analyze each component. Wood and steel were segregated for individual measurements. Weights of small and light objects were measured using weight in the lab. Heavy, clunky items were measured with body scale. A piece of furniture was disassembled and reassembled three times, and the amount of time taken will be averaged.

The standard spacious volume of an object was determined rather simply, by multiplying height, weight and width. However, this statistic should not be used for the calculation of cargo stacking and amount of material. Its purpose was to give estimated amount of room a furniture occupies in a classroom environment. In the case of cargo stacking, the minimum volume after disassembly was applied instead.

Multiple approaches were used to find the exact volume of an object. If the item was found to have even surfaces and a standard shape, for example cuboid or cylindrical, basic geometrical formulas were implemented. If the shape of a part or component was considered irregular and orthodox, its volume was quantified using the fluid displacement mechanic: by fully submerging the object in a liquid body, their volume can be inferred from the amount of fluid displacement. Water was used for this method due to their abundance and clearly specified properties. The tool for this experiment is a cuboid tank in the laboratory of the Leiritie campus. After immersing an object in the water, the shift in height was measured. By multiplying the height with the width and length of the tank, the quantity of displaced water could be found.

4.3 Inventory listing

This section includes inventory of all furniture aimed to be reused or recycled. Basic dimensions of each furniture type were measured, consisting height (H), width (W), length (L) and weight (WT). More detailed description and measurement can be found in Appendix 1. Some furniture is recommended to be disassembled before transportation in order to minimize their volumes. In such case, the description column provides average disassembly and assembly time. Table 1 shows the information obtained for the selected furniture products:

Table 1 Old furniture inventory overview in Bulevardi

Number of furniture items	584
Volume normal (before disassembly) (m^3)	181.2
Volume after disassembly (m^3)	7.04

Weight (kg)	7015
Disassembly time (hours)	35
Assembly time (hours)	55
Estimated moving time (excluding transportation) (hours)	40

It can be observed that without prior disassembling, the volume occupied by the furniture can be extremely large. Loading items in their original sizes will require a tremendous amount of vehicles and manpower. An important factor to consider, is that 7.04 m^3 is the volume of all furniture under the assumption that all items are tightly compressed together with zero wasted space, which is impossible in practice. In fact, the steel frames can only be stacked sparsely and occupy a huge amount of volume with or without disassembly. Consequently, the practical space required is much greater. On the other hand, reducing their volume can prove time consuming, and costs more labor resource. Therefore, an array of optimizations has to be applied to minimize the cost and time. After studying the furniture, following solutions were procured:

1. Certain chairs do not require disassembly, since they can be stacked on top of each other.
2. Desks can be partially stacked after separating steel frame and wooden surface.
3. Items of the same type have better stacking compatibility; therefore, it is more efficient to load similar furniture in the same cargo space.

After conducting the optimization, the volume and time consumption of all furniture to be recycled/reuse can be summarized in Table 2:

Table 2 Optimized furniture space and time consumption

Volume after stacking (m^3)	98.2
Disassembly time (hours)	13.5
Assembly time (hours)	28
Estimated moving time (hours)	40

5 Cradle-to-gate emission and energy consumption of furniture products

LCA, or Life-cycle Assessment, is a tool in engineering with the function of analyzing the life cycle of a product. The methodology researches all the stages of a product's life: raw material extraction, processing, manufacturing, distribution and disposal. LCA reviews can formulate data about material and energy consumption, financial cost and environmental impact of products. LCA guidelines dictate compliance of ISO 14040:2006 protocols (17). There are multiple criteria in an LCA, including cost, raw material consumption, legislation and market condition. In addition, an LCA requires multiple parameters, primarily system boundaries, functional unit, as well as assumption and limitation (18). However, due to shortage of resource and data, a proper LCA was not able to be conducted in this study. Instead, environmental impacts from cradle to gate of furniture materials were outlined. Data acquired in this part are rough estimations based on available sources. The categories chosen for this assessment were CO_{2e} emission per ton of wood and steel manufactured, financial cost for disposal, as well as total amount of energy expended on production. Materials' quantity has been measured in Table 3. As it can be observed, plastic is too low in quantity to be of any significance, so the analysis will focus mainly on wood and steel. The volume of steel is calculated by dividing the weight by steel density, which is around 7850 kg/m^3 (19).

Table 3 Total volume and weight of furniture by material

Material	**Total Volume (m^3)**	**Total weight (kg)**
Dimensional lumber	0.19	549
Plywood	3.97	780
MDF	0.21	2457
Steel	0.41	3225
Plastic	3.166E-09	2.6

5.1 Wood assessment

5.1.1 Overview

Wood is the most common material that comprises furniture products. There are four main types of wood make up the furniture composition in Bulevardi: dimensional lumber wood, plywood and medium-density fiberboard (MDF) (20). A furniture object can comprise more than one type of wood. For the purpose of classification, there are certain differences in appearance of wood variations, as presented in Figure 6:

Figure 6 Visual guide to different types of wood (21)

5.1.2 Global warming potential and biogenic carbon

Wood is classified as a biogenic carbon source, which means that GHG emission from burning and recycling wood does not contribute to global CO_2 level. Plants absorb CO_2 from the atmosphere to build their cellulosic body, creating wood. Upon combustion, the CO_2 is simply returned to the original carbon cycle. In other words, it is widely considered a carbon neutral material, thus the carbon emission from wood is not added into the total carbon pool (22 p. 22). To better picture the carbon cycle, we can take a look at Figure 7:

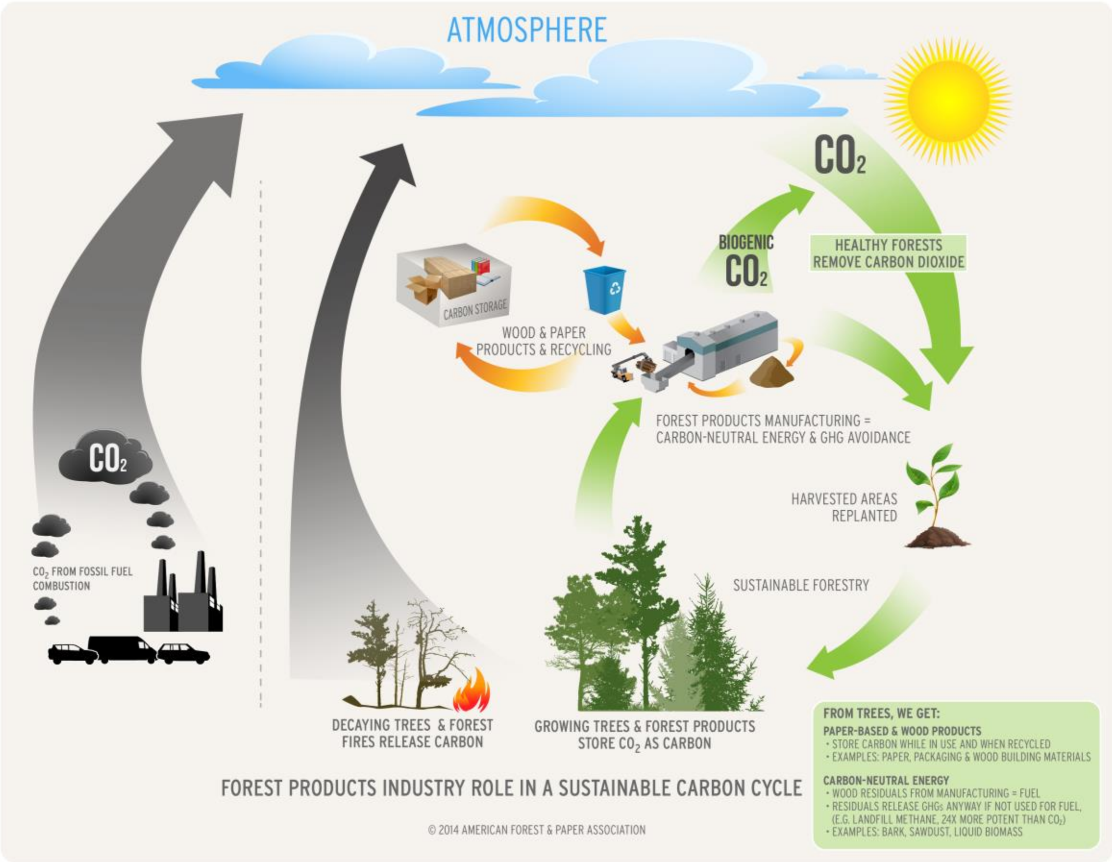

Figure 7 The cycle of carbon (23)

