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Sustainability of Construction Equipment Rental: Comparison to Owning

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Abstract

The climate change is a product of human activity, according to the fifth report of the IPCC. Shared use, such as rental, is suggested as a sustainable activity. The objective of this thesis is to prove whether the rental is sustainable or not. Due to the limitations in the data gathering, the answer to the hypothesis is inconclusive. Nevertheless, some indications of the relative sustainability of rental are found.

Literature on sustainability of rental is non-existent. Instead, concepts of ‘sharing economy’ and ‘sustainable business models’ are reviewed. Rental is deemed to be included in both of the concepts. However, the sustainability of these concepts is found to be not generalizable.

Sustainability of rental is modelled through a life cycle comparison of rental to owning. The global warming potential is considered as the studied environmental impact. From the construction equipment life cycle, the most important phases were chosen to this study, them being the manufacturing, the transportation and the usage phases. The example products in the study are boom lift, plate compactor and work site lights (LED and compact fluorescent). For the comparison, the data from Ramirent represents the rental. The data on owning was asked from the construction companies, but in the end not enough data was available.

As such the main content of this thesis is the literature review and the methodology on assessing the comparative construction equipment life cycle emissions. Based on the methodology construction equipment carbon dioxide equivalent emissions calculation model was developed.

For the boom lift, the results tell that all phases, the production, the transportation and the usage, are all important, with the relative shares of 30%, 20%, 50%. For plate compactor, and LED and compact fluorescent work site lights, the usage phase is the dominant emissions source (80%-90% of total GHG emissions). The most prominent indication for sustainability of rental derives from the optimization of equipment management of which rental companies with large fleets are well inclined. In addition, mass-to-power ratio of equipment was found to describe the relative importance of the transportation emissions compared to the usage emissions.

Keywords Sustainability, rental, construction equipment, boom lift, plate compactor, work site lighting, LCA, Global Warming Potential

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Tiivistelmä

Viidennen IPCC:n raportin mukaan ilmaston muutos on ihmisen aiheuttamaa. Jaettu käyttö, kuten vuokraaminen, on yksi ehdotettu ympäristöllisesti kestävämpi toimintamalli. Tämän työn tavoitteena on todistaa vuokraamisen ympäristöystävällisyys. Datan generoinnissa ilmenneiden haasteiden takia vastaus asetettuun tavoitteeseen on vaillinainen. Kuitenkin, väitettä tukevia havaintoja löydettiin.

Aiempaa tutkimusta vuokraamisen ympäristöllisestä kestävyydestä, ei ole löytynyt tämän tutkimuksen puitteissa. Sen sijaan, viitekehystä on hahmotettu konseptien 'sharing economy' ja 'sustainable business models' kautta. Vuokraaminen todetaan olevan osa molempia konsepteja. Kuitenkaan, näiden konseptien ympäristöystävällisyys ei ole yleistettävissä.

Vuokraamisen ympäristöystävällisyys on mallinnettu elinkaarianalyysillä rakennuskoneiden vuokraamisen ja omistamisen välillä. Tutkimuksessa tarkasteltu ympäristövaikutus on ilmaston lämpeneminen kasvihuonekaasupäästöjen myötä. Tarkastelu on tehty GWP-kertoimia (Global warming potential) käyttäen. Rakennuskoneiden elinkaaresta merkitsevimmät vaiheet on tunnistettu: valmistus, käyttö ja kuljetus. Tutkitut tuotteet ovat puominostin, levymaantiivistin ja työmaiden yleisvalaistus (LED ja pienoisloisteputki teknologioilla). Vertailun muodostamiseksi, Ramirentiltä kerätty data edustaa vuokraamista. Dataa omistamisesta on kerätty rakennusliikkeiltä, mutta lopulta datan määrä jäi hyvin rajalliseksi.

Siitä johtuen tämän työn pääsisältöä ovat kirjallisuusselvitys ja kehitetty menetelmä rakennuskoneiden elinkaaripäästöjen arviointiin. Menetelmän pohjalta on kehitetty laskentamalli rakennuskoneiden hiilidioksidi-ekvivalentti päästöjen laskentaan.

Puominostimen osalta tulokset kertovat, että kaikki vaiheet (valmistus, kuljetus ja käyttö) ovat tärkeitä: suhteelliset päästöosuudet samassa järjestyksessä ovat 30%, 20% ja 50%. Levymaantiivistimen sekä LED ja pienoisloisteputki valaistukselle käyttö dominoi päästöjä (80%-90% kaikista). Yleisin osoitus vuokraamiseen ympäristöedullisuudeksi omistamiseen verrattuna tulee vuokrausfirmojen suuresta kalustomäärästä. Suurta kalustomäärään voidaan hyvin optimoida, eli käyttää mahdollisimman tehokkaasti, mikä pääasiallisesti on myös ympäristön kannalta tehokasta. Lisähuomiona tutkimuksessa löydettiin, että rakennuskoneiden massa-teho -suhde edustaa hyvin kuljetuksen päästöjen suhteellista osuutta käytön päästöihin verrattuna.

Avainsanat Ympäristövaikutukset, vuokraus, rakennuskoneet, puominostin, levymaantiivistin, työmaavalaistus, LCA

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List of Abbreviations

B2P	Business-to-Peer
CFL	Compact fluorescent (lamp)
CO_2e	Carbon dioxide equivalent
EIO-LCA	Economic Input-Output Life Cycle Assessment
GHG	Greenhouse gas
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt-hour
LCA	Life Cycle Assessment
LED	Light-emitting diode
Mlmh	Million lumen-hours
P2P	Peer-to-Peer
PSS	Product Service System

1 Introduction

1.1 Background

The current consumption patterns are simply unsustainable and will therefore need to be altered if human society is to remain stable and at current (or even larger) population levels. The scientific evidence overwhelmingly demonstrates that humanity, in the past few hundred years, has dramatically disrupted the ecological systems on which it depends. (Assadourian, 2010)

The latest, fifth, assessment report of Intergovernmental Panel on Climate Change states that climate change is extremely likely product of human activity (Stocker *et al.*, 2013). Extremely likely in the report means over 95% in certainty (Stocker *et al.*, 2013). In year 2014, the global ecological footprint was 1.5 times the renewable capacity of the Earth (Global Footprint Network, 2014). Furthermore, “Planetary Boundaries” framework suggests that safe operating space for humanity is already overshoot causing climate change, loss of biosphere integrity, land-system change and altered biogeochemical cycles (phosphorus and nitrogen) (Steffen *et al.*, 2015).

One way to reduce economy’s dependency on ecological resources is through an increasing utilization of ready-made products instead of manufacturing new ones. The sharing economy proposes that solution is shared use of previously underused assets. Companies such as Airbnb and Uber are very prominent examples of achieving higher utilization rates with residential buildings and cars.

Literature on ownership is almost as old as literature itself. More than two thousand years ago Aristotle contemplated that: ‘True wealth is the use of things, not their possession’. The American law states, that the right of self-defence includes the right to protect property ‘as long as the measures are proportionate’. The underlying belief is that the right to inviolability of the body and the right to use physical things to the exclusion of others, are equally unalienable. This is in line with the old adage of owning your own labour and the fruits thereof. John Locke considered this as ‘the natural right of ownership’.

Conversely, Oscar Wilde phrased it ‘the recognition of private property has harmed Individualism [...] by confusing a man with what he owns [...]. So that man thought that the important thing was to have, and did not know that the important thing is to be’. The current, unsustainable, planned obsolescence economy is still subject to these logics of must to own.

The most well-known example behind the sustainability of the sharing economy is that half of the US households own a power drill and in average those power drills are used 6 to 30 minutes during their entire lifetime (Botsman and Rogers, 2010). The simplest form of shared use, sharing with neighbours, is clearly a way to achieve higher utilization rates and save resources of this planet. How about the big picture? What about organized or mediated shared use, such as renting?

The conventional car and equipment rental are older structures than the sharing economy. Furthermore, at the first glance the ideas behind the sharing economy hold these concepts apart. The activities in sharing economy are mostly seen between peers and the key enabler is a modern information technology. However, as Heinrichs (2013) argues the higher utilization rates connected to sharing economy are also elemental possibility of conventional rental business and as such should be studied within the concept.

With construction equipment used by companies, some clear examples, such as household power drills, are not that straightforward to conceive. In a business logic, it would make no sense to buy new equipment if it is only used once. However, there is a wide spectrum between using a product once and using it all the time. The construction equipment rental holds the promise of sustainability through higher utilization rates of assets, but no studies to support that was found.

This thesis aims to provide some answers for sustainability of rental, focusing on construction equipment rental. As no literature regarding the sustainability of rental was found, higher level concepts on sustainability, to which rental relates to, were reviewed. The concepts discussed are 'sharing economy' and 'sustainable business models'. Simplified life cycle assessment is conducted to examine the greenhouse gas emissions associated to the construction equipment.

From this construction equipment life cycle emissions model the difference of renting and owning was planned to be studied through different user scenarios. The scenario representing rental was formulated from the equipment utilization data of Ramirent, and the comparative scenarios were planned to be generated from interviews conducted on construction companies. However, the interviews could not provide adequate information. In conjunction with not enough time available to formulate new round of interviews the user profiles were left uncompleted.

Sustainability of rental was not studied before and as such all the work on aligning rental with 'sharing economy' and 'sustainable business models', conceptualizing the methodology for comparing rental and owning, and the results on construction equipment life cycle emissions can be considered pioneering.

1.2 Construction Equipment Rental

Equipment rental, also called plant hire in some countries, is a service industry providing mostly machinery, equipment and tools of all kinds and sizes (from earthmoving to powered access, power generation to hand-held tools) for a limited period of time to the final users. European Rental Association defines equipment rental as written in *Statistical classification of economic activities in the European Community*, NACE revision 2 code 77.32: "Renting of construction and civil engineering machinery and equipment without operator".

However, the definition of equipment rental is not universal. For example, American Rental Association (ARA) includes in it also party and event equipment rental in addition to construction and industrial equipment rental, and general tool rental. The final users are mainly construction contractors but also industry, public entities and individual customers.

According to ARA total North American equipment rental revenue in 2013 was $38 billion (RERMAG, 2014). Out of this, construction and industrial equipment had the largest share with $22.3 billion, the general tool segment $8.5 billion, and the party and event segment contributed $2.5 billion (RERMAG, 2014). Numbers by European Rental Association (ERA) declare that in the EU-27 and EFTA countries a total rental turnover in 2013 was € 22.63 billion (European Rental Association, 2014).

Rental is a prominent and growing model in the construction business. Development of the rental industry in new markets require a certain level of trust in a country and in a society. Rental agreements in the end are based on trust that the renter is not stealing the equipment. During the study it was identified that the few large construction companies in Finland, who still have their own equipment fleet, operate it through a division or a subsidiary which acts much like a rental company. The rental business model is used to efficiently manage the fleet, but the reason to still own is often attributed to the higher confidence of always getting what is needed.

The equipment rental industry is a relatively new one. First mentions are from the North America at the beginning of 20th century. The American Rental Association was founded in 1955 (Roth *et al.*, 2007). Europe followed a few decades later as many still thriving companies were established in the 50s and 60s such as Cramo and Loxam (Loxam, 2013; Rakentajain Konevuokraamo, 2003). The European Rental Association was founded in 2006 (European Rental Association, 2014).

In Finland, the pioneer of construction equipment rental was Rakentajain Konevuokraamo which was founded in 1953 to serve the post-war reconstruction. Since 2006 Rakentajain Konevuokraamo Oyj has been known as Cramo Oyj (Cramo, 2014). History of Ramirent also dates back to 1955; the name at that time was Rakennusmies and the business started with selling steel nails. Ramirent expanded to the rental market starting from 1983 and only at the beginning of 1990s the rental had become a core business of Ramirent. (Ramirent, 2015b)

Presently, Ramirent is one of the leading equipment rental companies in Europe. In 2014, the net sales of Ramirent accounted to 613.5 million Euros (Ramirent, 2015c) which resulted in it being the third biggest rental company in Europe. From the EU-27 market of € 22.5 billion, share of Ramirent is 2.9 percentages.

Ramirent's leading customer industry is construction, generating 63% of net sales. Then following, is industrial customers with 17% share and services and retail sector with 13% sector. The rest is divided between public and private entities. (Ramirent, 2015c)

1.3 Research objective and outline

The main objective of this thesis is to investigate whether the construction equipment rental is more sustainable than the practice of owning. Four questions and one objective make the core of this thesis.

1. Does literature support the notion of rental being sustainable?
2. How does the life cycle of construction equipment used through owning and through renting differ?
3. What are the life cycle CO_2-equivalent emissions of construction equipment?
4. What kind of utilization scenarios are beneficial through renting?
5. To develop a model to illustrate the findings for various customer cases.

1.4 Thesis structure

This thesis work consists of a literary review and empirical research. In the first chapter a background to this study and construction equipment rental is given. The second chapter contains a literature review on earlier research and discussion on the concepts of 'sharing economy' and of 'sustainable business models'. The purpose of literature review is to indicate basis for sustainability of business model of construction equipment rental. The third chapter describes the research method, the key concepts, the data utilized and the assumptions made. Building from the research method, the fourth chapter explains the developed model. The fifth chapter contains the results. Discussion and conclusions are the chapters six and seven. Finally, the chapter eight is bibliography.

2 Literature

Equipment rental associations and firms often say that renting is fundamentally sustainable (European Rental Association, 2010; Loxam, 2014; Ramirent, 2014b). Reference is often made to how one machine can service many users and that in turn means more sustainable. From within or about the rental industry, no study further elaborating this was found. However, there are other angles to look upon.

When searching about shared use instead of rental there are a lot more publications. The closest reference to how business logic of rental could be sustainable comes from recent publications on “sharing economy” and “sustainable business models”.

2.1 Sharing economy

The sharing economy has only risen to prominence in the last few years. However, the foundation for the name derives from the very old practices of sharing – such as sharing of food, tools and money with family and neighbours. While the sharing economy is not new, it has risen from the hyper-individualization of modern age and it has been reinvented by the “digital revolution” (Botsman and Rogers, 2010; Demailly and Novel, 2014; Hamari et al., 2015; Heinrichs, 2013).

It is essentially a new concept which is actively challenged on several dimensions (Bardhi and Eckhardt, 2015; Belk, 2014; Demailly and Novel, 2014) and does not have a shared definition (Botsman, 2013). Furthermore, there are a few linked concepts such as Collaborative consumption by Rachel Botsman and Roo Rogers (2010) and Collaborative Economy by Rachel Botsman (2013).

Generally, the sharing economy is understood as an emerging phenomenon which contains both economic and social systems, which enable shared access to goods, services, data and talent. The differences on definition are most often about what is included and what is not. Depending on the author, the actors can be individuals, businesses or governments and also their orientation can likewise be for-profit or not-for-profit. For defining, who exactly are considered to be part of sharing economy, the problem is well identified by Boston College professor Juliet Schor (2014): *“When I posed these questions to a few sharing innovators, they were pragmatic, rather than analytical: self-definition by the platforms and the press defines who is in and who is out.”* In this thesis sharing economy is understood in wide definition, containing all the points mentioned in previous sentences.

In 2013, Forbes magazine estimated that the revenue flowing through the sharing economy directly into people will surpass $3.5 billion during that year, with an annual growth exceeding 25% (Geron, 2013). In 2014 PwC estimated that the market size of the five most prominent sharing economy sectors (by their definition) – peer-to-peer (P2P) finance, online staffing, P2P accommodation, car sharing and music/video streaming – is currently $15 billion and could rise to $335 billion by 2025 (PwC, 2014).

There is a strong indication on the sharing economy practices gaining momentum. In addition to the notable pioneer companies, such as Airbnb and Zipcar, cities are adopting sharing initiatives. The City of Seoul announced The Sharing City initiative in 2012 (Rinne, 2014) and the US Conference of Mayors adopted The Shareable Cities Resolution in 2013 (US Mayors, 2013). The Shareable Cities Resolution contain three steps: to encourage better understanding of the Sharing

Economy, to revise the regulations hindering participation to the Sharing Economy, and to make appropriate publicly owned assets available for maximum utilization by the general public through proven sharing mechanisms (US Mayors, 2013). Following the publishing of the Friends of the Earth's Sharing cities report (Agyeman *et al.*, 2013), many cities around the world have since made their own initiatives.

All the authors whose writings have been perused for this study, have differences in their definition of the Sharing economy. The differences vary from marginal to major. Two definitions, one by Botsman and another by Schor, are first explained in this subchapter and then several comments to those are discussed. In the end of this subchapter, a definition of this concept is drafted to be used in this study.

One of the most cited authors on the **Sharing economy** is Rachel Botsman with her book What's Mine is Yours (Botsman and Rogers, 2010) which was written by her with Roo Rogers. Intriguingly though, the term they are using is Collaborative consumption. Instead of sharing, collaboration between people is the nominating idea for their analysis. Many other authors understand the sharing economy similar to the collaborative consumption defined by Botsman, but she makes clear difference between these two (Botsman, 2013).

In the following paragraphs the concept of Collaborative consumption is explained. Then, later on in this subchapter, the definition of the sharing economy by Botsman is discussed alongside all other contrasting views.

The book, What's Mine is Yours, lays a foundation on the hyper consumption experienced nowadays in the western world. How for several decades, owning has been the key nominator of one's success and buying has been the remedy to dullness. People own more and more things and use them less and less. The example given is that half of US households have a power drill whereas most of people only use it for six to thirty minutes during its entire lifetime. Botsman and Rogers argue that collaboration is the key to get more out of these power drills. Not everyone need to own whereas one can be shared by many. (Botsman and Rogers, 2010)

The relationship between physical products, individual ownership and self-identity is undergoing a profound evolution. We don't want the CD; we want the music it plays. We don't want the disc; we want the storage it holds. In other words, we want not the stuff but the needs or experiences it fulfils. As our possessions 'dematerialize' into the intangible, our preconceptions of ownership are changing, creating a dotted line between 'what's mine', 'what's yours', and 'what's ours'. … 'access is better than ownership'. (Botsman and Rogers, 2010)

To a high extent the platform for this new found collaboration is modern information technologies. Internet and mobile phones can facilitate the interaction between individuals like never seen before. (Botsman and Rogers, 2010)

The activities within collaborative consumption are many. Botsman and Rogers make the division into three different concepts: Product Service Systems, Redistribution Markets and Collaborative Lifestyles. In their definition the actors can be individuals, businesses and governments alike. (Botsman and Rogers, 2010)

Product Service System (PSS) is a concept, a business model, for achieving higher sustainability with various products. Sustainability is thought to be driven by the adjustment of business towards selling access, function or services instead of just the physical product. Rogers and Botsman have simplified the PSS array into two models: 'usage PSS' and 'extended-life PSS'

(Botsman and Rogers, 2010). Full array of PSSs is discussed in the following subchapter, Sustainable business models.

The first model, ‘usage PSS’, consists of products which:

- have high idling capacity (cars or household tools);
- have a limited use because of fashion (handbags);
- fulfil a temporary need (baby equipment and maternity clothes);
- diminish in appeal and value after usage (a film);
- have high investment cost (solar panels)

For such products, different models of accessing and utilizing are applicable, such as rental, lease and sharing. (Botsman and Rogers, 2010)

The latter model of ‘extended-life PSS’ is a case where an after-sales service such as maintenance, repair or upgrading becomes an integral part of the product’s life cycle, thereby reducing the need for replacement or disposal. Products that are expensive or require specialized knowledge to repair (electronic goods) or products that need to be updated or frequently maintained to preserve their appeal (furniture) are well suited to this type of product service system. (Botsman and Rogers, 2010)

The **redistribution markets** are market places of digital age where the focus is on markets of second-hand products. Modern information technology enables very convenient platform for an individual to get rid of things which they no longer need and in turn for searching second hand products in one’s proximity. With the easier exchange of products, consumption has a convenient way to be more collaborative. Active redistribution markets are such as Ebay, Amazon, huuto.net and tori.fi. All of these are also markets for new products and use money as a medium of exchange. Redistribution markets can also be solely giving for free (freecycle.com) or swapping products to products (swap.com). (Botsman and Rogers, 2010)

Whereas redistribution markets are about products, **Collaborative Lifestyles** are about less-tangible assets such as time, space, skills and money. Before this age of individualism, strong neighbourhoods were a common phenomenon. Time, space, skills and money were shared with neighbours with a hope of a payback on a later day. Growth of mobile and digital technology with real-time communication are seen as a force to revitalize these Collaborative Lifestyles and with location based GPS applications the limited notion of neighbourhood is expanded to a wider audience. There are programs such as time banks, where an hour of work can be exchanged to an hour of someone else’s work, and co-working spaces for the likes of freelancers and start-ups. (Botsman and Rogers, 2010)

To summarize, Botsman and Rogers have identified a growing trend of collaboration in consumption. Key drivers behind this are interest in saving money, easiness of information sharing through digitalization, reducing material clutter in people's lives and rising need for communality. All of these supposedly lead to less material consumption as the products made are used to a higher extent. (Botsman and Rogers, 2010)

The definition for collaborative consumption used by Botsman includes also businesses as an actor, and rental is mentioned as one part of ‘usage’ PSS. Even though Botsman and Rogers lean towards new businesses growing out of possibilities of modern information technology, there is no ruling out made to exclude the conventional rental practise. It even aligns completely with the phrase ‘access is better than ownership’.

The second definition to 'the sharing economy' is given by Professor Juliet Schor through her essay (Schor, 2014), based on more than three years of study on both non-profit and for-profit initiatives in the "sharing economy". Her first notion is that coming up with a solid definition, which reflects the common usage, is nearly impossible. The reason being that there is a great diversity among the activities as well as baffling boundaries drawn by participants.

First she defines that sharing economy fall into four broad categories which are:

- recirculation of goods,
- an increased utilization of durable assets,
- an exchange of services,
- and sharing of productive assets.

These four contain virtually the same ideas as in the collaborative consumption by Botsman and Rogers. *The recirculation of goods* is a synonym to the redistribution markets. *The increased utilization of the durable assets* is very closely aligned to 'usage' PSS. And *the exchange of services* have very similar notions as collaborative lifestyles. (Schor, 2014)

Finally, her idea of *sharing the productive assets* is something new. The focus on this sharing of assets and space, is to enable production, rather than consumption. She mentions cooperatives as the historic form these efforts have taken. Other examples of this category are hackerspaces, makerspaces, co-working spaces and educational platforms such as Skillshare.com and Peer-to-Peer University. (Schor, 2014)

Schor further divides the sharing economy actors by their market orientation (for-profit vs. non-profit) and market structure (peer-to-peer (P2P) vs business-to-peer (B2P)), as shown in Table 1. These dimensions shape the business models by their platforms, the logics of exchange, and the potential for disrupting the conventional businesses. (Schor, 2014)

Table 1: Sharing economy division to market orientation and market structure. Reproduced from (Schor, 2014).

		Type of Provider	
		Peer to Peer	**Business to Peer**
Platform Orientation	**Non-Profit**	Food Swaps, Time Banks	Makerspaces
	For-Profit	Relay Rides, Airbnb	Zipcar

She further explains that while all sharing economy platforms effectively create "markets in sharing" by facilitating exchanges, the imperative for a platform to generate a profit influences how sharing takes place and how much revenue devolves to management and others. There is a big contrast between for-profit platforms such as Airbnb and Uber pushing for revenue and asset maximization, and non-profit initiatives such as tool libraries and food swaps. The latter of which do not seek growth or revenue maximization, but instead aim to serve needs, usually on a community scale. (Schor, 2014)

Schor regards the for-profit vs. non-profit division as the more important one, but states that the other division between the P2P and B2P platforms is also significant. The peer-to-peer entities earn money by commissions and exchanges, so the revenue growth depends on increasing the number of trades. In contrast, B2P platforms often seek to maximise revenue per transaction, as traditional businesses often do. Finally, she questions should public goods with government-to-peer structures, such as libraries, be included. (Schor, 2014)

By this definition, rental can be included as it is a practise which is increasing utilization of durable assets, and it has for-profit orientation in business-to-peer market structure.

In the widest definition, what can a sharing economy can contain? Owyang (2014) has made an extensive visual representation of what the sharing economy market, in his own words collaborative economy market (Figure 1), looks like. He divides the market into six discrete families of goods, services, space, food, transportation and money. Furthermore, these families are broken down into 14 sub-classes within which there are example companies presented.

Figure 1: Collaborative Economy Honeycomb (Owyang, 2014)

It is worth noting that in the goods sector and under the loaner products sub-sector, companies like Rent the Runway and Bag Borrow and Steal are mentioned. In essence, the only thing differentiating these companies from conventional rental is the innovation on what products to rent, respectively designer party dresses and hand bags.

According to Owyang there is nine key market forces. For societal drivers these are desire to connect, sustainable mind set and population increase. The economical drivers are financial climate, untapped idle resources and that startups are currently being heavily funded. The last three of the key market forces are grouped under technology enablers: internet of everything, mobile technologies and social networks. (Owyang, 2014)

When evaluating **the contrasting** views on sharing economy and its definition, the key aspect is in the word 'sharing'. Various authors argue that sharing should be preserved for the traditional meaning of sharing, where the money generally is not changing hands (Bardhi and Eckhardt, 2015; Belk, 2014; Eberlein, 2013; Parsons, 2014).

Bardhi and Eckhardt (2012), through their research, make a distinction between owning, sharing and accessing. Furthermore, they propose that the most prominent examples of companies in the sharing economy should instead be regarded as companies of access economy (Bardhi and Eckhardt, 2015). Their research on Zipcar suggests that consumers are more interested in lower costs and convenience than they are in fostering social relationships with the company or its other consumers.

In their analysis the key benefits of the access economy is the convenient and cost effective access to valued resources, flexibility, and freedom from the financial, social, and emotional obligations embedded in ownership and sharing (Bardhi and Eckhardt, 2012). This view heavily contradicts the expectations that the sharing economy would be inherently more environmentally fair and socially just economic model, as proposed by the previously discussed authors.

With a similar results, Hamari et al. (2015) conducted a study on motivations of people to participate in the sharing economy. They note that the sharing economy has been expected to alleviate the societal problems such as hyper consumption, pollution, and poverty by lowering the cost of economic coordination within communities. In contrast, based on their study, they suggest that sustainability might only be an important factor for those people for whom ecological consumption is important. In the sharing economy they also notice a significant attitude-behaviour gap; people perceive the activity positively and say good things about it, but this good attitude does not necessary translate into action.

Belk enters this discussion from the angle of sharing in internet. He makes clear distinction between sharing and pseudo-sharing. The former he describes with examples like contributing to a Wiki, writing code for an open source program, offering goods for free through the platforms like Craigslist and Freecycle, and online facilitated hospitality such as CouchSurfing. The latter, the pseudo-sharing, he describes as a business relationship masquerading as communal sharing. He still notes that it may not be altogether unwelcome and it may be beneficial to all parties as well as friendly to the environment. (Belk, 2014)

Belk further elaborates his view that the key intention in sharing is not granting or gaining access, but helping and making human connections. Hospitality is a good example. But in an affluent Internet age sharing may be losing some of the moral power and sharing character that it once had (Belk, 2014). As Eisenstein (2011) argues, technology has had a major part in this development:

"The technology of the phonograph and radio helped turn music from something people made themselves into something they paid for. Storage and transportation technologies have done the same for food processing. In general, the fine division of labour that accompanies technology has made us dependent on strangers for most of the things we use, and makes it unlikely that our neighbours depend on us for anything we produce. Economic ties thus become divorced from social ties, leaving us with little to offer our neighbours and little occasion to know them. The monetization of social capital is the strip-mining of community… the oft-lamented vacuity of most social gatherings arises from the inchoate knowledge, 'I don't need you.'"

From the interviews conducted by PwC (2014) with sharing economy industry specialists, they reach similar elusive conclusion that no single label can neatly encapsulate this movement. For some, the word 'sharing' was a misnomer, a savvy-but-disingenuous spin on an industry they felt was more about monetary opportunism than altruism. For others, more apt titles included the Trust Economy, Collaborative Consumption, the On-demand or Peer-to-Peer Economy. Yet in between the haggling over the most-accurate moniker, there was uniform agreement that the so-called sharing economy is getting very big, very fast.

Three years after the publishing of her book, Botsman explained her definition of sharing economy in an article named "Sharing economy lacks a shared definition" (Botsman, 2013). Her definition of the sharing economy and how it positions in the big picture is expressed in Figure 2. She limits the sharing economy to be only half of the collaborative consumption, representing P2P activities and half of the B2C activities. By several other views, not only the collaborative consumption but even the collaborative economy is regarded as a synonym to the sharing economy. The PwC study (2014) cited earlier also defined sharing economy closely to the extent of collaborative economy by Botsman (2013) and Owyang (2014).

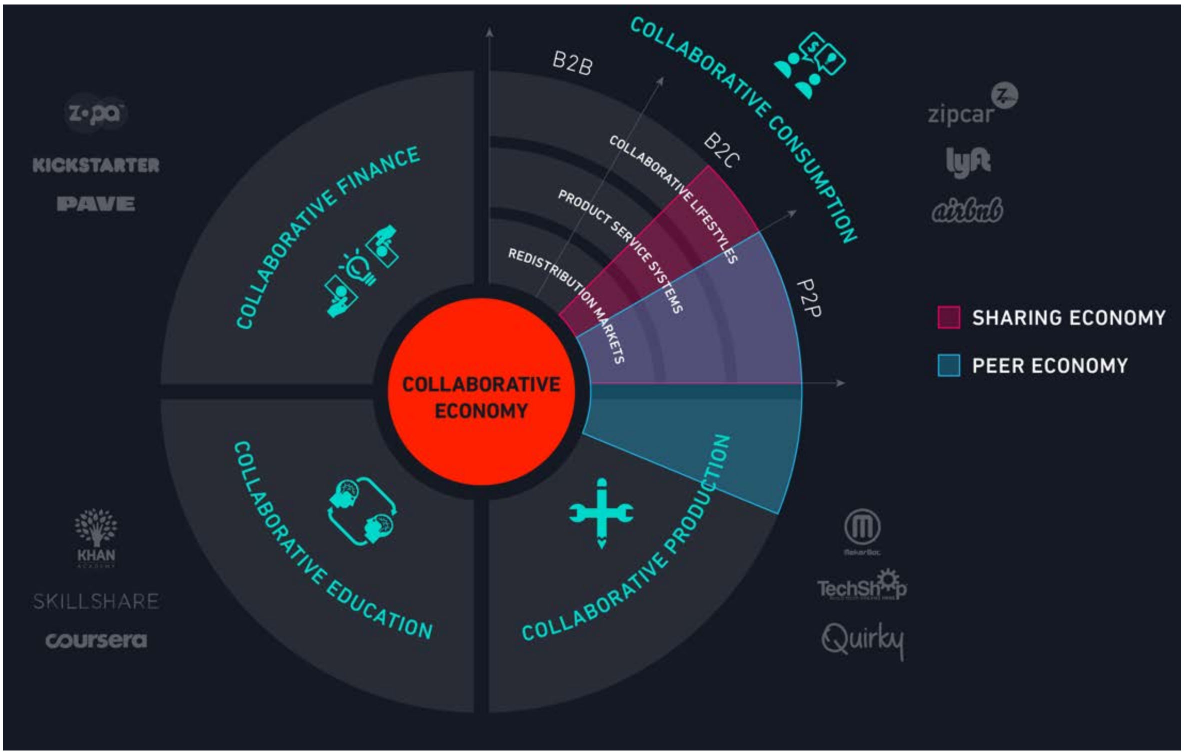

Figure 2: The complete picture of collaborative economy by Botsman (2013)

Regardless of the problems in the definition, the sharing economy is hailed by many with major possibilities. For Heinrichs, sharing economy could add a new perspective to the search for more fundamental sustainability visions. He emphasises the need of efficiency strategies to be checked rigorously regarding the rebound effect. Academic discourse on the sharing economy is lagging behind public discourse and practice. In his view, new development with relevance to sustainability seem to appear especially at the interface between product service systems, redistribution markets, and collaborative consumption. Furthermore, these forms of alternative ownership and usage should not be limited to end-consumer or peer-to-peer sharing but should include business-to-business relationships and the activities of civil society actors and government entities. (Heinrichs, 2013)

Heinrichs (2013) further considers the sharing economy as a promising pathway to sustainability but one still lacking a clear definition and robust research on its potential. Furthermore, he calls for unifying the fragmented landscape of academic discourse under this umbrella term of sharing economy. He proposes two reasons why this would be beneficial: 1. potentially game-changing new developments, such as the roles of information and communication technologies and social media, have not been incorporated in most work on similar topics. 2. The current debate on the sharing economy provides an opportunity for moving alternative ideas and approaches into the mainstream and developing a more comprehensive and stronger vision for sustainable development than there has been so far.

Parsons on his essay on the political evolution of the sharing economy (Parsons, 2014), sees it as a promising concept to better economic, ecological and social development. He emphasizes that the highest promises lie in the grassroots: activities which harness the resources of a community and grow its wealth unlike the mainstream economy. Economy, which in his view, mostly generates wealth for people outside of people's communities, and inherently generates extreme inequalities and ecological destruction.

He claims the problem to be that the so-called sharing economy, which is usually heard of in the media, is built upon a business-as-usual foundation, which is privately owned and often funded by venture capital (as is the case with Airbnb, Lyft, Zipcar). He concludes that, as a result, the same business structures that created the economic problems of today, are buying up the new sharing economy companies and turning them into ever larger, more centralised enterprises that are not concerned about people's well-being, community cohesion, local economic diversity or sustainable job creation. (Parsons, 2014)

Parsons finishes his essay discussing the inherent problem of the sharing economy. The problem derived from the wide approval of different activities under a single term. Parsons writes: "Unless the sharing of resources is promoted in relation to human rights and concerns for equity, democracy, social justice and sound environmental stewardship, then the various claims that sharing is a new paradigm that can address the world's interrelated crises is indeed empty rhetoric or utopian thinking without any substantiation." (Parsons, 2014)

On a similar tone, Professor Juliet Schor writes: "Will the sector evolve in line with its stated progressive, green, and utopian goals, or will it devolve into business as usual? This moment is reminiscent of the early days of the Internet, when many believed that digital connection would become a force for empowerment. The tendency of platforms to scale and dominate (think Google, Facebook, and Amazon) offers a cautionary tale. It is too early for definitive answers to these questions, but important to ask them." (Schor, 2014)

Furthermore, Eberlein (2013) in his article makes an interesting notion that is “sharing” already turning into the new “green”, another once well-intentioned word that has become an overused and mostly meaningless marketing gimmick.