While considering GHG emission from reusing (source reduction), the GHG saving is higher than the amount generated during production. This is because a large quantity of scientific sources also takes into account GHG saving from forest carbon storage. Forest carbon storage is the amount of CO_2 that plants and vegetation absorb and store. A reduction in wood consumption and harvest can bring about an increase in carbon storage, and subsequently a negative GHG emission (22). This is the reason trees are so important in the campaign to reduce CO_2 in the atmosphere. Despite being carbon neutral, combusting wood can still generate other GHG, such as CH_4 and N_2O (24). In terms of global warming potential (GWP), solely CO_{2e} value can be used for calculations since it is the equivalent of other GHG quantified as CO_2 release (25). It is calculated by multiplying the emission gas with its corresponding GWP factor. The baseline for GWP factor is CO_2, which is 1 per kg. Some notable gases such as CH_4 and N_2O have the factors of 23 and 296, respectively (26).

5.1.3 Formaldehyde in wood processing

During the processing of wood, certain amount of finishing sprays, such as paint, lacquers, varnishes, and coatings, are used (27). These additional layers of substances serve various purposes: flame retardant, protection from oxidation and thermites, water resistant and giving the products an enhanced appearance. The primary health hazard that these sprays pose is the emission of volatile organic compounds (VOC). They are comprised of a wide range of solvents and hydrocarbons. The most prominent VOC is formaldehyde, an adhesive resin widely used in the production of engineered wood, such as MDF, plywood and particle board (28).

With thorough safety precautions and containment, formaldehyde and other VOC hazards can be largely mitigated. A manufacturing facility should implement safety instructions and guidelines for employees, such as proper ventilation system, mandatory gas mask and goggles and regulated emission. Nevertheless, it is important to monitor and control these substances in order to avoid accidental inhalation, skin contact or leakage. Acute symptoms upon contacting formaldehyde include: asthma, eye irritation, headache and nausea. Prolonged exposure to formaldehyde can cause cancer, damage to respiratory and digestive systems (29).

5.1.4 Dimensional lumber

Dimensional lumber, or solid wood, is conventional lumber cut into pre-defined shapes and sizes, commonly used in furniture, building and containers. It is priced considerably high due to its superior quality and requirement of raw wood material. On the other hand, dimensional lumber consumes less energy, resources and possess lower environmental impact (20). This can be observed in Table 4, where GHG emission and energy consumption of dimensional lumber is lower than MDF. The data in the original report are given in short ton and British thermal units (BTU), which was converted into metric ton and MJ for convenient calculation. Dimensional lumber is quantified to be around 549 kg, or 0.549 ton (Table 3).

Table 4 GHG emission and energy consumption of dimensional lumber (22 pp. 396-400)

Process	**Per ton of wood**		**Total (0.549 ton of wood)**	
	Net emission ($kg\ CO_2$)	**Energy consumption (MJ)**	**Net emission ($kg\ CO_2$)**	**Energy consumption (MJ)**
Transportation (from extraction site to retail location)	90	1235	50	678
Wood processing and manufacturing	110	2671	60	1466
Total	**200**	**3906**	**110**	**2144**

As established earlier, wood is a carbon biogenic material, which means carbon storage needs to be taken into account when calculating net GHG emission. The carbon storage will offset the total CO_2 emission during reuse. Reducing raw wood extraction generates great CO_2 emission offset, since living trees are a constant cycling CO_2 plant, and the most important source of carbon sink on Earth; hence wood is often referred to as carbon neutral (30). Carbon sequestration of solid wood can be estimated applying following equation (30):

$$CO_2 \text{ storage} = A * 88\ \% * 50\ \% * 3.67 * R,$$

where A is the air dry weight of timber (kg), 88 % is the oven dry weight, 50 % is the carbon content, 3.67 is the CO_2 factor, and R the recovery rate, which is 35 % for hardwood and 50 % for softwood. In this scenario, the furniture is mostly softwood. Therefore, the carbon storage in dimensional lumber is as follows:

$$CO_2 = 549 \text{ kg} * 88\ \% * 50\ \% * 3.67 * 50\ \% = 443 \text{ kg}$$

If wood is reused and material extraction is decreased, the offset from carbon storage can surpass the emission from production, leading to negative CO_2 emission, also known as CO_2 saving. This can be observed in following calculation, as we find the net CO_2

emission from 549 kg of dimensional lumber by subtracting CO_2 emission during production from the carbon sequestrated. It also proves that decreasing raw wood extraction is a noteworthy practice towards reverting climate change.

$$\textbf{Offset } CO_2 = 110 \text{ kg} - 443 \text{ kg} = -333 \text{ kg}$$

Manufacturing solid wood also generates a small amount of formaldehyde. On the basis of measurements conducted by Lis Winther Funch, the formaldehyde emission from dimensional lumber does not exceed 100 µg/m^3, which is significantly lower than that of MDF and plywood (31).

5.1.5 Plywood

Industrial wood is commonly separated into two categories: softwood and hardwood. The differentiation is based on the reproductive system of the tree from which wood came from, rather than their characteristics (32). Therefore, despite the implication in their names, softwood is not necessarily softer than hardwood, and vice versa. Nevertheless, hardwood is generally tougher, more durable, and cost more than their counterpart. Being a cheaper and more abundant alternative, softwood accounts for 80 % of timber production in the world (32). Plywood is produced by slicing lumber into thin sheets, also known as veneers, then gluing them together using adhesive chemicals (33). Laminated wood is a type of plywood that can be commonly found in flooring. The key difference is that laminated wood can also consist of veneers pasted on high density fiber boards or particle boards. All plywood is considered laminated wood, but not all laminated wood is plywood (34). For the sake of simplicity, plywood will represent laminated wood in this study. It can be observed in Figure 8 that the manufacturing process of both softwood and hardwood plywood consists of nine primary phases:

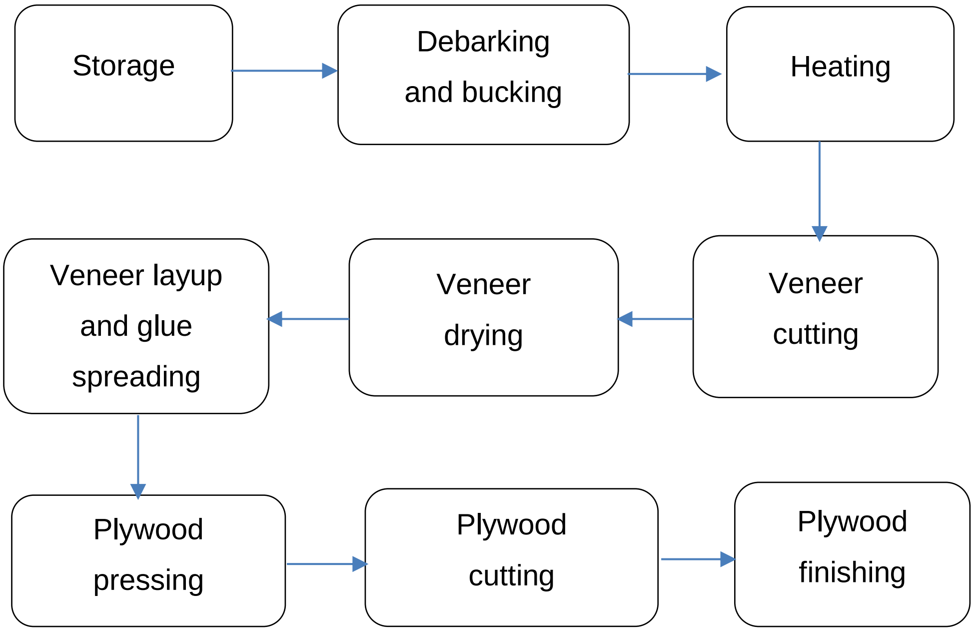

Figure 8 Plywood production phases (30)

In contrast to solid wood, plywood consumes more energy and chemicals in the making, due to the addition of heating, drying and gluing processes. In Finland, the typical adhesive used for this purpose is phenol formaldehyde resin, with relatively low emission (35). The accumulated volume of plywood in all furniture is measured to be 1.3 m^3. Utilizing the data from softwood plywood LCA by CORRIM, the total emission of formaldehyde and GHG of 1.3 m^3 of plywood can be exhibited in Table 5:

Table 5 Environmental impact of softwood plywood (36)

Factor	**Unit**	**Quantity per 1 m^3**	**Quantity total(1.3 m^3)**
Emission in extraction and production	Kg CO_{2e}	280	364
Carbon stored in product	Kg CO_{2e}	922	1198
Offset CO_2	**Kg CO_{2e}**	**-642**	**-834**
Primary energy consumption	MJ	10200	13260
Fresh water consumption	L	1190	1547

Formaldehyde emission	kg	0.0235	0.03

5.1.6 Medium-density Fiberboard (MDF)

MDF is a specifically engineered type of wood, which is constructed by adhering wood chips and sawdust with the assistance of high pressure, heat and resin. Due to the fiber-board being made of mostly waste wood and residues from other wood industry, MDF does not require raw material acquisition. This alternative timber material is preferred in lots of modern industries due to its reduced cost and wide availability. MDF's properties also include high density, toughness, along with even and grainless surface (37). The manufacturing of MDF follows a series of complex processes as exhibited in Figure 10. The most notable steps include the following:

- **Digesting:** using pressure and heat from steam, wood residue is cooked within digesters to soften the fiber connection
- **Refining:** a pressurized disk refiner shears the lignin binder in the fiber
- **Blending:** fiber is coated and blended in resin and wax
- **Drying:** heated air is used to dry the particles going through long tubes
- **Forming:** the mixture is placed into flat mats to take the panel shape
- **Hot-Pressing:** the mats are heated to 170 C and under 5.2 Mpa of pressure
- **Conditioning:** hardened panels are dried and cooled to reinforce the resin (37)

Overall, MDF and plywood share similar fundamental production mechanics, both involving resin and high heat-pressure environment. Many furniture in Bulevardi consist of MDF laminated with veneer, thus they possess properties of both wood types. Therefore, in a few sections, data formulated for MDF, such as recycling GWP and energy consumption, are applied for plywood as well. Since MDF production involves resin as an adhesive, a low amount of formaldehyde is emitted during the conditioning phase (37). The cumulative volume of MDF in Bulevardi furniture is 3.52 m^3, hence we can formulate Table 6:

Table 6 Environmental impact of MDF (37)

Factor	Unit	Quantity per 1 m^3	Quantity total ($3.52 m^3$)
Emission in extraction and production	Kg CO_{2e}	621	2185.92
Carbon stored in product	Kg CO_{2e}	1268	4463.36
Offset CO_{2e}	**Kg CO_{2e}**	**-647**	**-2277.4**
Energy consumption	MJ	10723	37744.96
Fresh water consumption	L	1387	4882.24
Formaldehyde	kg	0.167	0.59

5.2 Steel assessment

Steel is the primary component of furniture frames. Steel production from raw material is mainly done by extracting iron from iron ores via a reduction process. Along with other industrial sectors such as chemical and cement, steel and iron manufacturing constitutes to 20 % of total global emission (38). In the report on CO_2 reduction from steel manufacturing in Finland by Antti Arasto, this process is mainly conducted using the blast furnace (BF) technology (38). Table 7 displays emission and energy consumption from three types of steel:

Table 7 Emission and energy consumption from production and recycling per kg of steel (39)

		PED MJ	GWP kg CO_2e	AP kg SO_2e	EP kg phosphate e	POCP kg ethene e
Sections, 1 kg	Cradle-to-gate	19.6	1.6	0.0045	0.00036	0.0008
	Including recycling	16.4	1.2	0.0037	0.00034	0.0006
	Recycling benefit	-3.2	-0.4	-0.0008	-0.00002	-0.0002
Hot-rolled coil, 1 kg	Cradle-to-gate	21.6	2.0	0.0052	0.00035	0.00094
	Including recycling	11.9	0.9	0.0025	0.000282	0.00035
	Recycling benefit	-9.7	-1.1	-0.0027	-6.8E-05	-0.00059
Hot-dip galvanized steel, 1 kg	Cradle-to-gate	27.5	2.5	0.0074	0.00048	0.0012
	Including recycling	17.5	1.3	0.0047	0.00041	0.00061
	Recycling benefit	-10.0	-1.2	-0.0027	-0.00007	-0.00059

There are three main types of steel products: section steel, hot-rolled coil and hot-dip galvanized steel. Sections and hot-rolled coil steel are geared towards industrial usage and construction. Furniture and house appliances in general are made of hot-dip galvanized (HDP) steel (39). Since this thesis focuses on furniture, only data of HDP steel will be implemented. The data reveals that recycling steel will not only lower GHG emission, but energy consumption as well. For every kg of HDP steel recycled, 10 MJ of energy is saved, and 1.2 kg CO_{2e} is avoided. Knowing that the total weight of steel is 3225 kg (Table 3), we can calculate the cradle-to-gate emission and energy consumption, as shown in Table 8:

Table 8 Cradle-to-gate environmental impact of steel in furniture

	Without recycling	**With recycling**
Energy (MJ)	88698.2	56444.3
CO_{2e} (kg)	8063.5	4193
SO_{2e} (kg)	23.9	15.2
Phosphate (kg)	1.5	1.3
Ethen (kg)	3.9	2

6 Reusing solution

6.1 Environmental benefits

With the complete inventory, the next step would be contacting possible organization groups that deal with reusing and recycling. There are several companies in Helsinki that can assist with the donation process. It is important to consider the feasibility of each one regarding cost, location, time and labor while considering the viable partners. A number of the suggested companies are referred from the Office Furniture Project (40). According to EU, this is the most preferable solution for waste treatment in general, and furniture disposal in particular (16). The essential costs derive from logistics, hiring transportation vehicles and relocation services. It is simple, economic and environmentally friendly.

Chapter 5 showed that that both reusing and recycling wood will generate a notable amount of GHG saving, which is positive to the environment. Not only does it mitigate the CO_2 emission during manufacturing, it also generates a carbon sink that reduces the overall CO_2 in the atmosphere. It's important to note that this only applies to biogenic matters (22) , ergo reusing or recycling metal does not share the same benefit. Therefore, reducing steel manufacturing simply sets the CO_2 output to zero. Nevertheless, it does remove all CO_2 emission that would otherwise be emitted if new steel products are made, which is 8063.5 kg (Table 8). Utilizing all given data so far, we can calculate the quantity of GWP and energy consumption mitigated by source reduction method.