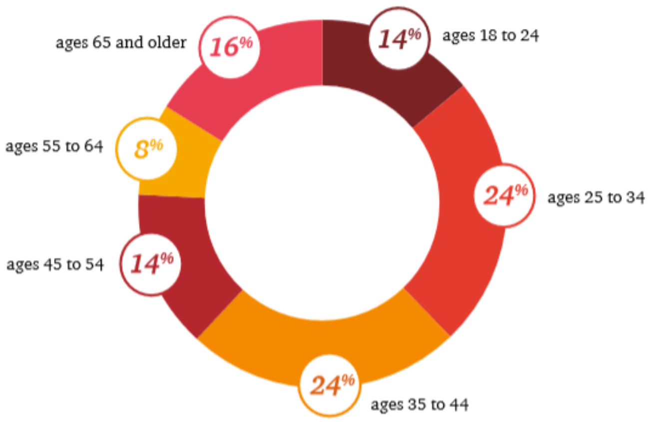

Figure 3: The sharing economy providers divided by age in US (PwC, 2014)

To analyse **who is participating** in the sharing economy, PwC made an internet survey for the US (PwC, 2014). The total sample of the study was 1000 respondents, of which 44% were familiar with the sharing economy. According to the survey, 7% of the US population are providers in the sharing economy and they cut across age and household income, as shown in Figure 3 and Figure 4. Even though, the definition appears to be elusive these charts well illustrate the wide participation on the sharing economy.

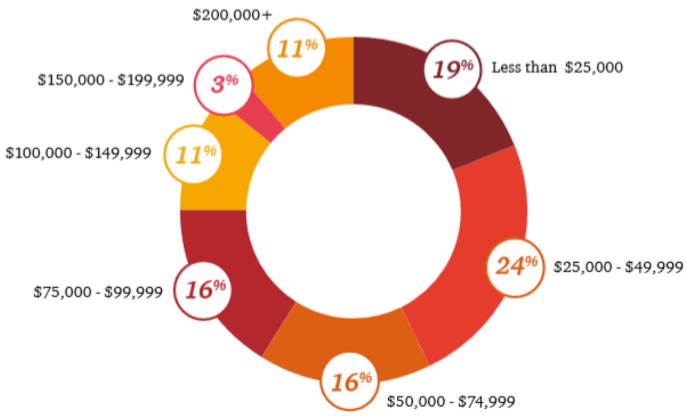

Figure 4: US providers in the sharing economy grouped by household income (PwC, 2014)

Whether we are talking about direct exchanges between individuals or through private companies, associations or public services, with or without monetary exchange, many practices can enable the optimization of the use of goods, services, data and space through "sharing".

As such, in this study, **the definition of a sharing economy** is understood with wide applicability. In essence, this means that: businesses, private persons and governments all are possible providers and participants; also both the for-profit and the not-for-profit activities are included; and for activities whole range covered by illustration (Figure 1) made by Owyang (2014) is included. This aligns with the general definition mentioned in the beginning of this chapter: Sharing Economy is a phenomenon which contains both economic and social systems which enable shared access to goods, services, data and talent.

As demonstrated by the literature, the critical discussion on the meaning of the word 'sharing' has a considerable merit. However, since this word is already applied to wide extent it would be really challenging, if not impossible, to regain the 'pure' meaning of sharing that Belk (Belk, 2014) calls for. Also, this wide definition makes it even harder to apply attributes like sustainability on the concept because the activities contained are so vast and diverse. The environmental sustainability of the sharing economy is discussed in the following subchapter. In addition, as identifiable by the quality of sources used in this subchapter and also as many authors noted, the research and academic discussion on the sharing economy is limited (Demailly and Novel, 2014; Heinrichs, 2013; Schor, 2014).

Demailly and Novel point out that, in particular, the analysis of the sustainability of the models is hampered by the lack of studies and its dissemination. They write that it is true for its environmental impact, but also for its economic and social impacts. Beyond the life cycle assessments that could be carried out, it is crucial to better understand how sharing models transform goods and their uses. (Demailly and Novel, 2014)

2.2 Environmental sustainability of the sharing economy

The sharing economy has been promoted as a solution for ecologically sustainable economic growth. However, there is only a few and even then limited studies to hint that. In this subchapter, the conceptual discussion on the sustainability of the sharing economy is first presented. Then for the second half of this subchapter, four empirical studies are presented. The conclusion reached is that the sharing economy has the potential for sustainability, but the concept is too wide for generalizing all activities within the sharing economy to be sustainable.

For some highly under-utilized assets the sustainability of sharing can be quite clear but the big unanswered question lies on whether assets with medium utilization can reach sustainable outcomes by raising utilization rates. Furthermore, there is the case of high utilization assets which could supposedly go for maximum utilization.

Many sharing economy actors advertise themselves as green and present sharing as a way to reduce carbon footprints. According to Schor (2014): It is a truism among "sharers" that sharing is less resource intensive than the dominant ways of accessing goods and services (e.g., hotels, taxis, shopping malls) because of the assumed reduction in demand for new goods or facilities. However, the actual environmental impacts are far more complicated.

Demailly and Novel make similar notion on how the reduction of the ecological footprint is often raised by sharing economy entrepreneurs as an intuitive benefit of these emerging modes of consumption: the practices considered enable a better use of underutilized capital, an increase in the usage rate of material goods, and thus help to reduce the amount of material goods that need to be produced to ensure the same level of service. (Demailly and Novel, 2014)

Schor continues that the ecological benefits of sharing are often seen as obvious: such as secondary markets reducing the demand for new goods, and therefore footprints go down. She further notes, that despite the widespread belief that the sector helps to reduce carbon emissions, there are almost no comprehensive studies of its impact. Schor argues that at this point, they are long overdue. In her view, the ordinary, general assumptions about the ecological impacts are generally about the first, visible shift made by a consumer – purchasing used products rather than new ones, or staying in a private home rather than a hotel. (Schor, 2014)

As she says, to assess the overall ecological impacts, the ripple effects have to be considered. What does the seller or the host do with the money earned? She may use the money to buy high-impact products. Does the appearance of a market for used goods lead people to buy more new things that they intend to sell later? If travelling becomes less expensive, do people do it more? All of these effects raise the ecological and carbon footprints. (Schor, 2014)

There is also the question of impacts at the level of the economy as a whole. The platforms are creating new markets that expand the volume of commerce and boost purchasing power. If so they are likely creating new economic activity that would not have existed otherwise – more travel, more private automobile rides – and not just shifting purchasing from one type of provider to another. (Schor, 2014)

Four studies concerning the actual environmental sustainability of sharing economy practices were found. First is about shareable household goods, second about Airbnb and the last two deal with the practice of carsharing. Furthermore, contrasting argument by Schor to sustainability of Airbnb is included even though she is not properly citing the studies she hints about.

Damien Demailly from Paris-based Institute for Sustainable Development and International Relations (IDDRI), and journalist Anne-Sophie Novel published a report titled The Sharing Economy: Make It Sustainable in July 2014. The main objective of that report was to analyse the environmental potential of the sharing economy, considered in its full diversity, and the conditions for the realization of this potential. The analysis is based on a literature review, French statistics, and a workshop with 40 actors keen on the subject with differing backgrounds from business, government and academics.

In their analysis, "shareable" goods (Clothing, vehicles, furniture, telephones, televisions, toys, sporting goods, home improvement and gardening tools) account for about a quarter of the total household expenditure and a third of household waste. Their finding is that, if the sharing models could be operated under the most favourable conditions, households could achieve savings of up to 7% in the household budget and 20% in terms of waste. (Demailly and Novel, 2014)

They make a clear note that the environmental balance sheet of sharing depends on the several conditions which are highly specific to each model. In general, they note that, there is an emergence of the following issues:

- the sustainability of shared goods, e.g. renting may enable a reduction in the number of goods produced - provided that the rented good does not wear out much faster;
- the optimization of the transportation of goods, because the long distance transport of goods is reduced while transport over shorter distances is increased;
- and consumption patterns, as sharing models can be the vector of sustainable consumption but also a driver of hyper consumption. (Demailly and Novel, 2014)

Demailly and Novel note that the pitfall of the redistribution markets is a new form of “hyper” consumption. Research on eBay shows that bestselling goods are clothes and fashion accessories. In this category eBay have identified group of people under definition of “fashionistas”. These “fashionistas” may sell their clothes to buy more new or used ones, in a strategy of accelerated renewal if not resulting in an increase in their wardrobe size, leaving the environmental impact very uncertain. (Demailly and Novel, 2014)

Important notion by Demailly and Novel is that in peer-to-peer models environmental impact depends heavily on the user behaviour and on the values that drive their actions. (Demailly and Novel, 2014)

An Airbnb commissioned study (Airbnb, 2014), conducted by Cleantech Group, analysed over 8,000 survey responses from hosts and guests worldwide and researched on residential and hotel sustainability levels and practices. The study found that in North America an average Airbnb guest uses 63 percent less energy than an average hotel guest and also consumes less water. But the important rebound effect of the cheaper accommodation leading to an increased consumption elsewhere is only partly touched. The press release plainly says that the study found the environmental benefits of home sharing to far outweigh the impacts of the induced travel. As no numbers are presented it is questionable what exactly is calculated in that.

In contrast, Schor (2014) hints that according to her and her students' research, Airbnb users are taking more trips and the availability of cheap ride services is diverting some people from public transportation. She concludes that these platforms result in higher carbon emissions, because their services use energy. Furthermore, she insists that the companies cannot have it both ways – creating new economic activity and reducing carbon emissions – because the two are closely linked. However, she cites no studies.

Martin et al (2010) conducted an online survey of over 6,000 North American carsharing members in the late 2008. The questions asked were about the travel behaviour of respondents’ households during the year before they joined carsharing, and about their travel behaviour “at present”. Also the number, model and year of vehicles owned were inquired. They found out that after participating to carsharing the number of vehicles owned per household dropped from 0.47 to 0.24. For fuel economy the shared cars were 30% more fuel efficient. Furthermore, from these findings and evaluating the sample population, they estimate that every carsharing vehicle removes between 9 and 13 other vehicles from the road.

Martin and Shaheen (2010) also conducted a follow-up research focusing on GHG emissions of carsharing. Similarly to previous study, over 8000 North American carsharing members were surveyed on how their transportation behaviour has been affected. The results indicated that in average the emissions decreased by 0.58 tons of GHG per household per year for the observed impact. An important notion in this study was that the reduction is not generalizable across all members or even a majority of members. Rather, carsharing as a system facilitates large reductions in the annual emissions of some households, which compensate for the collective small emissions increases of other households.

According to Demailly and Novel, the carsharing is the most studied model, and where the results are not only the potential optimization of vehicle usage but there is an additional benefit that a shared car is not used in the same way as a private car. As presented by the two previous studies, sharers are travelling less with a private car compared to owners, favouring public transport options. Interesting question is raised that does in general the distancing users from a good open up new areas for innovation that could encourage ecological transition. (Demailly and Novel, 2014)

As explored in this subchapter, sharing economy can be a vector for sustainable development. However, there is only few studies and the activities it contain are so diverse that **the environmental sustainability of sharing economy cannot be generalized.**

2.3 Construction equipment rental in sharing economy

As expressed in previous chapters conventional rental can be aligned as part of the sharing economy. However, there are also construction equipment equivalents of Airbnb established. San Francisco based startup companies such as KWIPPED, getable and Yard club connect businesses and organizations which need to rent equipment with those that have equipment available to rent. Traditional rental companies can offer their equipment through these platforms but also traditional construction companies and contractors have in addition to renting the needed equipment the option to rent out their own idle-assets.

Yard Club, founded in 2013, got backed up in spring 2015 by prominent construction equipment manufacturer Caterpillar. Through this agreement Yard Club have now a coverage of several metropolitan markets throughout the U.S. and Canada due to Caterpillar dealer rental inventories being added in. In general, higher rental rates hurt sales of new machinery but Caterpillar supports customers who prefer to rent “because it may mean that contractor can bid on or complete more projects”. (Hagerty, 2015)

Interestingly Caterpillar is also investing heavily on the technology and data analytics by buying a startup to speed up development of its telematics[1] and crunching more data to deliver more predictive diagnostics to enable more repairs before a failure on its machines (Grayson, 2015). Caterpillar reinforced that commitment with the creation of an Analytics & Innovation division whose vice president Greg Folley said about the Yard Club agreement: “With all of the advances in peer-to-peer technology going on around us, we asked ourselves, why shouldn’t our customers have the ability to share assets to increase efficiency and lower the cost of ownership?” (Grayson, 2015)

One of the identified problems of rental which these rising companies answer to is the complexity of ensuring fair prices from multiple rental providers. Through these platforms the customer can leave just one equipment request which then will be distributed to all suitable providers.

[1] Construction equipment telematics means tracking of data, such as operating hours, location and fuel consumed, and diagnostics.

Essentially, only one request is needed to get offers from all market players streamlining the process noticeably. (Salter, 2015)

2.4 Sustainable business models

Sharing economy is one connection for exploring the sustainability of rental. Research on ‘sustainable business models’ provides another point of view. The business models discussed in previous subchapters are, in general, also sustainable ones, but those are only a few of many. However, it must be noted that similarly to research on ‘sharing economy’ the academic discussion on sustainable business models is still relatively young.

Sustainable business models are opened by first defining business model. Then it is narrowed to sustainable ones through categorization found from literature. Subsequently, the Product service systems are explored as they are the most related model to rental. The conclusion reached is that the rental is a sustainable business model, but the literature only gives it the promise of sustainability, which needs to be researched further on.

What is a **business model?** By one definition it is a conceptual tool to help understand how a firm does business, and it can be used for analysis, performance assessment, comparison, management, communication and innovation (Osterwalder *et al.*, 2005). Business models deal with how the firm defines its competitive strategy through the design of the product or service it offers to its market, how it charges for it, what is costs to produce, how it differentiates itself from other firms by the value proposition, and how the firm integrates its own value chain with those of other firms in a value network (Rasmussen, 2007).

In addition, business models for sustainability have a triple bottom line approach to define performance and to consider a wide range of stakeholder interests – including environment and society – into the way business is done. In contrast to conventional business models, sustainable business models are not only about satisfying customer demand and generating economic value for the company. Businesses with sustainable business models seek (also) to contribute positively to society and the environment rather than exploiting these through the way they do business. (Bocken *et al.*, 2014)

Those businesses, which adopt sustainable business models, may be more resilient and competitive in the longer term by recognizing the interdependencies between their business, and the society and environment in which they operate (Bocken *et al.*, 2014). There is growing evidence to support that already: studies by Harvard Business School professor Eccles et al. (Eccles *et al.*, 2012), environmental risk management non-governmental organization CDP (Fox, 2014) and management consulting firm A.T. Kearney (Mahler *et al.*, 2009) show that companies which are performing best in sustainability are also performing better than their peers in conventional business performance. Furthermore, big investors, such as Norway sovereign wealth fund (Carrington, 2015), French insurance company Axa (Patel, 2015), and Rockefeller Brothers Fund (RBF, 2014) are divesting from companies which have high environmental risks, most notably from coal industry.

Sustainable business models are needed for the sake of sustainability but are showing also hints of high economic performance. Bocken et al. (2014) evaluated the current academic discourse on the subject to formulate categorization in their article *A literature and practice review to develop* *sustainable business model archetypes*. The categorization is shown in Figure 5. They conclude in eight archetypes: Maximise material and energy efficiency, Create value from waste, Substitute with renewables and natural processes, Deliver functionality rather than ownership, Adopt a stewardship role, Encourage sufficiency, Repurpose for society/environment and Develop scale up solutions. These eight can be grouped to technological, social and organizational archetypes. First three being technological, following three social and last two organizational, as defined by their core activities.

For rental the most relevant archetypes are Maximise material and energy efficiency and Deliver functionality rather than ownership. **Maximising material and energy efficiency** means doing more with fewer resources, generating less waste, emissions and pollution. This contains much of the existing work on industrial sustainability but is distinct from mere process innovation in the sense that 'maximising material and energy efficiency' should run through the entire business and subsequently enhance the value proposition. (Bocken *et al.*, 2014)

Efficiency in material and energy use should always be an important objective, but its tendency to rebound effects when used in isolation cannot be ignored (Bocken *et al.*, 2014). The rebound effect is further explained in the end of this subchapter.

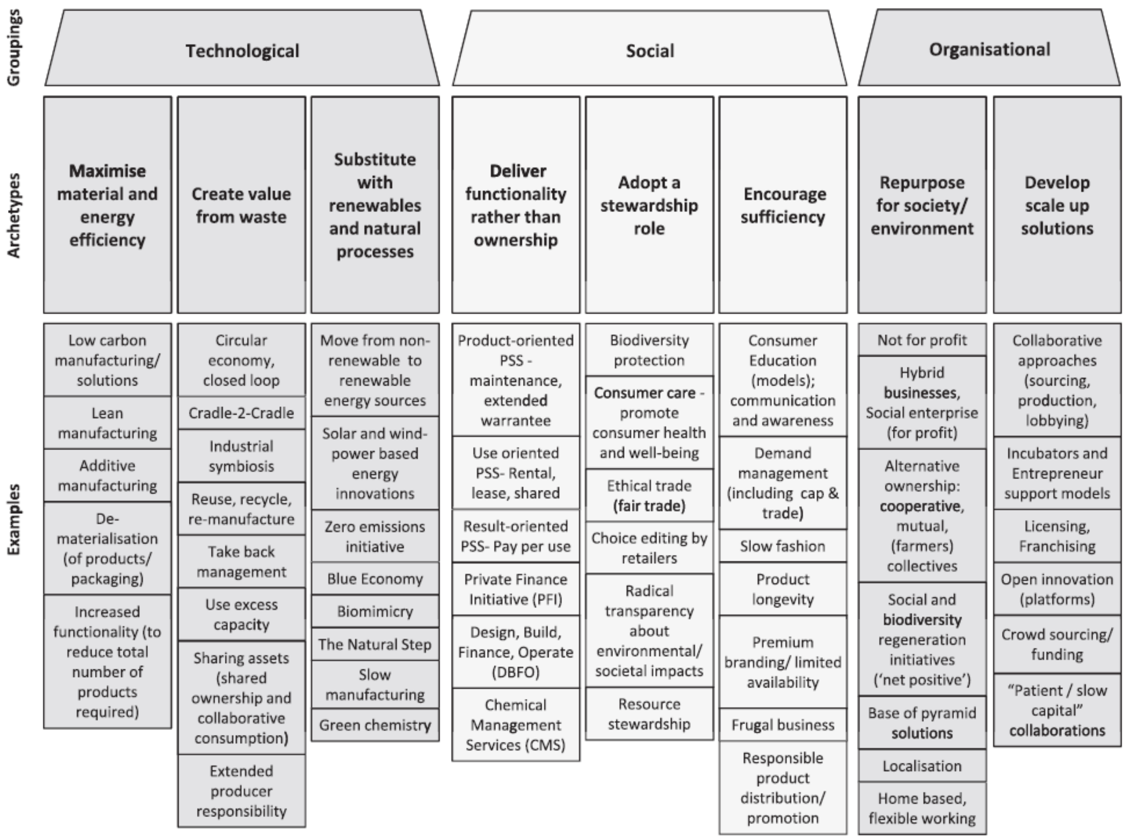

Figure 5: Sustainable business model archetypes (Bocken et al., 2014)

For rental 'Maximise material and energy efficiency' means the opportunity of maximizing utilization rates of equipment. As rental companies operate larger fleet of equipment than construction companies they have more room to optimize the utilization. Also equipment is the core of a rental business so they can have more focus on using it in the most efficient way. Furthermore, rental companies typically have newer equipment and therefore can achieve higher benefits from the technological efficiency improvements.

The sustainability of "**Deliver functionality rather than ownership**" is not that self-explanatory. The definition by Bocken et al. (2014) says "Provide services that satisfy users' needs without having to own physical products." Furthermore, the Product Service Systems discussed in previous subchapter are in the core of this archetype. Key concern here is how companies shift the business model from offering a manufactured product to offering a combination of products and services. The product is still important but customer experience is fundamental to the offering or value proposition.

Whereas, Botsman and Rogers (2010) divided Product Service Systems into two: 'usage PSS' and 'extended-life PSS', in this categorization there are 'product-oriented PSS', 'use-oriented PSS' and 'result-oriented PSS'.

Tukker (2004) further explains that the difference between these three PSSs are division between product content and service content, which is elaborated by Figure 6. The division here can be illustrated by power drill and home owner needing two holes. Outside the product service systems, the left most, the pure product, approach is to sell the power drill. The second option, the product-oriented service, means still selling the product but on top of that offers services such as a maintenance contract, a financing scheme or consultancy on how to use the power drill most efficiently.

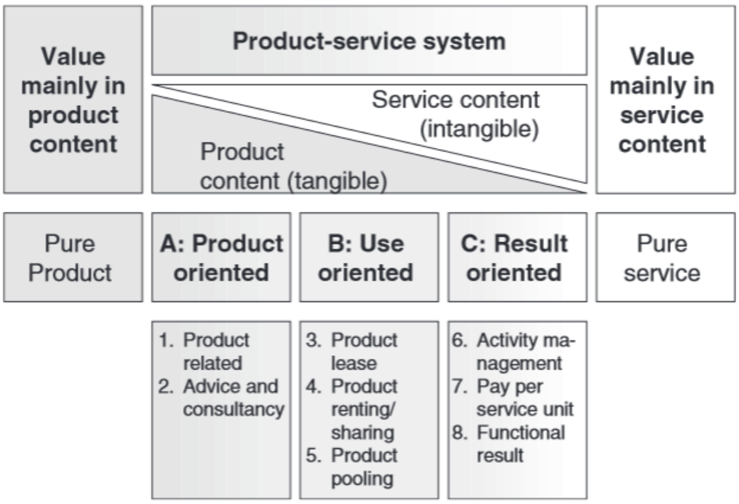

Figure 6: Main and subcategories of Product service systems (Tukker, 2004)

The use-oriented service is where the conventional renting stand. Here, the power drill still plays a central role, but the business model is not geared towards selling it. Instead it is rented, leased or shared only for the time it is required. In the result-oriented service, 'pay per service unit' means that you pay by the amount of holes drilled. More understandable example in this category is the pay-per-print formulas now adopted by most copier producers. Following this formula, the copier producer takes over all activities that are needed to keep a copying function in an office available. The right most, the pure service, then would be someone else coming to drill the two holes for you.

Literature suggests that potential benefits of this approach of better alignment of the customer's needs with that of the manufacturer are (Bocken *et al.*, 2014):

- Breaks the link between profit and production volume (but probably not usage volume)
- Can reduce resource consumption
- Motivation and opportunity to deal with through-life and end-of-life issues as the manufacturer retains ownership of assets
- Enhanced efficiency in use
- Enhanced product longevity/durability
- Reuse of materials

This, Deliver functionality rather ownership, archetype has the potential to change consumption patterns, in particular by reducing the need for product ownership. In addition, it may incentivize manufacturers to develop products that last longer and design for upgradability and reparability, potentially reducing resource use (Bocken *et al.*, 2014).

However, according to Mont and Tukker (2006), the literature and the practice indicate that Product Service Systems and models are not inherently more eco-efficient and consumers are unsure whether they will live up to their expectations. Furthermore they note, that the product-service systems have had higher environmental impacts than the previous situation in several cases. For to PSSs to have sustainable impact they need to designed with that goal.

Bocken et al. (2014) discuss PSSs as something for manufacturers only to do, but in essence rental operator can be the provider of PSS-like service to manufacturer. For realizing the best benefits of this archetype rental companies need to have close collaboration with manufacturers.

From the categorization of sustainable business models it is clear that rental belongs there. But, the sustainability of sustainable business models seems to be more of a possibility than true attribute of certain business model. With these findings, **rental is a sustainable business model** and as such it has the potential to be sustainable. However, with the current knowledge it still has to prove the reality.

Sustainability is presently popular word in media, businesses and organizations. Sustainability has already been adopted into many practices and it is important to make the difference between meanings of sustainability: even in the ecological sustainability there is absolute sustainability and relative sustainability. Relative sustainability is the more common understanding, which means that for product or service to be sustainable it has to have reduced environmental impact compared to competing product or service. Relative sustainability as such does not contain the ecological limits defined by one planet. For absolute sustainability the human impact on and the limits of a one planet are the starting point of analysis. In this thesis sustainability is regarded as relative unless specified otherwise.

Human impact on the planet can be expressed with a simple equation formulated by Paul Ehrlich and John Holdren in the early years of 1970s. The Ehrlich equation tells us quite simply that the impact (I) of human activity is the product of the three factors: the size of the population (P), its level of affluence (A) expressed as income per person and a technology, or eco-efficiency, factor (T), which measures the impact associated with each unit of money we spend. (Jackson, 2011)

$$\boldsymbol{I = PAT} \tag{1}$$

For as long as the *T* factor is going down there is progress on relative sustainability done. However, to have a chance for absolute sustainability the technological advancement *T* has to outrun the growth of population *P* and income per capita *A*. Even more so, *I* may already be over sustainable value.

The historical data on global carbon dioxide emissions paint a grim picture. Carbon intensities have declined on average by 0.7 percent per year between 1990 and 2008. Whereas, population has increased at a rate of 1.3 percent and average per capita income has increased by 1.4 percent each year over the same period. Efficiency has not even compensated for the growth in population, let alone the growth in incomes. Instead, carbon dioxide emissions have grown on average by 1.3 + 1.4 – 0.7 = 2 percent per year, leading over 17 years to an almost 40 percent increase in emissions. (Jackson, 2011)

The rebound effect can be illustrated through the discussed equation. The Ehrlich equation is intuitively interpreted as describing how three independent variables contribute to environmental degradation in a multiplicative manner. However, all three variables are interdependent (Huesemann and Huesemann, 2007). The most relevant mechanism here being the influence of technology factor (*T*) on the material affluence factor (*A*). A decrease in *T* often induces an increase in *A*. This phenomenon is known as the rebound effect, and may occur because increases in eco-efficiency often result in cheaper goods and services due to reductions in raw material and energy use (Bjørn and Hauschild, 2013).

There are indirect and direct rebound effects. In the direct rebound increase in technology or eco-efficiency (*T*) of a product leads to higher consumption (*A*) of it. The direct ones has been documented empirically by a number of researchers with cases such as, increases in fuel efficiency for cars have resulted in consumers generally driving longer distances (Bjørn and Hauschild, 2013), and increases in the insulating properties and/or a switch to cleaner fuels for the heating of households leads to their inhabitants generally choosing a higher indoor temperature (Sorrell *et al.*, 2009).

The indirect rebound effect is a phenomenon where increase in technology or eco-efficiency (*T*) of a product or service leads to increased consumption (*A*) of another product or service. The reasons why that would happen range from money and space to time. The indirect rebound effect is more difficult to study empirically and its effect on environmental impact is controversial. An indirect rebound effect is such as that the reduced price leads to consumption elsewhere, or a service requiring shorter time is rebounded by time used elsewhere. (Bjørn and Hauschild, 2013)

3 Research Method

Rental equipment contains very diverse collection of items. Ramirent has 200 000 different items to rent and when grouped with certain power or size and independent of a manufacturer there are over ten thousand category classes. Category classes are such as, “Plate compactor petrol 100kg”. As established in the literature subchapter, environmental concerns when comparing renting to owning are not well researched.

Therefore, it was decided that this thesis would take a brief look on the big picture of construction equipment life cycle. Then, to identify the most feasible way to make well-grounded conclusions in conjunction with the goal of having a wide perspective on rental equipment. Following that, during the extensive discussions with the experts from Ramirent, three products (initially four) were identified to represent equipment rental cases. Selected items are diesel powered telescopic boom lift, plate compactor and work site lighting. These three items cover wide selection of important research questions.

The research methodology is explained in this chapter. Firstly, the method of study, life cycle assessment is described. Then, the subject of study, how to assess sustainability of rental is conceptualized. Finally, the used data sources are discussed.

3.1 Life Cycle Assessment

Life cycle assessment (LCA) is a methodological framework to estimate and assess the environmental impacts of goods and services to our societies. It was developed for common methodology to achieve better comparability of environmental impact studies. Key idea with LCA is that every product has a “life”, starting with design and development of the product, followed by resource extraction, production, use/consumption and finally end-of-life activities (collection, reuse, recycling and waste disposal). (Rebitzer *et al.*, 2004)

In this study the LCA framework is used as a rough guideline to methodology. Full LCA is not conducted because it is too cumbersome. Furthermore, the purpose of this study was to identify the most important sustainability aspects which still are researchable with moderate effort. LCAs are presently often conducted with robust computer software containing vast databases of unit processes making the process easier. However, this study was done without any commercial LCA software.

All activities, or processes, in a product’s life result in environmental impacts due to consumption of resources, emissions of substances, and other environmental exchanges. Whole product life completes a cycle, which is represented in Figure 7. Including the whole life cycle into the analysis avoids the problem of partial optimization of results. For example, an improvement in one stage, which only moves the impact to other stage, is a bad improvement (Rebitzer *et al.*, 2004). The life cycle presented below is for the purposes of explaining a concept. A simplified life cycle, applied for this study, is discussed in subchapter 3.3 Life cycle of construction equipment.

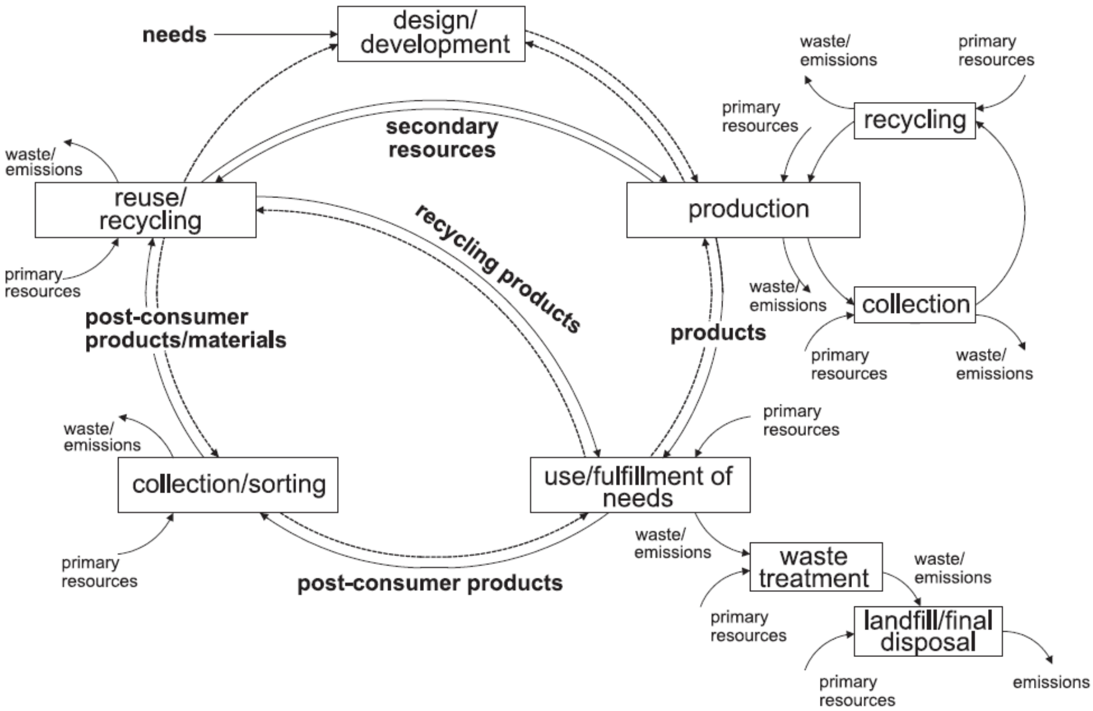

Figure 7: Schematic representation of a generic life cycle of a product (the full arrows represent material and energy flows, while the dashed arrows represent information flows) (Rebitzer et al., 2000)

The procedures of a life cycle assessment are part of the ISO 14000 environmental management standards: in ISO 14040:2006 and 14044:2006. The standards state that Life Cycle Assessment consists of four distinct phases which are Goal and Scope Definition, Inventory Analysis, Impact Assessment and Interpretation, as illustrated in Figure 8. The phases are often interdependent in that the results of one phase will inform how the other phases are completed, which can be seen in the two-way arrows in the figure.

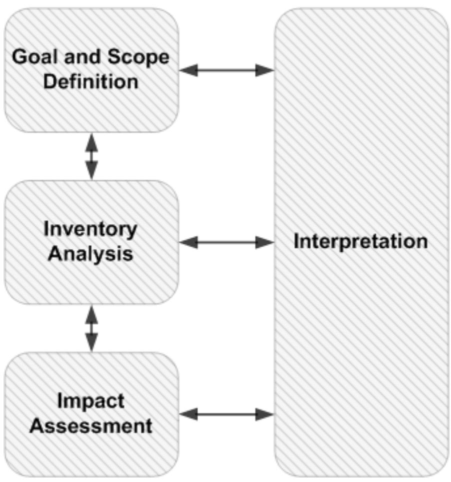

Figure 8: Illustration of LCA phases (Public domain)

The goal of this study is to determine the environmental impact of construction equipment usage and whether the practice of rental has lower environmental impact than the practice of owning. The chosen impact category for this analysis is the global warming potential (GWP), measured in carbon dioxide equivalents (CO_2e).

Global warming is caused by several atmospheric gases, known also as greenhouse gases (GHG). All of these gases have differing warming potential which is also relative to time interval under review. To sum all of these potentials, gases are converted to relative global warming potential of carbon dioxide with values defined by Intergovernmental Panel on Climate Change (Myhre *et al.*, 2014). Resulting number is the global warming potential, also carbon dioxide equivalent. GWP over 100 years was chosen to be the impact which is studied in this thesis.