6.2 Reuse by donation

When considering the cost, reusing is the most economic solution out of all. This is owed to the fact that source reduction method does not require additional steps in processing of the material. Old items can be simply distributed to other places with demand, and only takes up resources in moving and transportation operations. Recycling and combustion options both need to go through a sorting phase to segregate different types of wastes before the actual processing. It is then followed by distribution of finished products, which are recycled materials and heat, electricity respectively. This leads to extra cost in resource and time. The processes can be visualized in Figure 9:

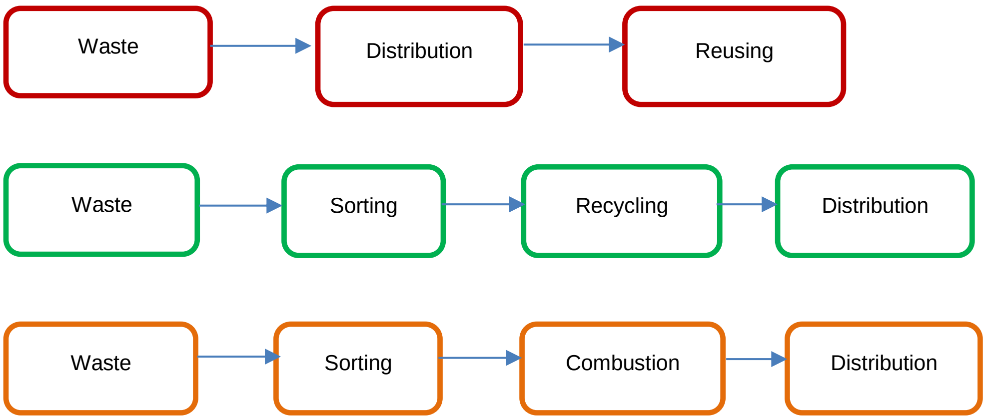

Figure 9 Phases of waste disposal methods

Donation is a popular approach to effective reusing of old products. Furniture in Bulevardi can be given to either charity groups or second-hand retails. Such services are quite numerous in Helsinki. KEPA and Kierrätyskeskus Oy were chosen as suitable donation destination due to their company size and capacity to handle large amount of furniture. The donation process only involves delivery and installation steps, no additional cost is required. There are two facilities in Helsinki that are viable for donation.

Kierrätyskeskus is a recycling and reusing center in the Metropolian urban area. This company collects and resells old items and products for affordable costs. Furniture can be donated to their location (41). The closest center is at Hermannin rantatie 2, which is also about 6km away from Bulevardi campus. Kierrätyskeskus is the priority destination in case of donation thanks to their availability and affordable cost.

KEPA is a Finnish civil society non-governmental organization (NGO). They have the agenda of promoting civil and cultural work, capacity building, as well as raising education awareness. Their activity can also be found in the southern countries, such as Tanzania and Mozambique. There, KEPA improve the civil society via various events and international cooperation (42). KEPA's facility is located at Elimäenkatu 25-27, which is approximately 6km from Bulevardi campus. The drawback of KEPA is that they don't directly distribute the donated items, but rather transport them to another organization or facility. This can potentially cost extra time and money until the products are settled down. Therefore, Kierrätyskeskus is a more convenient option.

7 Recycling solution

7.1 Recycling materials overview

In the event that an item cannot be donated or reused, the recycling option should be examined. Research on the materials needs to be conducted to ensure that the sorting process occur smoothly, thus avoiding any unprecedented expenses. Recycling is the second preferable option in the waste hierarchy (16). This option is slightly more expensive and has a higher carbon footprint than reusing. Depending on the material, furniture waste may have to go through various processes and facilities before recycling can commence. When calculating the cumulative environmental impact, we can assume that materials in the furniture have been extracted raw, and would be recycled process after their usage in Metropolia.

7.1.1 Wood

Generally, waste wood is often shredded and turned into laminated wood, chipboards or pulp. This will later be used for fabrication of new wood products such as pallets, furniture, paper and cartons. Another way to repurpose cascaded wood is to synthesize biomass fuel. Debris of timber and sawdust are compressed into small pellets that can be combusted for energy output (43). A commonly encountered problem in wood recycling is the sorting process. Wooden furniture usually includes bolts, nuts and other small parts that are made of either metal or plastic. These objects need to be segregated from the wood before shredding and defibration. The process can be conducted etiher mechanically or manually (43).

As detailed in WRAP's report, recycling can bring greater environmental benefit than reusing regarding net GHG saving under certain circumstances. This is explained as the outcome of low displacement phenomenon: only a proportion of reused furniture will replace the new products. It is estimated that 50-80 % of office chairs and desks actually replace other old furniture (44). Nonetheless, we can assume that all furniture would replace new products in this scenario for the sake of consistency. Table 9 indicates the total amount of emission and energy consumption dimensional lumber and MDF recycling phase. In this case, the same date is applied for MDF and plywood (segment 5.1.6).

Table 9 GWP and energy consumption of wood recycling (22)

Process	**Dimensional lumber**		**MDF and Plywood**	
	Net emission (kg CO_2)	**Energy consumption (MJ)**	**Net emission (kg CO_2)**	**Energy consumption (MJ)**
Quantity per ton of material	77	357	20	380
Quantity total	42	196	65	1231

The result of recycling benefits can then be calculated as follows:

- Mitigated CO_2 emission: 3444 kg – (65 kg+42 kg) = 3337 kg
- Mitigated energy consumption: 523148 MJ – (196 MJ+1231 MJ) = 51721 MJ

Generally, recycling and reusing are quite similar processes, since they both omit the need to extract raw materials. Although recycling requires one extra phase, the outcomes reveal that both solutions do not differ considerably in terms of carbon emission and energy consumption.

7.1.2 Metal

In a similar fashion, metallic components of furniture undergo a sorting process in the beginning. Following the separation phase, metal is crushed and shredded in grinders. Afterwards, it is melted in the forge, and then moulded into pellets, which will be shipped to other facilities. Metal recycling is a strongly developed industry that saves a large amount of material and can generate lots of revenue. According to the National institute of Health, metal recycling can decrease the mining waste by 97 %, and water consumption by 40 %. Energy saved while recycling aluminum and steel are 92 % and 50 % respectively (45).

Metal recycling facilities consume a substantial amount of electricity, and emits more toxic and harmful greenhouse gases than wood recycling. Processing heavy metals, such as steel, can produce CO, CO_2, SO_2 and NO_x (39). Nevertheless, recycling metal is still regarded as the superior option to generating new products from raw material. It is reported by The Institute of Scrap Recycling Industries (ISRI) that recycling metal cut down between 300 million and 500 million tons of GHG emission (45). GWP and energy consumption of steel recycling is displayed in Table 8. If steel is produced from recycling old products instead of extracting raw material, cumulative emission is lowered by 32254 kg CO_2, and energy utilized by 3870 MJ per kg of steel.