The scope, or the boundaries, of this study start from the raw material extraction until the end of use phase. Two functional units are used: for the construction machinery grams of CO_2e per machine work hour, and for the work site lighting, grams of CO_2e per million lumen hours. The goal, the impact category, the boundaries, the functional unit, the used assumptions and limitations are further discussed in the following subchapters.

The general **Life cycle inventory analysis** estimates the processes within the life cycle and the associated material and energy flows, as well as other exchanges which are modelled to represent the product system and its total inputs and outputs from and to the natural environment, respectively (Rebitzer *et al.*, 2004). The idea of the inventory analysis is used in the construction equipment emissions model in this study but it is applied only in a very simplified manner, as only CO_2e impacts are estimated and modelled.

For the most part the data sources in this study are already in CO_2e units. Furthermore, for the raw materials, design and manufacturing, all information is already combined in the data source, EIO-LCA model. EIO-LCA stands for Economic Input-Output Life Cycle Assessment of which the methodology and the model used are presented in subchapter 3.7.

Life cycle impact assessment, in this study, concentrates on the Global Warming Potential, which is in itself represented by the carbon dioxide equivalent emissions.

3.2 What Environmental Impacts Are of Interest?

As long as humans will exist, they will always have an impact on the environment. Everything from breathing and walking makes an impact on this planet. During the most of natural history collective human impact has been limited on global scale. However, local environmental disasters have been known at least since the beginning of farming. As one of the Sumerian clay tablets reads, “the earth turned white” (Desha *et al.*, 2010), already 4,000 years ago in Mesopotamia over-farming lead to salinization of soil and eventually to a collapse of a civilization.

Human impact today is bigger than ever, both by the size of people and the size of economy. In this study global warming potential has been chosen as an impact to study. The rest of this subchapter discusses on what environmental impacts could have been chosen and why the choice of GWP is made over the others.

Large number of indicators and supporting methodologies are feasible for estimating the different impact categories in LCA. Pennington et al. (Pennington *et al.*, 2004) have gathered following typical impact categories from several authors:

- Climate change
- Stratospheric ozone depletion
- Human toxicological effects
- Ecotoxicological effects
- Photooxidant formation
- Acidification
- Acidific eutrophication
- Terrestrial euthrophication
- Extraction of abiotic resources
- Extraction of biotic resources
- Land use impacts

Each of these categories are further divided into many specific indicators, such as for climate change “Increase of radiative forcing (GWPs)” and “Increase in crop and primary production damage”. Impact categories here include indicators of global effect, such as the increase of global warming potential, but also very local impacts such as a construction project causing change in land use.

Another prominent concept in identifying important environmental impacts is “Planetary boundaries” proposed by Rockström et al. (2009) and updated by Steffen et al. (2015). The former article identified nine “planetary life support systems” essential for human survival, and attempted to evaluate and quantify just how far these systems have been pushed already. The latter article further defined the concept, result of which is presented in Figure 9.

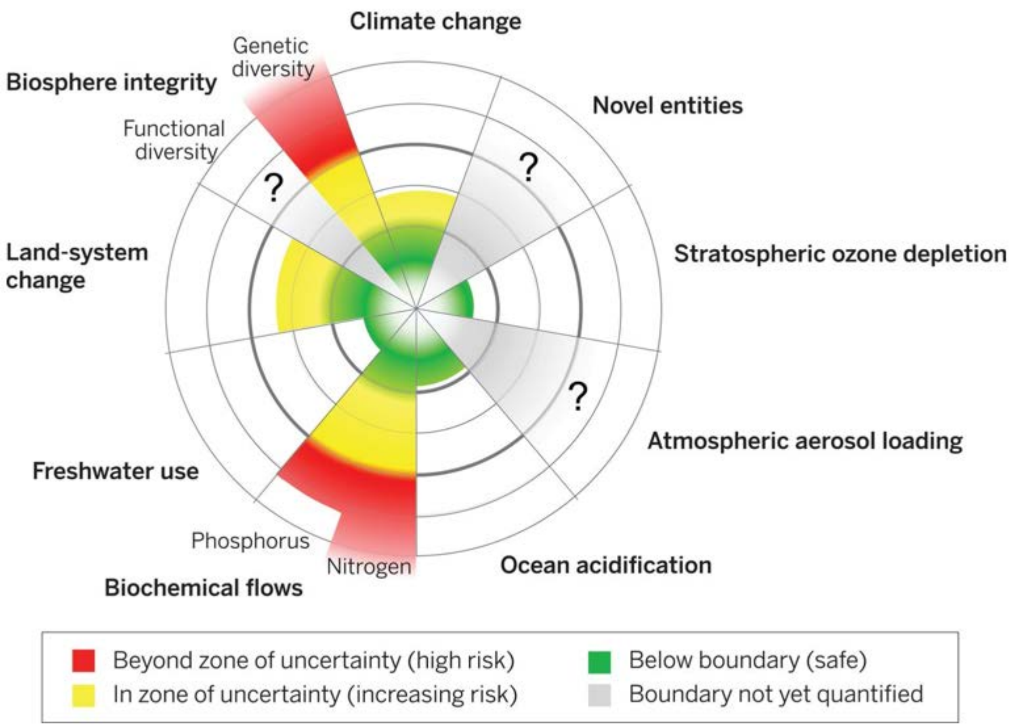

Figure 9: Planetary boundaries and the associated risk levels (Steffen et al., 2015)

There are many important environmental indicators of human impact. For this pioneering study on environmental sustainability aspects of rental business, the whole range of indicators mentioned here are too manifold to study. What are the most important impacts caused by construction equipment, and more precisely when comparing rental to owning?

One of the initial premises and assumptions of this study was that maybe through renting less machines are needed, which would lead to smaller production and thus to lower material consumption. Therefore, impact on abiotic resources would be interesting aspect to study. However, with initial literature review and manufacturer contacts, it became evident that the information on material consumption of construction equipment manufacturing was not readily available.

Soil pollution and surface water pollution are introduced by the construction machines, heavy ones especially, which are dominantly powered by diesel and also contain other toxic substances such as lubrication oils. EU and Finland have in place a regulation of handling toxic waste in repair and maintenance of machinery, and it is just as binding for both equipment owners and rental providers. As there is no significant difference in owning or renting in this aspect, therefore, soil pollution and surface water pollution was considered to be out of the scope of this study.

True to its name, global warming is a phenomenon that has worldwide impact. Carbon dioxide equivalent emissions which represent global warming potential are information that is gathered around the world, from both countries and businesses. United Nations Framework Convention on Climate Change (UNFCCC) is trying to achieve legally binding and universal agreement on climate, limiting CO_2e emissions, from all the nations of the world. Also, some companies are compensating their emissions by funding projects which cut CO_2e emissions in developing countries, at times reaching net zero CO_2e emissions level.

For construction equipment CO_2e emissions can be found for the relevant phases of manufacturing, usage and transportation. Definitely, GWP is not extensive measurement for environmental impact, but it is a good indicator of one of the most urgent global environmental issues. Therefore, global warming potential is chosen as the environmental impact to study.

3.3 Life cycle of construction equipment

Life cycle thinking is an approach to study products and services which integrates the whole range and cycle of impacts, instead of limiting the study only to one most obvious impact. It takes into account the impacts from beginning to the end, from extraction of raw materials to the disposal or recycling of the product or service, and not, for example, limiting the impact of a car only to the gasoline burned when the car is driven. Life cycle thinking has been applied to several frameworks when optimizing impacts of the whole life cycle instead of optimizing one stage at the cost of another. Applications are used in environmental, economic and social fields.

Fundamentally, all construction equipment have similar life cycles, but there are differences to note on details. As explained in subchapter 3.1 Life Cycle Assessment, at the beginning of a product life cycle, the raw materials for it are extracted. Then, from the possibilities of materials, item is designed and manufactured. Next, it is delivered to customer where it is used, repaired, stored and moved between working sites. After this usage phase, equipment is generally sold to next customer where a new usage phase begins. Alternatively, after the first usage phase, but generally for construction equipment after two or three phases, the equipment is scrapped, recycled or refurbished (Vandenbroucke *et al.*, 2010).

Generalization made for TYKO 2012 work machine model says that construction machines have two distinct usage phases: younger than average age and older than average age(Mäkelä *et al.*, 2000). For most of the machines at the younger than average age they have higher usage hours per year, but for some, the usage hours per year before and after average age is the same(Mäkelä *et al.*, 2000). Person lifts and aerial work platforms are not considered in that model but assumption is made from the TYKO 2012 data on tele-handlers, cranes and drivable diesel work machines in general, and from expert interviews. Based on this information, the average age of a boom lift is estimated to be 9 years and the usage hours per year, after the average age, are assumed to be half of the hours in the first usage phase. The usage hours per year for the first usage phase were found from Ramirent boom lift statistics.

Plate compactors are included in TYKO 2012 and thus the available data on petrol fuelled plate compactors is used. Average age is 9 years and there is no difference in usage hours before or after average age. From TYKO 2012 usage hours per year are 200. With Ramirent plate compactor utilization rate and assumed 4 hours of machine use per rented day the relative value is 211 usage hours per year.

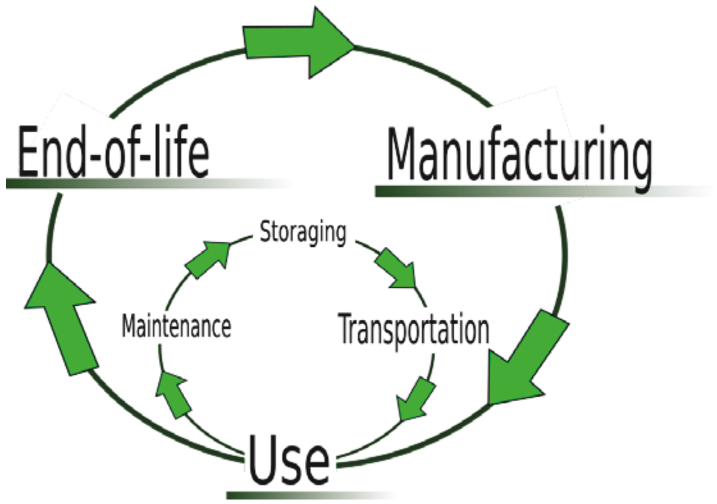

Figure 10: Life cycle of a product, respective to this study

In Figure 10, there is a presentation of a construction equipment life cycle as regarded in this study. The manufacturing contains a whole range of processes from extraction of raw materials, through design and production until packaging and distribution. However, as EIO-LCA provides all this data in a single value, only manufacturing is discussed in this study. The usage phase (Use) contains use, maintenance, storing and transportation of equipment. This smaller cycle represents the rental cycle.

It follows the equipment, how it is first transported to a customer, then used, followed by new transportation to maintenance and storing. Then, it is transported to the next customer and so on, thus the rental cycle functions. From this usage phase, use and transportation are activities which are examined in detail in this study. Maintenance and storing are considered to be not so relevant for this study, as will be explained in the following subchapter. Sale from the rental company to the new owner is regarded as End-of-life, from which a new usage phase starts. End-of-life also contains recycle, and disposal.

However, as the perspective of this study is comparative, the life cycle framework is applied with some modifications. The general idea behind the assumption that the shared use is more ecological than private use, comes from the thought that an individual cannot use a product to its full capacity. This idea is illustrated in the scenario in Figure 11 where individual usage rate of 7 out of 16 weeks is enhanced to 16 out of 16 weeks through two additional users.

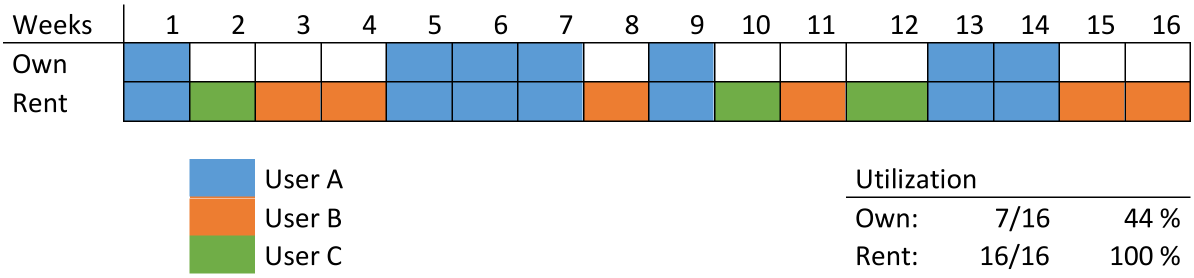

Figure 11: Basic assumption for usage rate comparison between owning and renting

This is a typical example brought forward about sharing private consumption, including products such as cars, power tools, books and camping equipment (Botsman and Rogers, 2010). The higher usage rate obtained by renting comes usually at the cost of transportation. This trade-off between the usage rates and the need of transportation is one of the key areas of study for this thesis.

Also the various rental companies and associations hint that higher usage rate is the key notion for equipment rental to be ecologically more sustainable than owning. However, the private customers needing machines only for a short time periods represent only a small portion of the total amount of customers. Instead, the most customers - or the most typical customer - are companies which are using these machines to run business themselves, to make profit. In these circumstances utilization rate is important performance indicator for equipment.

The Figure 11 draws a comparison between owning and renting. In this scenario the user A needs equipment only sporadically, and thus the usage rate of rented machine is optimized between three users. Now, we can imagine a scenario where the user A would need the equipment for himself for the whole time: a maximum utilization with minimum need of transportation. This scenario is shown in Figure 12.

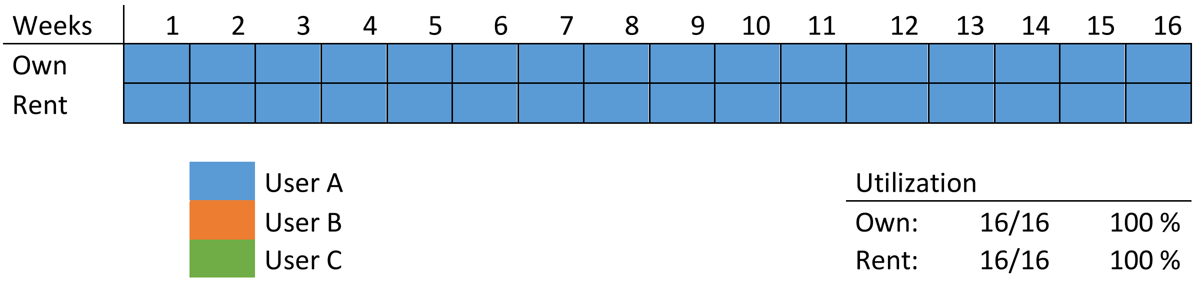

Figure 12: Usage rate scenario with full utilization by single User

An important notion with this latter owning scenario in Figure 12 is that is it not to be compared with the former renting scenario of Figure 11, but should be compared with the renting scenario of this same Figure 12. When there is an owner with a 100% utilization rate, the rental scenario to compare with should be one where the rental provider is renting for this one customer for the whole time period, as is presented in renting scenario of Figure 12. Economically this might not be the most feasible solution, but for the sake of sustainability comparison, it is the correct viewpoint.

3.4 Comparison of rental to owning

During the life cycle of an equipment there are many phases making difference between rental and owning. Eight questions were identified from literature and dialogues with experts during the pre-study phase. The following list shows them in order of relevance to this study. The following paragraphs after the list describes each of these questions in more detail.

- Is equipment utilized in a different manner between owning and renting?
- What is the difference in the need of transportation of the equipment?
- Can renting lower the number of manufactured equipment?
- Does renting lead to the usage of more modern equipment?
- Is rental equipment repaired and maintained in a better way?
- Is rental equipment disposed of in a better way than owned machines?
- Does renting allow for a lower need for storage capacity?
- Is there a rebound effect for the rental benefits?

Is equipment utilized in a different manner between owning and renting? This question actually contains two different aspects that are considered. Firstly, how does the equipment work hours differ in a specific time period, such as annually? This is a key aspect to study. On the one hand, rental practice holds the promise that the underutilized equipment can achieve higher utilization rates through many users. On the other hand, if the owned equipment is already utilized at a maximum rate, then renting does not provide any possibility of increasing the utilization of such an equipment. The interesting balance lies somewhere in the trade-off between the need of transportation and the achieved usage rate.

Secondly, is the equipment used in a more wearing manner when renting or when owning? Questions were raised whether rental machines are misused more often because the user does not feel the ownership of or the responsibility for the machine. Quantifying this relation would have required a complete study of its own as there is no applicable data available.

Furthermore, it was proposed that in big construction companies the workers hardly feel any more ownership of or responsibility for the construction company and its equipment, than they would for a rental company and its equipment. In addition, concerning the smaller companies, it was brought up that while the equipment would be handled more carefully, the actual expertise on maintaining and repairing it would be lower compared to the centralized services of rental companies. All in all, studying the difference, in how equipment is handled, was considered to be too time-consuming this time, and the results to be of small importance regarding the main topics of this study.

What is the difference in the need of transportation of the equipment? Transportation of the equipment is connected to optimizing the utilization of the equipment, as mentioned already in the first paragraph of the previous question. Through transportation a higher utilization rate can be achieved for underutilized equipment but there is always an environmental cost on transportation activity.

Can renting lower the number of manufactured equipment? A common misperception is that a higher utilization rate leads straight to a lower need of manufacturing. Actually instead, the key variable is how many hours the equipment can work during its lifetime. The misperception comes from the underutilized household equipment such as power drills which are commonly used for less than one hour during its lifetime. In such scenarios the part of equipment wearing out of old age is so prominent that higher utilization rate can be very strongly linked to the smaller number of equipment needed to be manufactured.

For other scenarios, if the work hours achieved from an equipment are considered to be constant (at maximum), the raising utilization rate only leads to quicker replacement of the equipment. More about this average age of equipment is discussed in later paragraphs. The question of the amount of work hours over the lifetime of an equipment is a viable one to study as heavy construction equipment have had work hour meters for some 15 years.

Does renting lead to the usage of more modern equipment? As already hinted in previous paragraph, the average age of equipment depends linearly on the usage rate. When assuming that the equipment reaches the end of its life cycle when either it has been used certain amount of hours, or it has reached a certain age, or it has reached a certain combination of these two aspects. Actual usage hours vary widely between different users. Homeowners might need a power drill once a year for decorating purposes, an individual contractor might own one excavator and operate it every day of the year, whereas a construction company needs certain specialized construction machinery for a limited number of hours per building site.

A power drill used by a homeowner will most likely reach the end of its life cycle primarily through aging, whereas excavator operated 200 days annually will most likely reach the end of its life cycle mainly through the amount of hours used. Renting tries to maximize the portion of wearing by usage over the portion of wearing by aging, so it is reasonable to analyse a case where the aging can be omitted by accounting zero percentages of wear during the equipment life cycle. When we assume that the work hours available from a piece of equipment over its lifetime are constant, the utilization rate determines the average age. The higher the utilization rate the lower the average age.

The author of this thesis, formulated an equation to describe the correlation of increasing average lifetime and a decrease in demand for new pieces of equipment:

$$\Delta \boldsymbol{d} = \frac{\frac{n}{a} - \frac{n}{ax}}{\frac{n}{a}} = \frac{(\boldsymbol{x} - \mathbf{1})}{\boldsymbol{x}} \tag{2}$$

where $\Delta \boldsymbol{d}$ is the decrease in demand of new pieces of equipment, *n* is the pieces of equipment already in use, *a* is the average age or the average hours over a lifetime and *x* is the increase of *a* in percentages. Assumption behind the equation are as follows: The machines are used for an average amount for each single year. So the increase in age means linearly higher total capacity staying in use. The equation, in essence then, means that an increase in average lifetime of equipment gives diminishing returns in decrease of demand of new pieces of equipment.

What a more modern equipment means environmentally? In the equipment which has on-use energy consumption, their main environmental impact is through the usage part of lifetime. The term more modern stands for technological advances which in turn have, in many cases, positive correlation both to lower emissions and to environmental impacts.

EU and US legislation have tightening limits to the emissions from non-road mobile machinery. Stage I of EU non-road mobile machinery emissions directive was implemented in 1999 and, the latest, Stage IV was implemented in 2014. In the US the first federal standards (Tier 1) for off-road diesel engines were implemented starting from 1996, and currently they have Tier 4 in use.

In some other fields too, the technological advances are making a difference, such as: the LED technology replacing the older compact fluorescent and halogen lamps, and the temporary modules are equipped with heat pumps and district heating connections saving electricity or reducing the fuel consumption for heating. On top of the EU and the US limits on machinery emissions, new innovations are made based on different power sources, such as battery powered or hybrid machinery.

Is rental equipment repaired and maintained in a better way? The thought behind this questions is that since rental companies operate bigger fleet of equipment they can have centralized maintenance and repair centres where there is more knowledge, better facilities and better equipment available. In practice it is really hard to measure clearly the impact of maintenance and repair activities as there are many crossing variables to the condition of equipment such as how it is used and how much it is used.

Nevertheless, as the amount of usage is actually measured and considered in this study, and the question of how it is used, is considered to be of small significance for this study, if there is a difference on lifetime working hours between the owned and rented equipment, it is likely that it is due to the maintenance and repair. The aspect of lifetime work hours was further elaborated in the first question.

Is rental equipment disposed of in a better way than owned machines? It was suggested that since rental companies handle larger fleet of equipment they would be able to manage the disposal in a more environmentally conscious way. But during this study there was no good indication found of this to be so.

Does renting allow for a lower need for storage capacity? Raising the usage rate, which is in the core of this study, could lower the need of storage capacity. The idea behind this is that since equipment is more at the customer's property, there is need to store fewer items at one time. Strong connection between these two was not identified. Bigger equipment is usually stored outdoors and as such require only space and have limited environmental impacts. Also, many of the pieces of rental equipment have seasonal variation on the usage rates and the substitutability of storage space between products is not that straightforward. This question was left out of this study because it was deemed too hard to quantify and also to be of small significance.

In the interviews made at the end part of this study, one equipment fleet manager of a large construction company said that storage costs were the tipping point for them to decide to switch from owning to renting. He further explained with more detail that storage costs were not the biggest factor for them in the decision, but in the end it was meaningful.

Is there a rebound effect for the rental benefits? Rebound effect is a common phenomenon in the energy and material efficiency improvements. Rebound effect happens when the improvement in efficiency frees up capital, or other resources, which in turn, are then invested back. For example, lighting efficiency improvements often lead to an increase in the amount of lighting used. Similar phenomenon can happen when switching from owning to renting. Renting lowers your need for capital which in turn can lead to usage of bigger than necessary machines. Freeing up your capital can also lead to other investments, such as starting new construction projects. This question of rebound effect is acknowledged but is not further studied in this research.

3.5 Usage profiles

Usage profiles were made to represent several typical users of construction equipment. Identified user categories were large, mid-sized and small construction companies and individual contractors. Large construction company was defined as having more than one thousand employees, mid-sized from one hundred to one thousand, small from ten to one hundred and individual contractor from one to nine employees. For comparison, data from Ramirent was gathered to represent renting. The categorization of usage groups is shown in Table 2 below.

Table 2: Categorization of usage groups

	Number of employees
Large construction company	>1000
Mid-sized	100-1000
Small	10-99
Individual contractor	1-9
Ramirent	Rental provider

Large construction company is a nation-wide company which often operates also internationally. Large amount of construction projects annually need a big fleet of equipment and as such their fleet management has similarities to rental providers. They are able to reach high usage rates moving equipment between different work sites. Firstly, most often the rented equipment is specialized ones which they need only seldom, such as person elevators of certain size, and secondly, they use rental equipment to level out demand spikes.

Mid-sized company is a nation-wide or strong regional company. They have many projects every year but less than larger companies. Their ability to optimize usage rate between different projects is somewhat limited and therefore rental is an appealing option for wider range of equipment than for large companies.

Small construction company operates often in a regional level. They are somewhat specialized which is limiting their need in the variety of equipment. As such, they can achieve high usage rates with some specific equipment. Also, as they are operating only regionally, their need for logistics is lower than their bigger counterparts. Renting provides flexibility to small companies.

For **Individual contractor** two archetypes are considered. The first one, takes specialization even further and owns very limited amount of equipment, and they mostly choose their contracts based on that special equipment. For this key equipment they are able to have considerably high usage rates. Other supplementary equipment is mostly rented when necessary. The second one, works as general handy men and have a wide range of general equipment. The special equipment they usually rent, but in general their equipment is old.

3.6 Data Collection

Three major sources of data were used in this study. First, scientific journals and publications were mostly used for background information on manufacturing emissions, specific emissions of transportation and specific emissions of usage. Secondly, the fleet management data from Ramirent was used to make baseline scenarios from annual work hours, usage rates, annual transportation needs and average ages. Thirdly, various construction companies were interviewed for comparative scenarios, but unfortunately results from them turned out to be quite meagre.

The masses and nominal powers are collected from the technical sheets of products. The purchasing price of those products, which is used to get the EIO-LCA manufacturing emissions, is derived from the Ramirent acquisition data. For boom lifts, comparative data on actual machine work hours was gathered from two websites auctioning heavy equipment.

Nominal power and light output of work site lighting products are from manufacturer's technical specifications. For LED solutions Mberg lamp is used, which is also in Ramirent's fleet under the name LEDa (Ramirent, 2015a), and Goliath 100 lamp by Schneider Electric is used for compact fluorescent (CFL) solutions (Schneider Electric, 2015).

Data concerning the manufacturing emissions of work site lights, is mainly derived from the dissertation by Leena Tähkämö (2013). In the dissertation a total of 23 different LCAs on light sources are analysed. The light sources in question are household light appliances and as such are not completely applicable to the study of work site lights. However, no LCAs for work site lighting appliances were found, and also the questions to selected manufacturers yielded almost no relevant information. Therefore, the results from the aforementioned dissertation are used as an approximation for LED and CFL manufacturing emissions.

Table 3: Data on the compact fluorescent lamp (CFL) and LED lamp. Underlined values are used in this study.

	Values from Tähkämö (2013)				**Values from manufacturers**		
Lamp type	Primary energy consumption in lamp manufacturing	Power	Life of lamp	Luminous efficacy	Power	Life of lamp	Luminous efficacy
unit	*MJ/lamp*	*W*	*h*	*lm/W*	*W*	*h*	*lm/W*
CFL	<u>65</u>	13	8000	58	21	<u>8000</u>	<u>62</u>
high	199		20000	69			
low	4,32		6000	54			
LED	<u>343</u>	13	15000	62	21	<u>35000</u>	<u>95</u>
high	1490		25000	92			
low	39,9		10000	54			

Tähkämö has gathered the information on all reviewed LCAs for LED and CFL light sources respectively, and grouped it together by quality, to low, high and average quality lamps under each technology. The selected values for this study are presented underlined in Table 2. For this study the average values were used to represent the primary energy consumptions in the lamp manufacturing. Especially for LED lights there is a huge variation in the energy consumption of manufacturing; the difference between the low and the high quality lamps is significant, 39.9 MJ/lamp and 1490 MJ/lamp respectively.

Even though the characteristics given by manufacturer for LED lights correlate closest with the ‘high’ quality product group of Tähkämö’s analysis, the average value of consumption of energy in lamp manufacturing was chosen because LED technology is currently progressing at a fast pace. Also in the dissertation the ‘high’ category's high value was regarded as a pilot manufacturing value which has a tendency to fall quickly when production is scaled up.

Transportation load factors for all products and user profiles are estimates based on the knowledge gathered during this project, as no data on equipment transportation was available.

A round of **interviews** was conducted to generate the usage profiles. A total number of interviews was eleven, eight of those were made face-to-face and the remaining three were interviews done by phone. The interviewees were mainly managers and directors of procurement or fleet, from construction companies of different sizes. The list of contacts was compiled with Ramirent's sales department and contained their customers. The list of companies interviewed can be found in Appendix 3.

The main purpose of creating usage profiles was not fulfilled. Out of these interviewees no one owned a boom lift, only two owned plate compactors and four owned work site lighting. None of the owners of plate compactors had the requested data available and for the work site lighting only two companies provided the requested data, which in fact were only expert estimates. Due to time constraints further interviewing round was not possible to make.

There were several reasons for this meagre outcome from interviews. Firstly, the chosen products, especially the boom lift, is owned very seldom. It is one of the most typical pieces of rental equipment, according to the interviews and also by the net sales of Ramirent. Several interviewees told that they do not own plate compactors because they either use subcontractors for earthworks, or they rent the machinery for the few occasions they need it, or earthworks just was not relevant for their construction business.

Secondly, the interviewed companies were already using renting to some extent. Five out of eleven companies had the rental penetration at over 70% of the equipment value, for one company the situation was 50-50. The rest (5 companies) had about 20% rental and 80% owned from their equipment value.

Interviews included also questions about environmental awareness and reasons for renting or owning. When asking how mainstream and daily environmental aspects are handled in the companies, the most popular notion (8 answers) was that environmental legislation and regulations define it. Five out of eleven answered that there is a pressure from clients for environmental considerations. On a scale of one to ten “How important environmental concerns are for your company's business?” mean was 7.9 (Table 4).

Table 4: How important environmental concerns are for companies business?

How important environmental concerns are for companies business (1-10)?			
Mean	7,9	**Minimum**	5
Median	8	**Maximum**	10
Standard Deviation	1,4	**Count**	10

3.7 EIO-LCA

Economic Input-Output Life Cycle Assessment (EIO-LCA) model was used to calculate values for manufacturing energy consumption and GHG emissions of boom lifts and compactors. The online tool used in this research was made by Green Design Institute of Carnegie Mellon University (http://www.eiolca.net/).

Economic Input-Output analysis was developed by Wassily Leontief. Work which was also acknowledged with a Nobel Prize in 1973. The model quantifies the interrelationships among the sectors of an economic system, thus enabling the identification of both direct and indirect economic inputs of purchases. Leontief also recognized the usefulness of these models in assessing environmental impacts. With modern information technology and a variety of new information available, Green Design Institute extended Economic Input-Output models, by including data about environmental and energy analysis from each sector, to account also for the supply chain environmental implications of economic activity. (Hendrickson, 2006)

The Economic Input-Output Life Cycle Assessment method estimates the materials and energy resources required for, and the environmental emissions resulting from, activities in our economy. It is one technique for performing a life cycle assessment; an evaluation of the environmental impacts of a product or process over its entire life cycle. The method uses information about industry transactions to estimate the total emissions throughout the supply chain; the purchases of materials by one industry from the other industries, and the information about the direct environmental emissions. A more detailed explanation of the theory and the method behind it, is found in Appendix 2. (Hendrickson, 2006)

As defined before, the EIO-LCA values are aggregate values of one industry in the US. The values therefore can differ much from the actual values of a certain production facility regardless of its location. It is assumed that the US and the European manufacturing industries are both highly developed and therefore the US values are considered to be reasonable for this study. In addition to this many large equipment manufacturers are in fact based in the US, such as JLG and Genie Industries in Aerial Work Platform sector.

The EIO-LCA provides only aggregate data on the industry sector level defined by North American Industry Classification System (NAICS). For example, the manufacturing of a telescopic boom lift is represented by Aerial work platforms manufacturing which does not have an own grouping for it. Instead, it is grouped with 14 separate sub-sectors, such as automobile wrecker hoists, block and tackle, metal pulleys and winches manufacturing, under the definition of 333923 Overhead Traveling Crane, Hoist and Monorail System Manufacturing.

Furthermore, the EIO-LCA does not have the data on this level but only at one level higher: 33392 Material Handling Equipment Manufacturing. On this level there are four sub-sectors grouped together as shown in Table 5. The EIO-LCA cannot provide the exactly accurate data on manufacturing an individual product. However, keeping in mind that this research is proving wider phenomenon of equipment rental through studying a number of products, the aggregate data is, in fact, more suitable for the generalization of the findings.

Table 5: NAICS classification of boom lift (US Census Bureau, 2002)

33392	**Material Handling Equipment Manufacturing**
333921	Elevator and Moving Stairway Manufacturing
333922	Conveyor and Conveying Equipment Manufacturing
333923	Overhead Traveling Crane, Hoist, and Monorail System Manufacturing
333924	Industrial Truck, Tractor, Trailer, and Stacker Machinery Manufacturing

From the data of the EIO-LCA year 2002, the US producer price model was used. Conversion to present day Euros was done with Consumer Price Index and currency exchange rates. First, the 2002 dollar value was converted to the 2014 dollar value through the Consumer Price Index published annually by United States Department of Labour, as proposed by the authors of the model (Hendrickson, 2006) and then that value was converted to Euros with European Central Bank exchange rate from 30th of March 2015 rate. The exchange rate used is 1 Euro to 1.0845 Dollars.

3.8 LIPASTO

LIPASTO is a calculation system for traffic exhaust emissions and energy consumption in Finland developed by the Technical Research Centre of Finland (VTT). It was used as a data source for machine use emissions, machine usage factors and road transport unit emissions. Also, some information on average machine ages and work hours over machine lifetime was collected from it.

Comparative data on average machine ages, work hours over machine lifetimes and machine usage factors mainly for UK was found from McGinlay (2004) and Vandenbroucke et al. (2010). The data provided by both of the reports assured the quality of the data in LIPASTO to be reasonably good. Furthermore, both of the authors had compared their findings to the LIPASTO data, and the biggest differences were assumed to be from the difference in the composition of industries.

The first part of LIPASTO, LIISA-model, concerning road traffic emissions, was published in 1988. The working machine emissions model, TYKO, was published in 1999. The latest versions are from the year 2012 and those were used for this study.

TYKO has some specific data on machine use emissions and machine usage factors of petrol powered plate compactors. For boom lifts, similar specific data is not available. But instead, the applicable data is picked and combined on case by case basis. For diesel powered drivable machines the in-use emissions per kWh are very similar. An average from the data concerning 24 work machines is used to represent the boom lift in-use emissions. Usage factor means the average amount of nominal power which is utilized when the machine is in use.

TYKO 2012 model has history data on the working machine specific emissions. The effect of age is calculated according to that data.

Table 6 shows how the average emissions have developed between years 1997 and 2012 for diesel powered drivable work machines (representing boom lifts) and plate compactors. From the actualized development seen in the data, the effect of EU legislation is straightforward. The work machines having a big average output have been included in the emissions directive since it was laid down, but small machines with nominal power under 17 kW, such as this plate compactor, will only be bound by the proposed Stage V directive starting from 2019 (Directive 97/68/EC, 2012).