7.1.3 Plastic

Regarding furniture components in Bulevardi, plastic only weighs 2.5 kg in total, too little to be significant in this study. Notwithstanding that fact, recycling plastic is an important step because of plastic's slow degradation speed and high toxin potential. Under normal conditions, it can take from 500 to 1000 years for plastic debris to decompose. Therefore, disposing waste plastic into landfills is not an environmentally friendly solution (46). The process of recycling plastic includes 5 main steps:

- **Sorting:** segregate plastic from alien debris and materials
- **Washing:** omit impurities and adhesive matters

- **Shredding:** plastic is cut into small pellets for easier treatment
- **Classification**: classifying plastic by type and quality
- **Extruding:** plastic is melted and moulded into new pellets (47)

7.2 Recycling facility

The most suitable organization to handle this approach is Helsinki Region Environmental Services Authority (HSY). HSY is a municipal organization that takes responsibility in waste management and water services in Helsinki Metropolitan Area. Their task includes sorting and recycling municipal waste. There are five available stations within Helsinki, Vantaa and Espoo. The closest one to the Metropolia's campus is located in Konala (48). In order to recycle, we need to consider the material types that compose a piece of furniture. Table 10 is the price list of HSY for sorting services, metal is free of charge:

Table 10 HSY price per material, excluding transportation cost (48)

Waste type	Price/ small quantity	Price/ cubic metre
Wood	1,8 € / 200 litres	9 €
Mixed waste Gypsum	4 € / 200 litres	20 €
Aggregates Non-combustible waste	2,5 €/ 50 litres	50 €
Garden waste and brushwood • Garden waste from December to February, at the price of mixed waste.	5 € regardless of the size of the load	5 € regardless of the size of the load

Using the information in Table 10, we can calculate the recycling cost of furniture at HSY sorting station, provided that furniture has already been delivered to the site. Wood's total volume is 4.37 m^3, so the price for recycling is around 39 euros. Since recycling metal is free of charge, and plastic volume is only 0.03 L, they can be omitted from the cost equation.

8 Waste to energy solution

After recycling solutions have been utilized, the last approach is to convert any remaining materials into energy. Incineration is the second most common method of municipal waste treatment. The most convenient location would be Vantaan Incinerator, a WTE power plant located in East Vantaa. It is one of the facilities belonging to Vantaan Energia Company that provides heat and electricity from waste incineration (49). Municipal waste can be combusted in incineration plants to generate heat or electricity. There are three main techniques of WTE: combustion, gasification and pyrolysis. In this research, only energy generated from combustion will be covered. Combustion works on the principle of complete oxidation of the material. The heat released from such exothermic process removes moisture from combustible waste. This process creates a volatile gas, which is then ignited to heat up water, creating high-pressure steam to run the electric turbines (50).

8.1 Energy output

In this scenario, only energy output from wood will be calculated. According to Katona Lorant’s study on combustible waste, (18) steel is not a proper fuel for incineration. Energy input in this scenario is not included, since the combustion process is constantly maintained in the incineration chamber with a relatively low energy consumption (18). Metal in general is non-combustible, hence energy recovery is not feasible. It is more efficient to recycle metals. Wood waste is a common fuel for incinerators, with a considerable net calorific value (NCV) and low environmental impact thanks to its carbon neutral properties. Nonetheless, it is crucial to control the moisture content in the timber, since that can hamper its combusting effectiveness (18). NCV of common municipal solid wastes are listed in Table 11:

Table 11 Heating value of municipal wastes (51)

Components	MATERIAL COMBUSTION PROPERTIES			
	Moisture	Ash	Combustibles	Heating value
combustible fraction		(%)		(MJ/kg)
textile	7,56	5,76	86,68	16,65
chart board	6,85	11,88	81,27	17,49
soft paper	23,99	12,43	63,58	10,1
plastic foil	0,51	13,24	86,25	40,14
hard foil	0,4	5,28	94,32	40,12
PET bottles	0,42	0,15	99,43	21,51
wood	12,52	2,31	85,17	16,32
styrofoam	1,07	9,98	88,95	27,95

According to this table, NCV of waste wood is 16.32 MJ/kg. Since Vantaan Energia converts waste fuel into both electricity and heat, the efficiency is relatively high, approximately 95 % (18). The cumulative amount of waste wood cascaded from old furniture in Bulevardi is 3785 kg. That gives the following energy yield:

3785 kg * 16.32 MJ/kg * 95 % = 58682.6 MJ

8.2 Emission from incinerator

GHG emissions and other pollutants are the main drawbacks of WTE plants when considering environmental influence. If this method is implemented, there are multiple aspects that can affect the efficiency and emissions of the plant. Most prominently, incineration plants leave a significant amount of carbon footprint. Converting waste into energy via combustion or pyrolysis methods requires a substantial amount of heat and energy. The final by-products commonly include CO_2, CO, NO_x, other harmful gases to biosphere, as well as fly ash (50). With the development of technology, emissions from incinerators have been better controlled and monitored. It has been estimated that combustion of wood emits 0.39 kg CO_2/kwh, or 109.6 kg CO_2/GJ (52). To find out the emission from burning 1 ton of wood, we can conduct the following simple calculations:

1. 1 kg of wood generates 16.32 MJ /1000 = 0.01632 GJ
2. That yields a total of 0.01632 GJ * 109.6 kg CO_2/GJ = 1.78 kg CO_2 per kg of wood
3. 3785kg of wood emits 3785 kg * 1.78 kg CO_2/kg = 6733 kg CO_2

4. With carbon storage, the CO_2 emission is 6733 kg - 3918 kg = 2815 kg

Again, we need to take carbon sink of wood into account. The carbon that is already stored in wood will be released back into the atmosphere upon combustion. Hence, it does not increase the total amount of carbon in the carbon cycle, as explained in section 5.1.2. However, it is still not recommended to use wood as primary fuel for WTE. As stated by Philippe Leturcq in his book, emission from wood combustion is not lower than that of other fuels (53). The total carbon emission from wood is calculated by summing numerical values from Table 5, Table 6 and Table 7.

9 Means of furniture containment and transportation

The next step is to find the most cost efficient method to relocate the furniture. This chapter presents the potential donating target. Follow up is finding the best transporting company and means. Logistical services can be relatively expensive in Finland, especially considering international routes. However, this study will only cover transportation to the processing facilities.

9.1 Containers

For the purpose of long distance relocation, regular 40-foot dry intermodal containers are highly recommended. This type of containers is standardized around the globe. They are compatible with various means of transportations, including lorry, train and shipping through sea via freights. While the 20-foot containers are suitable for carrying heavy cargo, 40-foot containers are geared towards containing voluminous cargo, which is cargo that takes up lots of space (54). Furniture can be categorized as voluminous items since they cannot always be dismantled and put into storage boxes, nor be compressed to minimize their size. Nevertheless, given that the amount of furniture is not large enough to justify the usage of a 40-foot container, the 20-foot type will be used instead for cost efficiency. In practice, most logistic companies in Helsinki only use 20-foot type containers for intra city transportation. The 40-foot type are primarily used for international shipping. The specific characteristics of two containers are presented in Table 12.