Moreover, for the bigger machines, carbon monoxide (CO), hydrocarbon (HC), nitrogen oxides (NOx) and particle emissions have fallen as those are limited by the legislation. But in contrast, CO2 emissions have been virtually constant as those have not been a subject to the directive. The immense reduction in SO2 emissions is accountable to the EU legislation on fuel and how much sulphur it can contain.

Table 6: Average work machine emissions between 1997 and 2012

Work machines*	Average n. output	CO	HC	NOx	Part.	CH4	N2O	SO2	CO2	Fuel Cons.	Energy
	kW	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	MJ/kWh
1997	76	4.3	1.94	11.66	1.36	0.04	0.02	0.91	832	260.5	11.12
2002	77	3.7	1.59	10.35	1.08	0.04	0.02	0.91	832	260.5	11.12
2007	77.63	2.9	1.10	7.91	0.50	0.04	0.02	0.01	815	258.9	11.05
2012	78.59	2.54	0.85	6.37	0.36	0.05	0.02	0.01	799	258.9	11.05
Plate compactor	Average n. output	CO	HC	NOx	Part.	CH4	N2O	SO2	CO2	Fuel Cons.	Energia
	kW	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	g/kWh	MJ/kWh
1997	3.5	563	27.9	2.6	0.060	2.25	0.030	0.043	1 362	435	18.7
2002	3.5	555	27.4	2.7	0.060	2.25	0.030	0.043	1 347	430	18.5
2007	3.5	510	25.2	3.0	0.060	2.25	0.030	0.007	1 308	417	18.0
2012	3.5	413	20.6	3.6	0.060	2.25	0.030	0.006	1 114	390	16.8

Although, there is a clear indication that the emissions of machines, under the control of directives, have decreased throughout the years, some emissions are staying constant. The most relevant emissions for this thesis, i.e. methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2), are staying constant. Further inspection to CO_2-equivalent emissions was done on the yearly specific emissions differences. Analysis tells that between years 1980 and 2013 the average annual decrease in specific emissions are 0.1% for work machines in general and 0.2% for petrol powered plate compactors. Consequently, during the study, the effect of age on work machine emissions was found to be of small significance.

4 Model

4.1 Description of the emissions model

During this thesis, a model was made to represent construction equipment carbon dioxide equivalent emissions. The model is done in Microsoft Excel 2013. In the model there are two main sheets: one for calculating emissions of construction machines and one respectively for worksite lighting. In both of these models emissions are calculated separately for production, transportation and use. Explanation in detail on why these three are the only ones considered can be found in subchapters 3.3 Life cycle of construction equipment and 3.4 Comparison of rental to owning.

Division to construction machines and work site lighting is made because of the functional units. For construction machines the functional unit is grams of CO_2e per machine work hour and for the lighting it is grams of CO_2e per million lumen hours. Functional units were developed for their easy implementation on customer cases.

For example, a customer has a window renovation project in a high-rise building where he needs a boom lift with a 20-metre reach for 100 hours in total. After the initial information is filled in, the model gives values for the two chosen cases, the normal case of rental and the case of owning. These two emission values can then be multiplied by the 100 hours of needed machine work, resulting in total emissions and the difference over a whole project. Similarly, for the work site lighting: the total illuminance need of a project can be multiplied with the value from the model, resulting in work site lighting emissions over a whole project.

Overview of the construction machine emissions calculation sheet is shown in Figure 13. The yellow boxes have drop-down lists to choose from. For examined products the options are the already mentioned boom lift and plate compactor, and in the similar looking work site lighting emissions sheet the products are a LED work site light and a compact fluorescent work site light. Options for the transportation equipment are a semi-trailer articulated lorry and a van. The last two yellow boxes reading “Ramirent” and “Custom choice” contain the pre-set values of usage profiles. The possible usage profiles are Ramirent, large construction company, mid-sized construction company, small construction company, individual contractor and custom choice, as explained in subchapter 3.5 Usage profiles.

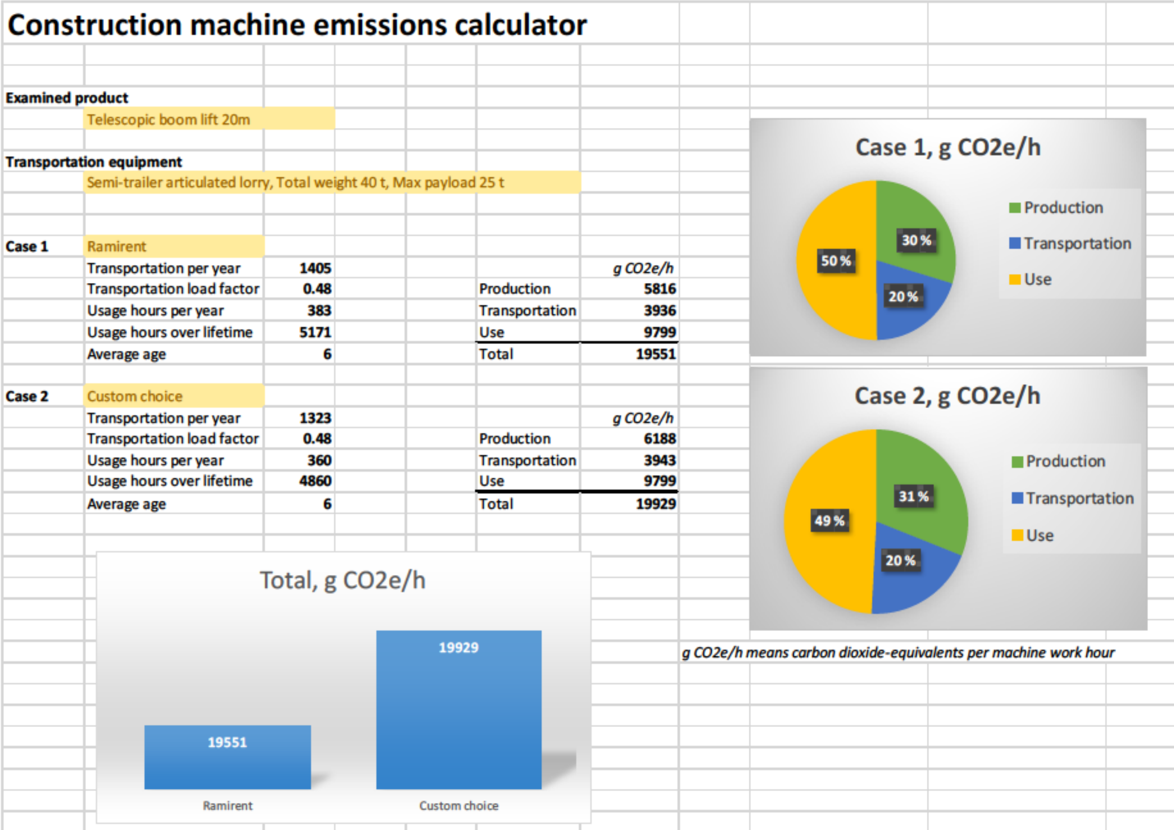

Figure 13: Construction machine emissions model, main sheet

The chosen products are examined in detail in the following subchapters. For transportation the semi-trailer articulated lorry was chosen, because it is the most common means of transportation for Ramirent Finland, according to their logistics manager. In general, all heavy equipment, modules, most of the lifts and the rest of large equipment require a heavy equipment trailer which can only be attached to a lorry. The van is chosen to represent a transportation option for the smaller equipment such as small plate compactors and work site lighting. Both of the vehicles are presented in the following Table 7.

Table 7: Transportation vehicles

Vehicle	Gross vehicle mass	Pay load capacity
Van	2.7t	1.2t
Semi-trailer art. lorry	40t	25t

The production, transportation and usage phase emissions are calculated similarly for the construction machines and the work site lights, but there are also differences because of the functional units chosen and because of other characteristics. The calculation principles are explained first for construction machines and then for lights.

The specific **Production** emissions are calculated from general manufacturing emissions which are derived from various sources. The data for machines is from the EIO-LCA model (subchapter 4.6) and for lighting technologies from the dissertation by Tähkämö (Tähkämo, 2013). The production emissions for a construction machine, as grams of CO_2-equivalents per machine work hour, are calculated with following equation:

$$E_{PM} = \frac{Production\ emissions\ of\ one\ unit}{Usage\ hours\ over\ lifetime} \tag{3}$$

where, E_{PM} is emissions component of construction machine production. The production emissions are evenly divided over products whole lifetime. The usage hours over lifetime are estimated as a multiple of usage hours per year. For the boom lift, a factor of 13.5 is used and for the plate compactor a factor of 18. The numbers are defined by the average age, and the amount of usage hours after average age. This is further explained in 3.3 Life cycle of construction equipment.

The respective equation for work site lights is following:

$$E_{PL} = \frac{Energy\ consumed\ to\ manufacture\ a\ lamp * Emissions\ of\ electricity * 10^6}{3.6 * Lamp\ output * Luminous\ efficacy * Usage\ hours\ over\ life\ time} \tag{4}$$

where E_{PL} is the emissions of lighting appliances manufacturing. The equation notes, that for the work site lights, the production emissions of a single lamp is first converted to production emissions per one lumen. Then, MJ is converted into kWh and multiplied with the average Finnish electricity emissions. Finally, a multiplication with one million is made to get the functional unit of million lumen hours.

The **transportation** emissions are based on the annual transportation and the annual usage hours. The equation for construction machines in descriptive form is:

$$E_{TM} = \frac{Transp.\ per\ year * (Vehicle\ spec. emis.)}{Usage\ hours\ per\ year} * \frac{Product\ mass}{Load\ factor * Max. payload} \tag{5}$$

where E_{TM} is the transportation component of emissions per machine work hour. The vehicle specific emissions are dependent on the load factor, which is explained in the following detailed equation:

$$E_{TM} = \frac{D(V_e + 0.5fV_l)}{t} * \frac{m}{fP} \tag{6}$$

where E_{TM} is the transportation component of emissions per machine work hour, D is the distance transported per year, V_e is the vehicle specific emissions of an empty load, f is the load factor of transportation, V_l is the vehicle specific emissions difference between a full and an empty load, t is the usage hours per year, m is the mass of a product and P is the maximum payload of a transport method.

For the work site lights there is only a small difference in the calculation. The equation described above has a unit of emissions per machine work hour. For the lights, this is further divided into emissions per lumen hour by dividing it with the nominal output of the product and then multiplying it with million to end up with the proper functional unit.

$$E_{TL} = E_{TM} * \frac{10^6}{Light\ output} \tag{7}$$

where E_{TL} is emissions of transportation of work site lights.

The transportation per year for Ramirent's profile is estimated as an average of the actual distances of specific products transported to the customers during last year. The transportation load factor is calculated only for one way and the return trip is regarded as empty. The return trip with an empty load is a suboptimal situation but good actual numbers were not available, and for some cases it still holds true. In this respect, the transportation emissions are overvalued. Furthermore, this equation does not include the transportation for maintenance, repair and strategic fleet movements to different regions, which undervalues transportation emissions. Essentially these two balance each other out to some extent.

The model also takes into account the division between driving a highway or in an urban area. This study uses an estimation of 50% highway driving and 50% urban driving.

The **usage** emissions are caused by the energy consumption of a machine. In this model the equation for calculation is:

$$E_U = Nominal\ power * Usage\ factor * Specific\ emissions \tag{8}$$

where E_U is the emissions of the use, the nominal power refers to the nominal power of a specific product, the usage factor is a value estimating how much of the nominal power is in use, the specific emissions are CO_2e emissions per kWh. The specific emissions are also a function of the average age.

The work site lights use electricity instead of diesel or petrol and as such the equation is completely different:

$$E_{UL} = \frac{Emissions\ of\ electricity * 1000}{Luminous\ efficacy} \tag{9}$$

where E_{UL} is emissions of work site light usage per million lumen hours. Inverse of luminous efficacy is taken to get consumption per lumen which is then multiplied with the average emissions of electricity. Lastly, conversion to emissions per million lumen hours is done.

4.2 Products in the study

For this study, three products were selected to be examined. The products are boom lift, plate compactor and worksite lighting. They are explained in the following subchapters.

Initially, temporary modules were also included to be inspected in this study. Especially the findings from "high class" and low energy modules were considered interesting to study. However, the modules were dropped out during the process because not enough data was available and there was lack of time to produce it.

4.2.1 Boom lift

From boom lifts the **self-propelled telescopic boom lift, 20 meters** (operating height)**, diesel fuelled,** was chosen for this study as it is the most typical boom lift in Ramirent's fleet. Two examples of such boom lifts are JLG 660SJ (Figure 14) and Genie S65.

Boom lift, also known as a cherry picker or kuukulkija in Finnish, belongs in the construction machine definitions to the group of aerial work platforms (AWP). An aerial work platform is a mechanical device used to provide temporary access for people or equipment to inaccessible areas, usually at a height. They are generally used for flexible access purposes such as maintenance and construction work or by firefighters for emergency access which distinguishes them from permanent access equipment such as elevators. They are also designed to lift limited weights, thus distinguishing them from most types of cranes.

A boom lift consists of a platform or a bucket at the end of a hydraulic lifting system. Figure 14 represents a typical self-propelled telescopic boom lift and its working dimensions. The name 'cherry picker' comes from the original use in orchards to harvest fruits from upper tree branches instead of using ladders.

The boom lifts are divided in two categories by structure: articulating and telescopic. Also a combination of these two is possible. The boom lifts can be mounted on trucks, trailers or self-moving platforms. Diesel engine is the most common power source for boom lifts, but nowadays also battery powered and hybrid ones are growing in popularity, especially in the smaller size categories. (Ramirent, 2014a)

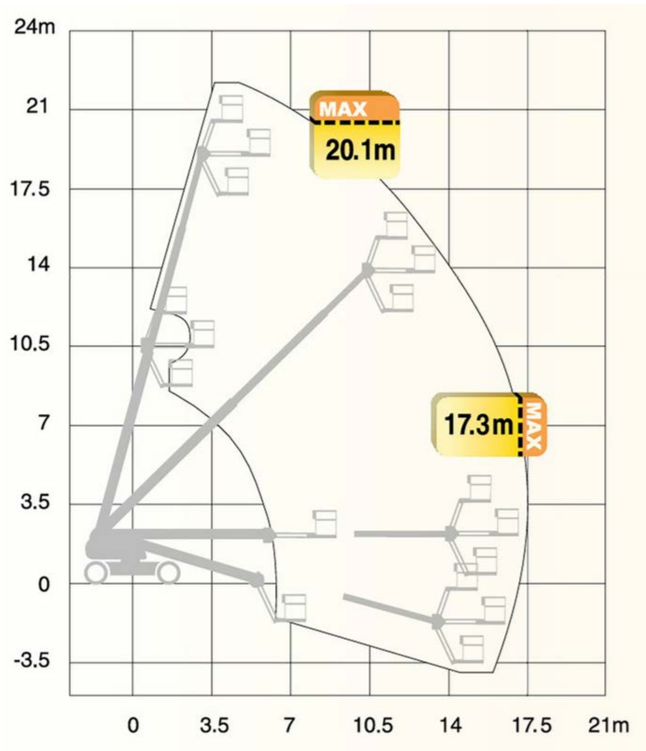

Figure 14: Illustration of self-propelled telescopic boom lift and its working dimensions. JLG 660SJ (Ramirent, 2014b)

Boom lifts are a piece of equipment which have a high rental penetration - In Finland up to eighty percent in year 2013, according to inside sources. Boom lifts are also the biggest business sector for Ramirent representing 20 percent of net sales in Finland.

An additional, interesting, feature to study is the relative size of boom lifts: they need to be transported by trucks and heavy equipment trailers.

4.2.2 Plate compactor

Compactors as construction machines are used to reduce the thickness of soil through compaction. Compactors are also found in other applications such as trash or waste compaction. With construction compactors the compaction is achieved either by mass or by the combination of mass and vibration. The power source of compactors is most typically a combustion engine, either diesel or petrol, and seldom electricity. There are three types of compactors: rollers, plate compactors and vibratory tampers.

Figure 15: Plate compactor, round, petrol, 100kg. Dynapac LX90 (Dynapac, 2015)

The roller type compactors are used for compacting a base layer underneath either concrete, stone foundations or slabs with large rolling mass (2 to 20 tons), but they can also have vibrating rollers. The plate compactors are generally lighter than rollers. They have a vibrating baseplate, and depending on the size, can be one-directional manually pushed (50-150kg), two-directional with a mechanical course reversal (150-800kg) and then the heavier ones are remote-controlled. Vibratory tampers are relatively small compactors (50-100kg) with smaller plates than the plate compactors and a high impact power as the nick name ‘jumping jack’ suggests.

The small plate compactors can further be divided into two types; with a square and a round baseplate. The round plate compactors are especially designed for tight spots and are manually operated (Dynapac, 2015). For this study, a petrol-powered round plate compactor, around 100kg, was selected. A plate compactor was selected for this study to represent the light construction machinery from Ramirent’s selection, and they also account for two percent of Ramirent Finland’s net sales.

For three other reasons: Firstly, it is one of the smallest plate compactors, so it was proposed to also have small scale users, starting from homeowners working on their yard. Secondly, the chosen boom lift is diesel powered so the petrol usage here was thought to give more variety for the study. Thirdly, the size of the chosen compactor is small enough so it can be transported in a van.