Table 12 20-foot and 40-foot container dimensions (55)

	20-foot container	**40-foot container**
Width (m)	2.34	2.35
Height (m)	2.29	2.4
Length (m)	5.9	12.1
Volume (m^3)	33.2	67.7
Weight tare (kg)	2229	3701
Payload limit (kg)	21727	26780

In this case, two most noteworthy dimensions are load capacity and maximum weight limit for a payload. For the 20-foot type, the measurements are 33.2 m^3 and 21 272 kg respectively. In reality, it's relatively challenging to fill up 100 % of load capacity. Furthermore, to provide a cushion surface that protects the cargo, pallets are commonly placed at the bottom of containers. Pallets also enables loading machines to transport and move packages. A standard pallet is about 1000*1200*144 mm in dimensions, weighing approximately 20 kg (56). A 20-foot container can fit 10 of these pallets as described in Figure 10:

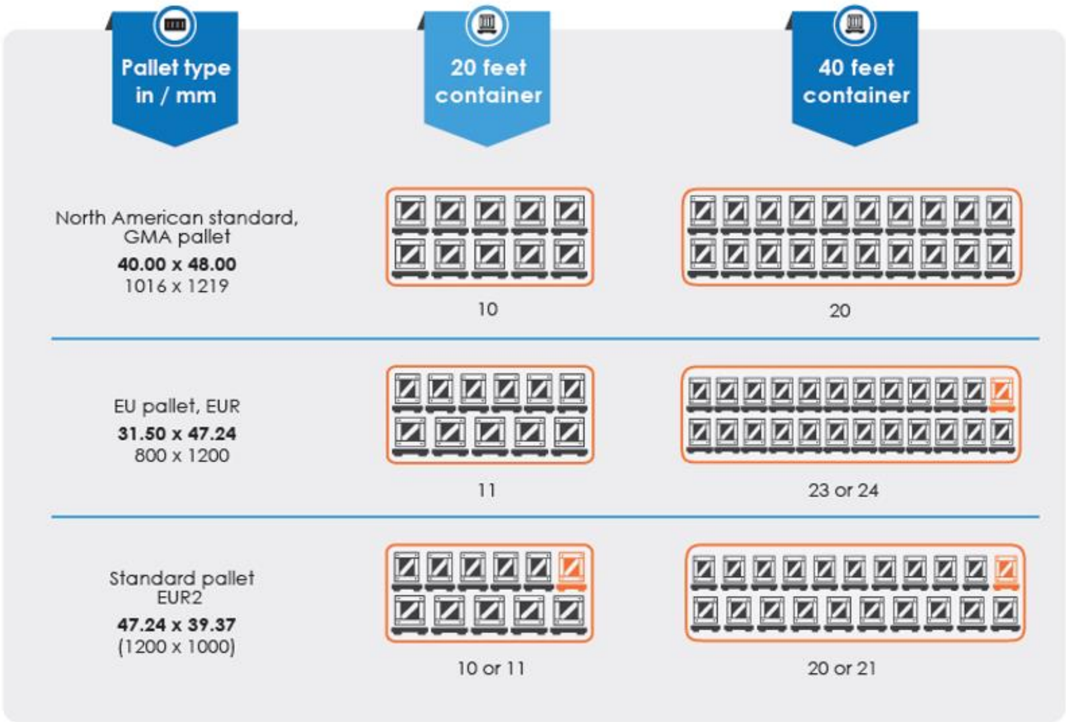

Figure 10. Pallets fitting in containers (57)

Using information in Figure 10, we can conduct following calculations:

1. The accumulated volume: 1*1.2*0.144*10 = 1.79 m^3,
2. Which is: (1.79/33.2) m^3 * 100 % = 5.7 % of a 20-foot container volume.
3. In terms of weight, pallets take up: (20*11/21 727) kg * 100 % = 1.01 %

Another issue is that the used furniture is not pre-packaged, as opposed to newly purchased ones, causing more difficulties during loading and stacking process. It can be assumed that another 10% of volume of the container would be unused. In total, it can be assumed 15.7% of volume would be wasted. Under such assumption, we can estimate that the volume used in a 20-foot container would be: 33.2 m^3 * (100 %-15.7 %) = 27.9 m^3. In case of space shortage, pallets can be removed, which would increase the available volume to 33.2 m^3 * (100 %-10.7 %) = 29.6 m^3.

Using similar calculations, we can estimate the wasted space in a 40-foot container. Its interior capacity is 67.6 m^3. One container needs 21 pallets covering its floor.

1. Total volume of 21 pallets: 1*1.2*0.144*21 = 3.62 m^3
2. Which amounts to: (3.62/66.7) m^3 = 5.4 % of a 40-foot container volume.
3. Again, summing the estimated unused space of 10 %, that gives 15.4 % of wasted volume.
4. Therefore, the actual available volume is: 67.7 m^3 * (100 %-15.4 %) = 57.3 m^3. Without pallets, the available volume is: 67.7 m^3 * (100 %-10.4 %) = 60.7 m^3.
5. In terms of weight, pallets take up: (20*21/26 780) kg * 100 % = 1.57 %

No data about pallet fitting can be found for smaller containers. Therefore, it is assumed that pallets are not necessary in those situations, and the wasted volume of 10 % is used in calculations instead. With this obtained information, we can derive the amount of furniture one container can hold, hence identify the total amount of containers needed. The approximate volume of furniture is approximately 98.2 m^3. **We can arrive at the conclusion that four 20-foot containers would be required to properly fit that amount. If 40-foot containers were used instead, only two would be necessary.** Depending on the planning and budget, either solution is viable. Nonetheless, using two 40-foot container trucks will have lower GWP.

9.2 GHG emission from transportation

In this section, we will find estimations of GHG emission by vehicles during the process of moving and shipping of furniture. Data utilized in this chapter is extracted from webpage LIPASTO Traffic Emission, developed and maintained by VTT Technical Research Center of Finland Ltd. Table 13 gives an insight into emission and fuel consumption by delivery of 6-ton class lorries in Finland.

Table 13 GHG emission and fuel consumption of trucks (58)

	Empty truck	**Fully loaded cargo**
40-ton truck with 25-ton cargo load		
CO_{2e} [g/km]	965	1662
Fuel [MJ/km]	15	25
15-ton truck with 9-ton cargo load		
CO_{2e} [g/km]	436	606
Fuel [MJ/km]	6.5	9.1
6-ton truck with 3.5-ton cargo load		
CO_{2e} [g/km]	287	364
Fuel [MJ/km]	4.3	5.4

The data obtained shows that delivery by 15-ton and 40-ton trucks leads to lower GHG emission, as well as higher fuel efficiency. In terms of environmental impact, it is more advisable to select the larger trucks.

9.3 Moving companies

9.3.1 Niemi Oy

Niemi is a moving and logistics company. Their service comes with assembly and disassembly of furniture. The company has a huge array of equipment and personnel fitting this job. These are data gathered from their website (59) and Office Furniture Project report (40). Their facility is positioned at Pohjoisesplanadi 39, and the price of their services are shown in Table 14:

Table 14 Niemi Oy price list (60)

Transportation price		
Vehicle	**Cargo volume (m^3)**	**Price per hour (€)**
Large truck	25-50	61.29
Small truck	15-22	52.42
Personnel price		
Service		**Price per hour (€)**
Moving		34.68
Assembling/disassembling		42.55

Accumulated cost of using Niemi Oy personnel service for moving and installation is shown in Table 15, assuming a crew of 10 people is hired:

Table 15 Total cost of Niemi Oy personnel service

Item	**Time (hours)**	**Cost (€)**
Installation	4.15	1765
Moving	4	1387
Total	8.15	3152

As deduced from the calculation, the majority of expense is invested into assembling and disassembling furniture. Therefore, it is not recommended to use the instalment services from moving companies, as that will drive the cost astronomically high. It would be more efficient to disassemble all furniture in advance using existing personnel on the campus to avoid extra fees. This solution is more time consuming, but in return is much more economically viable.

9.3.2 Lainaalatikko Oy

Lainaalatikko Oy is another company that provides moving services, including personnel and vehicles. However, their services should only be considered as substitutional option, since their address is at Fonseenintie 1, about 15 km away from Bulevardi campus (60). Table 16 describes the prices of Lainaalatikko company for reference. The drivers can be hired along with trucks, which cost 58 €/h for both. Driver and installer are interchangeable in their roles. The benefit of this company over Niemi, is that trucks can be rented individually for a fixed price per day. This gives a less costly option, provided that a suitable driver can be found.

Table 16 Lainaalatikko oy price list (60)

Item	Price
Driver + truck	58 €/h
Installer + mover	36 €/h
Small truck	140 €/day + 0.4 €/km
Large truck	120 €/day + 1.1 €/km

9.4 GWP and energy consumption from transportation

When the vehicles have been loaded, the next resource consumption phase is transportation. Using satellite imaging from Google, we can devise the most suitable routes for the vehicles. All transportation operations consist of three phases: from the logistic company to Bulevardi, then to the desired destination, and finally return to the starting point. The trucks are empty during the first and last phases, and are only loaded during the second one. Locations of closest facilities are referred from Office Furniture report (40). Data presented in Table 17 was is formulated by estimating distance travelled of trucks while empty and fully loaded, as the emission varies depending on the weight of the vehicle.

Table 17 Total distance (km) covered by Niemi Oy trucks to different locations

Kierrätyskeskus (reuse)	
Distance travelled while empty	6.3
Distance travelled while full	6
Sorting station (recycle)	
Distance travelled while empty	15.5
Distance travelled while full	15.2
Vantaan Energia (WTE)	
Distance travelled while empty	20.5
Distance travelled while full	19.6

One noteworthy outlier in the list is WTE solution. In this scenario, steel and wood would reach separate locations. Wood would be transported to Vantaan Energia and steel to recycling station, since it cannot be combusted efficiently (segment 8.1). Therefore, one truck would travel to Vantaan Energia, and the rest to HSY sorting station. In total, four medium-sized trucks would be used: three carrying steel to the sorting station, and one to the incinerating site. Every other scenario would use two large trucks instead. Given that furniture is transferred to HSY, recycling cost of 39 euros is added. Furthermore, the waiting time of trucks during moving and installation is included for good measures, which is estimated to be 8.15 hours. Finally, the moving and installation cost of 3152 euros is summed with the transportation cost. Overall, the estimated cost, CO_2 emission and energy consumption from gas in all scenario are presented in Table 18:

Table 18 Logistic data in each scenario

Kierrätyskeskus (reuse)	
Cost (€)	4200
Gasoline consumption (MJ)	489
Emission (kg CO_{2e})	32.1
Sorting station (recycle)	
Cost (€)	4313
Gasoline consumption (MJ)	1225
Emission (kg CO_{2e})	80.4
Vantaan Energia (WTE)	
Cost (€)	5117
Gasoline consumption (MJ)	1029
Emission (kg CO_{2e})	68.7

10 Conclusion

In summary, we can condense important data into Figure 11. The graph illustrates cumulative CO_2 emission and energy consumption of all the furniture in Bulevardi from the material extraction phase up until they are removed from the campus. From the acquired information, the reuse option amounts to lowest GWP due to carbon sequestration in wood, and second highest on energy consumption. Recycling generates an average amount of GHG, but consumes most energy. This is primarily contributed by the recovery and treatment of scrap steel. As a result, WTE has the highest emission due to the combustion process, over three times greater than reuse. On the other hand, generated heat and electricity from burning wood compensates for a large proportion of energy. Hence WTE option has the lowest energy consumption.

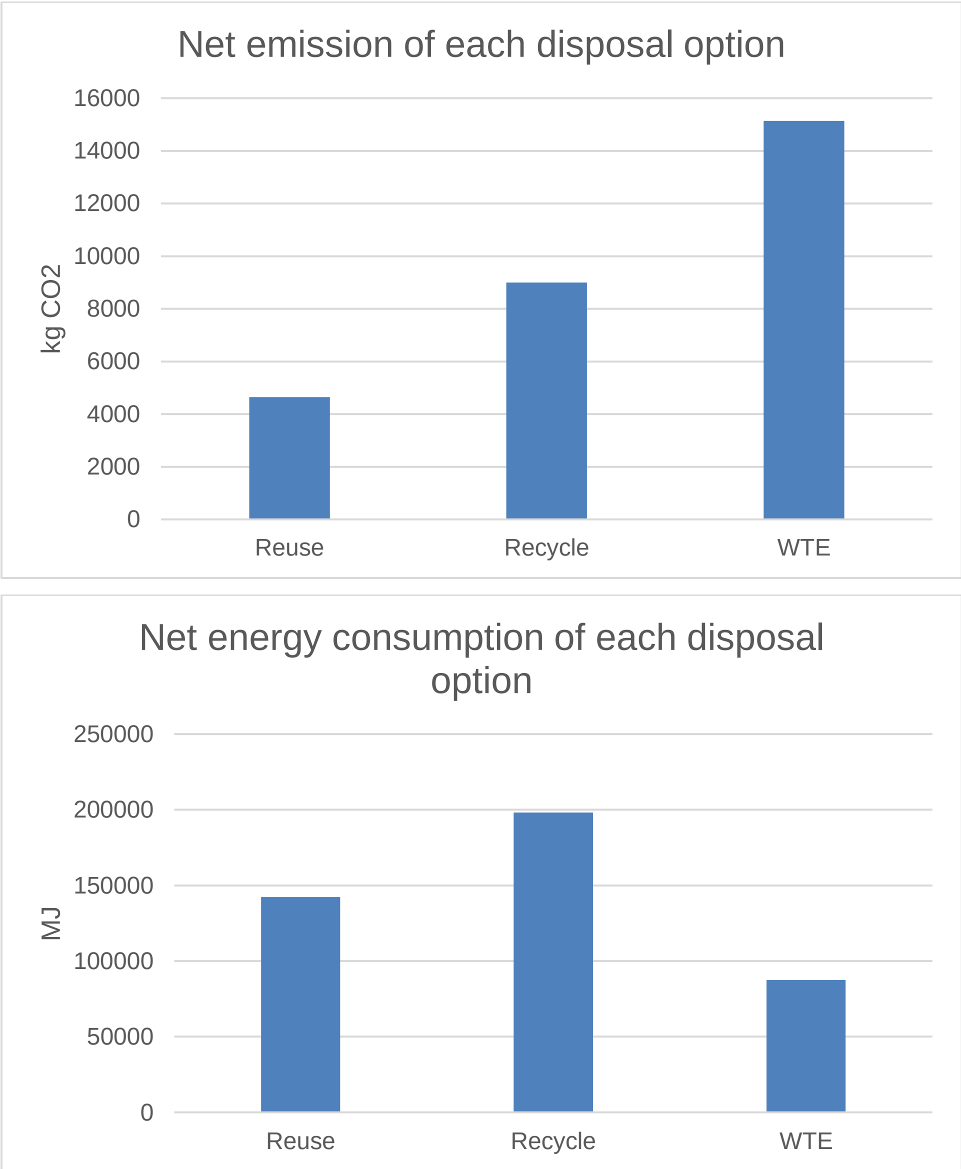

Figure 11 Cumulative environmental impact and energy consumption of each disposal method

Surprisingly, there is not a significant difference between reuse and recycle considering the cost. In case of WTE, separating furniture to two different locations contributed to a substantial cost increase. The price of recycling and reusing are very close, thanks to minimal expense of recycling facility. Overall, reusing is the most efficient solution in terms of GHG emission, money and time. Figure 12 displays the financial burden of each furniture management approach.

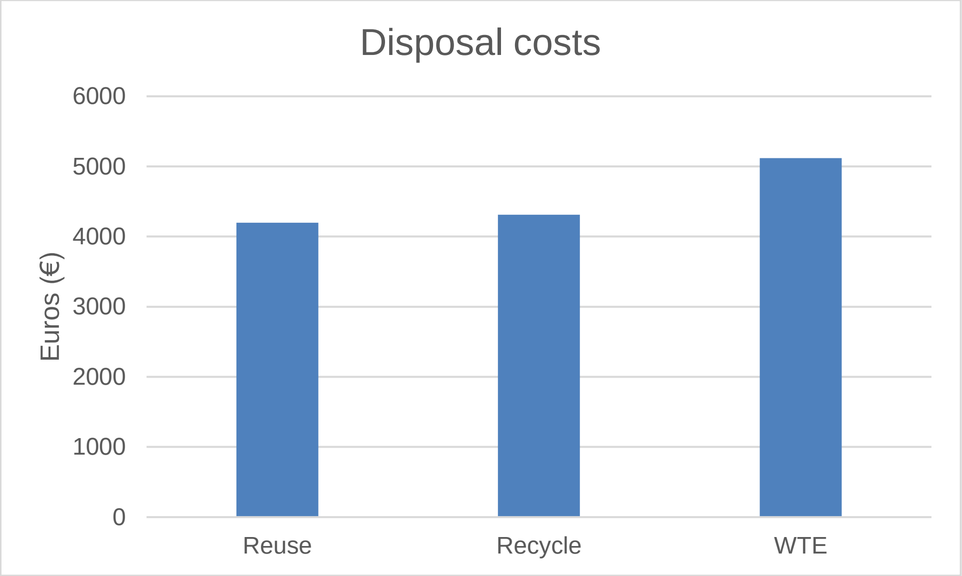

Figure 12 Monetary cost of each disposal option

From the various literary studies, as well as data and calculations established in this thesis, it can be concluded that reusing and recycling options are almost always more preferable to WTE. This is solidified by the fact that a large quantity of material is steel, which is not suitable for combustion. There were a number of obstacles in data acquisition. Primarily, it was not feasible to precisely characterize every type of wood and metal, hence they are generalized as softwood and steel. The problem is further exacerbated by the lack of documents detailing product LCA and WTE facilities in Finland.

Nevertheless, all the outcomes reaffirm the initial proposal by the waste hierarchy model (Figure 5): circular economy surpasses linear economy in regards to finance, efficiency and environmental sustainability. Had the furniture been disposed into landfills, the burden on the environment would have been tremendous. Additionally, no materials would be recovered from the old products; hence, their value would be wasted. Resource scarcity is a tangent threat to global economy and sustainability. In order to solve this issue, we need to adopt innovative strategies in developing our world.

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Appendix 1 : Furniture inventory in Bulevardi 31

Prod-uct/Quantity	**Image**	**Description**
Desk metal legs-big Quantity: 247		H: 73 cm W: 75 cm L: 90 cm WT: 19.8kg Volume normal: 492750cm^3 After disassembly: MDF: 9.3kg, 13410cm^3 Steel: 10.5kg, 6272cm^3 Plastic: 9g, 8.8 cm^3 Disassembly time: 3 min Assembly time: 6.5 min
Wooden chair type 1 Quantity: 192		H: 74 cm W: 45 cm L: 49.5 cm WT: 5.9kg Volume normal: 164835 cm^3 After disassembly: Plywood: 2.76kg, 5095cm^3 Solid wood: 2.86kg, 2700cm^3 Steel: 0.28 kg, 37 cm^3 Disassembly time: 5 min (not rec-ommended) Assembly time: 6 min

Black and white wooden chair Quantity: 43		H: 83 cm W: 42 cm L: 43 cm WT: 5.96 kg Volume normal: 149898cm^3 After disassembly: Plywood: 2.19 kg, 2757cm^3 Steel: 3.67kg, 489cm^3 Plastic: 4g, 4cm^3 Disassembly time: 2.5 min (not recommended) Assembly time: 4 min
Desk metal legs -small Quantity: 28		H: 72 cm W: 50 cm L: 70 cm WT: 13.1 kg Volume normal: 252000 cm^3 After disassembly: Steel: 7.4 kg, 3502cm^3 MDF: 5.7kg, 7547 cm^3 Plastic: 5.6g, 5.5 cm^3 Disassembly time: 2.5 min Assembly time: 3 min

Wooden chair type 2 Quantity: 74		H: 77 cm W: 46 cm L: 54.5 cm WT: 4.98 kg Volume normal: 193939 cm^3 After disassembly: Plywood: 2.1kg, 2644cm^3 Steel: 2.88 kg, 384 cm^3 Plastic: 9g, 8.8cm^3 Disassembly time: 3 min (not recommended) Assembly time: 4 min

Appendix 2 : Small truck emission and energy consumption in Finland

Emission standard	CO2 e [g/km] Empty	CO2 e [g/km] fully loaded (3.5t load)
--> 1992	275	349
EURO I (1993 - 1996)	279	354
EURO II (1997 - 1998)	283	359
EURO III (1999 - 2003)	289	366
EURO IV (2004 - 2007)	285	361
EURO V (2008 - 2013)	290	367
EURO VI (2014 -->	283	357
Average in 2016	**287**	**364**

Emission standard	Energy [MJ/km] Empty	Energy [MJ/km] fully loaded (3.5t load)
--> 1992	4.1	5.2
EURO I (1993 - 1996)	4.2	5.3
EURO II (1997 - 1998)	4.2	5.4
EURO III (1999 - 2003)	4.4	5.5
EURO IV (2004 - 2007)	4.2	5.4
EURO V (2008 - 2013)	4.2	5.4
EURO VI (2014 -->	4.1	5.2
Average in 2016	**4.3**	**5.4**

http://lipasto.vtt.fi/yksikkopaastot/tavaraliikennee/tieliikennee/kajakpienijakelue.htm

Appendix 3 : Medium truck emission and energy consumption in Finland

	CO_2 e [g/km]	
Emission standard	Empty	fully loaded (9t load)
--> 1992	418	593
EURO I (1993 - 1996)	418	588
EURO II (1997 - 1998)	419	591
EURO III (1999 - 2003)	429	605
EURO IV (2004 - 2007)	438	605
EURO V (2008 - 2013)	444	611
EURO VI (2014 -->	444	611
Average in 2016	**436**	**606**

	Energy [MJ/km]	
Emission standard	Empty	fully loaded (9t load)
--> 1992	6.3	8.9
EURO I (1993 - 1996)	6.3	8.9
EURO II (1997 - 1998)	6.3	8.9
EURO III (1999 - 2003)	6.5	9.2
EURO IV (2004 - 2007)	6.6	9.1
EURO V (2008 - 2013)	6.6	9.1
EURO VI (2014 -->	6.6	9.1
Average in 2016	**6.5**	**9.1**

http://lipasto.vtt.fi/yksikkopaastot/tavaraliikennee/tieliikennee/kajaksuurijakelue.htm

Appendix 4 : Large truck emission and energy consumption in Finland

	CO2 e [g/km]	
Emission standard	Empty	fully loaded (25t load)
--> 1992	1005	1657
EURO I (1993 - 1996)	985	1626
EURO II (1997 - 1998)	970	1651
EURO III (1999 - 2003)	968	1688
EURO IV (2004 - 2007)	958	1649
EURO V (2008 - 2013)	966	1659
EURO VI (2014 -->	965	1656
Average in 2016	**965**	**1662**

	Energy [MJ/km]	
Emission standard	Empty	fully loaded (25t load)
--> 1992	15	25
EURO I (1993 - 1996)	15	25
EURO II (1997 - 1998)	15	25
EURO III (1999 - 2003)	15	26
EURO IV (2004 - 2007)	14	25
EURO V (2008 - 2013)	14	25
EURO VI (2014 -->	14	25
Average in 2016	**15**	**25**

http://lipasto.vtt.fi/yksikkopaastot/tavaraliikennee/tieliikennee/kappkatue.htm