4.2.3 Work site lighting

The lighting at construction sites is used to create a safe and efficient working environment regardless of the natural lighting conditions. The worksite lighting in this study consists of general working lights which means that excluded are lighting masts, floodlights and other large scale outdoor and indoor hall lights. Several types of worksite lights are available: such as halogen, fluorescent, compact fluorescent and LED lamp.

Figure 16: Compact fluorescent tube work light, Goliath 100 (Schneider Electric, 2015)

Nowadays, the halogen and fluorescent lights are being replaced with the newer technologies because of better efficiencies but they are still widely in use. The compact fluorescent light was for years the option with which to replace the older ones. Market is now moving towards the LED lighting. From the interviews I conducted, sourcing people in construction industry say that the LEDs have seen an immense rise in the last year or two.

Figure 17: Led work site light, Mberg (Ramirent, 2015)

The rental companies can be thought of as being in the forefront of investing into new equipment. The work lights, led by LED lights, provide an interesting case, on what are the impacts of a quickly rising technology on this comparison of renting to owning. Lighting accounts for 0.7% of Ramirent's net sales in Finland.

Worksite lighting appliances are generally small units. Both units, also shown in Figure 16 and Figure 17, weight approximately one kilogram. Many transportation options are usable depending on the need. In a typical freight trailer the theoretical maximum carried amount of Mberg lighting is 2600 units. The lighting is a part of a worksite usually from beginning to end, leading to long use and long rental periods, and thus to a relatively small transport need.

5 Results

In this chapter the results for the selected products with the Ramirent (rental) profile are shown. The other user profiles could not be completed, because of the problems in data gathering, which is further explained in 3.6 Data Collection. Therefore, the comparison of rental and owning in results is not actualized. However, the findings for the balance of transportation to utilization rate are presented through the rental results. After the results of every product, the sensitivity of model used is analysed at the end of the chapter.

5.1 Self-propelled boom lift

For the self-propelled telescopic boom lift, 20 m, the CO_2-equivalent emissions of Ramirent profile are shown in Table 8 and Figure 18. The transportation per year, Usage hours per year and Average age values are from the Ramirent fleet management data. A transportation load factor of 0.48 is used as it stands for one boom lift with 12 tonnes of weight, carried with a semi-trailer articulated lorry with a max payload of 25 tonnes. For boom lifts of this size it is also possible to load two pieces on a one equipment trailer. Usage hours over lifetime are calculated based on usage hours per year from Ramirent and the average age distribution of work machines in Finland from LIPASTO.

The total emissions per machine work hour are 20 kilograms of CO_2-equivalents.

Table 8: Boom lift emissions. Ramirent, Semi-trailer articulated lorry

Ramirent					
Transportation per year	**1405**				*g CO2e/h*
Transportation load factor	**0.48**			Production	**5816**
Usage hours per year	**383**			Transportation	**3936**
Usage hours over lifetime	**5171**			Use	**9799**
Average age	**6**			Total	**19551**

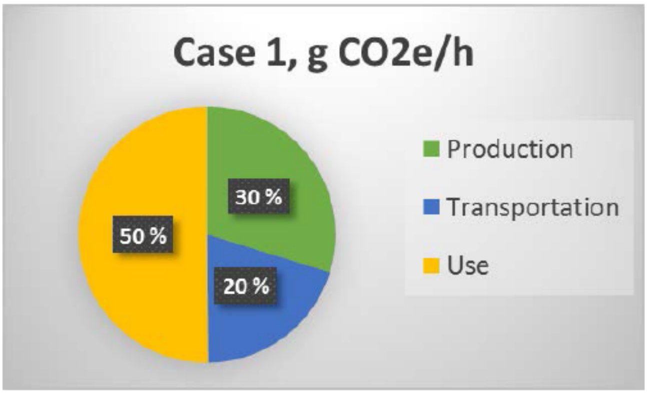

Figure 18: Boom lift emissions. Ramirent, Semi-trailer articulated lorry

Burning diesel while using the machine, is the main emission source of boom lifts, representing half of the total emissions. The average age is a factor in usage emissions but it has only marginal effect on CO_2e emissions, a decrease of 0.1% per year. Otherwise the usage emissions per machine work hour are constant and not differing between cases of rental and owning.

The production emissions represent the second biggest sector with a 30% share. For emissions per machine work hour the usage hours over lifetime is the key factor. As the production emissions equation in chapter “4.1 Description of the emissions model” reads, the usage hours over lifetime have negative (exponential) correlation to the production emissions per machine work hour.

Transportation then accounts for one fifth of the emissions. Increasing the load factor and the usage hours per year, and decreasing the annual transportation, are ways to reduce the transportation emissions.

To study the sensitivity of different variables, scenario analyses were made. The base scenario is the Ramirent profile with a lorry transportation (Table 8 and Figure 18). The studied variables are transportation per year, load factor and usage hours per year. Four scenarios per variable are run: 80% of the base value and respectively 90%, 110% and 120%. The percentage difference for 90% and 110% are calculated in comparison to the base scenario (100%). The following steps are compared to the previous step: 80% scenario is compared to 90% scenario and 120% to 110%.

Table 9 and Table 10 show scenarios for Transportation per year, and Load factor, both of which have only effect on the transportation emissions. The scenarios for Usage hours per year are shown in Table 11. As Usage hours over lifetime is dependent on Usage hours per year, the scenarios have impact on Production and Transportation emissions. For the question of trade-off between transportation and utilization rate: the percentage differences on total emissions show that with this base scenario the sensitivity of Usage hours per year is two to three times higher than the sensitivity of Transportation per year. In other words, an increase of 40 usage hours would be environmentally friendly with an increase of annual transportation up to 280 kilometres.

Table 9: Boom lift, scenario analysis with 10 percentage point steps to Transportation per year

Scenario	Production	Diff.	**Transp.**	**Diff.**	Use	Diff.	**Total**	**Diff.**
0.8	5816	*0.0 %*	**3148**	*-11.1 %*	9799	*0.0 %*	**18763**	*-2.1 %*
0.9	5816	*0.0 %*	**3542**	*-10.0 %*	9799	*0.0 %*	**19157**	*-2.0 %*
1	5816	-	**3936**	-	9799	-	**19551**	-
1.1	5816	*0.0 %*	**4329**	*10.0 %*	9799	*0.0 %*	**19944**	*2.0 %*
1.2	5816	*0.0 %*	**4723**	*9.1 %*	9799	*0.0 %*	**20338**	*2.0 %*

Table 10: Boom lift, scenario analysis with 10 percentage point steps to Load factor

Scenario	Production	Diff.	**Transp.**	**Diff.**	Use	Diff.	**Total**	**Diff.**
0.8	5816	*0.0 %*	**4828**	*11.4 %*	9799	*0.0 %*	**20443**	*2.5 %*
0.9	5816	*0.0 %*	**4332**	*10.1 %*	9799	*0.0 %*	**19947**	*2.0 %*
1	5816	-	**3936**	-	9799	-	**19551**	-
1.1	5816	*0.0 %*	**3611**	*-8.2 %*	9799	*0.0 %*	**19226**	*-1.7 %*
1.2	5816	*0.0 %*	**3341**	*-7.5 %*	9799	*0.0 %*	**18956**	*-1.4 %*

Table 11: Boom lift, scenario analysis with 10 percentage point steps to Usage hours per year

Scenario	Production	Diff.	Transp.	Diff.	Use	Diff.	Total	Diff.
0.8	**7270**	*12.5 %*	**4920**	*12.5 %*	9799	*0*	**21989**	*6.6 %*
0.9	**6462**	*11.1 %*	**4373**	*11.1 %*	9799	*0*	**20634**	*5.5 %*
1	**5816**	-	**3936**	-	9799	-	**19551**	-
1.1	**5287**	*-9.1 %*	**3578**	*-9.1 %*	9799	*0*	**18664**	*-4.5 %*
1.2	**4847**	*-8.3 %*	**3280**	*-8.3 %*	9799	*0*	**17925**	*-4.0 %*

5.2 Plate compactor

For the plate compactor, round, 100kg, petrol driven, the emissions for Ramirent profile are shown in Table 12 and Figure 19. The values for the Transportation per year and the Average age are from the Ramirent fleet management data. A transportation load factor of 0.3 is used. It represents a van where the plate compactor is not the only item transported but still there is ways to optimize the load as only 360 kilograms out of 1200 is used. The Usage hours per year are calculated based on yearly utilization efficiency from Ramirent data multiplied with four hours of machine work per day of utilization. Furthermore, the Usage hours over lifetime are calculated similarly to boom lift: the Usage hours per year are multiplied with the plate compactor average lifetimes from LIPASTO.

The plate compactor total emissions per machine work hour are 2.7 kilograms of CO_2-equivalents.

Table 12: Plate compactor emissions. Ramirent profile, Van transportation

Ramirent					
Transportation per year	**264**				*g CO2e/h*
Transportation load factor	**0.3**			Production	**183**
Usage hours per year	**211**			Transportation	**81**
Usage hours over lifetime	**3801**			Use	**2427**
Average age	**6**			Total	**2691**

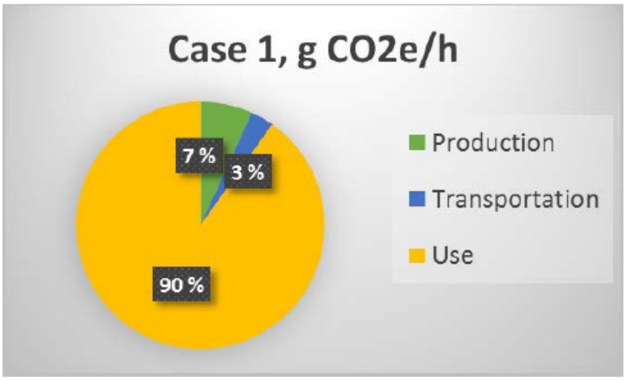

Figure 19: Plate compactor emissions. Ramirent profile, Van

The usage phase emissions dominate the emissions of plate compactors, accounting for 90% of total. Production comes second with a 7% share and then transportation stands for 3%. Similar to boom lifts one factor for the usage emissions is the average age, but the effect is tiny. The realized decrease of specific machine usage emissions is 0.2% per year. With the small shares of production and transportation emissions, the potential to emission reductions there is limited.

The sensitivity of results is calculated with similar method than for the boom lift. The conducted analysis is shown in Tables 12-14. The analysis is done through scenarios, with the base scenario being the Ramirent profile with van transportation (Table 12 and Figure 19). The studied variables are transportation per year, load factor and usage hours per year. Four scenarios per variable are run: 80% of the base value and respectively 90%, 110% and 120%. The percentage difference for 90% and 110% are calculated to the base scenario (100%). The following steps are compared to the previous step: 80% scenario is compared to 90% scenario and 120% to 110%.

The dominance of Usage emissions is further elaborated by the scenarios. Only Usage hours per year with ten percent decreases has over one percent impact on total emissions. The balance between utilization rate and transportation with this base scenario is indicated by Usage hours per year having four to six times the sensitivity of Transportation per year.

Table 13: Plate compactor, scenario analyses with 10 percentage point steps to Transportation per year

Scenario	Production	Diff.	**Transp.**	**Diff.**	Use	Diff.	**Total**	**Diff.**
0.8	183	*0.0 %*	**41**	*-11.1 %*	2427	*0.0 %*	**2651**	*-0.2 %*
0.9	183	*0.0 %*	**46**	*-10.0 %*	2427	*0.0 %*	**2656**	*-0.2 %*
1	183	-	**51**	-	2427	-	**2661**	-
1.1	183	*0.0 %*	**56**	*10.0 %*	2427	*0.0 %*	**2666**	*0.2 %*
1.2	183	*0.0 %*	**62**	*9.1 %*	2427	*0.0 %*	**2671**	*0.2 %*

Table 14: Plate compactor, scenario analyses with 10 percentage point steps to Load factor

Scenario	Production	Diff.	**Transp.**	**Diff.**	Use	Diff.	**Total**	**Diff.**
0.8	183	*0.0 %*	**64**	*12.1 %*	2427	*0.0 %*	**2674**	*0.3 %*
0.9	183	*0.0 %*	**57**	*10.7 %*	2427	*0.0 %*	**2667**	*0.2 %*
1	183	-	**51**	-	2427	-	**2661**	-
1.1	183	*0.0 %*	**47**	*-8.8 %*	2427	*0.0 %*	**2657**	*-0.2 %*
1.2	183	*0.0 %*	**43**	*-8.0 %*	2427	*0.0 %*	**2653**	*-0.1 %*

Table 15: Plate compactor, scenario analyses with 10 percentage point steps to Usage hours per year

Scenario	**Production**	**Diff.**	Transp.	**Diff.**	Use	Diff.	**Total**	**Diff.**
0.8	**229**	*12.5 %*	**64**	*12.5 %*	2427	*0.0 %*	**2720**	*1.2 %*
0.9	**203**	*11.1 %*	**57**	*11.1 %*	2427	*0.0 %*	**2687**	*1.0 %*
1	**183**	-	**51**	-	2427	-	**2661**	-
1.1	**166**	*-9.1 %*	**47**	*-9.1 %*	2427	*0.0 %*	**2640**	*-0.8 %*
1.2	**152**	*-8.3 %*	**43**	*-8.3 %*	2427	*0.0 %*	**2622**	*-0.7 %*

5.3 Work site lights

For the work site lights two different technologies were modelled: LED and compact fluorescent (CFL). LED represents technological advancement compared to CFL. The technological advances supposedly are adopted faster in rental companies.

Table 16: LED work site light emissions, Ramirent, Van

Ramirent					g CO2e/Mlmh
Transportation per year	**25.2**			Production	**305**
Transportation load factor	**0.1**			Transportation	**55**
Usage hours per year	**1902**			Use	**1456**
Usage hours over lifetime	**35000**			Total	**1816**

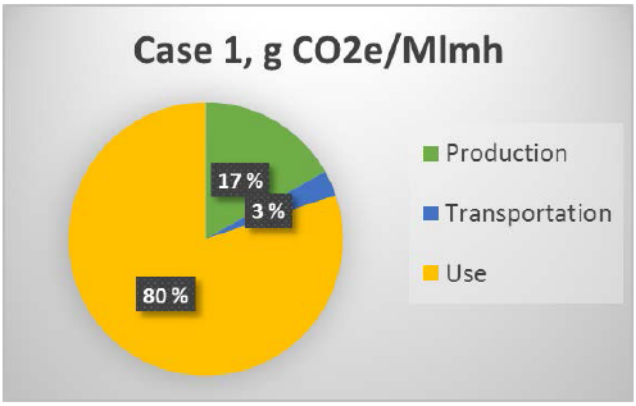

Figure 20: LED work site light emissions. Case: Ramirent, Van

The LED work site light emissions are heavily dominated by the energy consumed during the use, as shown by Table 16 and Figure 20. The value for the Transportation per year is based on Ramirent fleet management data. Usage hours per year are calculated based on yearly utilization efficiency and estimated 10 hours of usage per day of utilization. The Usage hours over lifetime value is from the manufacturer. In this case a low load factor of 0.1 with van is used to underline the small impact transportation has. There are several reasons for this. Firstly, the work site lighting is often used for long periods of time - from the beginning of a construction or a renovation project until the end of it. Secondly, lights are typically used about ten hours per work day resulting in high usage hours per year.

As the LED work site lights are relatively new type of equipment there is not yet evidence on how long the lamps will actually last. With the usage hours of 1900 per year, it would require nineteen years to fulfil the 35000 working hours given by the lamp manufacturer.

The sensitivity analysis of this profile is shown in Tables 17-20. The analysis is done through scenarios, the base scenario being the Ramirent profile with van transportation (Table 16 and Figure 20). In addition to the three variables studied for boom lift and plate compactor, also the usage hours over lifetime are studied. The usage hours over lifetime are considered in this study as independent variable for the work site lights. As such, a sensitivity analysis for it is also conducted. The other studied variables are transportation per year, load factor and usage hours per year.

Four scenarios per variable are run: 80% of the base value and respectively 90%, 110% and 120%. The percentage differences for 90% and 110% are calculated in comparison to the base scenario (100%). The following steps are compared to the previous step: 80% scenario is compared to 90% scenario and 120% to 110%.

The sensitivity analysis showcases that all the variables are sensitive to the corresponding emissions. However, for the total emissions, the transportation component is so small that the sensitivity follows only slightly. The production emissions being bigger part of the total emissions have also higher sensitivity. From the percentage differences it is important to note that the sensitivity to higher emissions is always larger, in absolute, and in relative terms. For example, reducing the usage hours over lifetime by 75 percent (from 35000 hours to 8750 hours), increases the production emissions by 300 percent (from 305 to 1220 g CO_2e) almost reaching the emissions of the use.

Table 17: LED, scenario analysis with 10 percentage point steps to Transportation per year

Scenario	Transportation	Difference	Total	Difference
0.8	**44**	*-11.1 %*	**1805**	*-0.3 %*
0.9	**49**	*-10.0 %*	**1811**	*-0.3 %*
1	**55**	-	**1816**	-
1.1	**60**	*10.0 %*	**1821**	*0.3 %*
1.2	**66**	*9.1 %*	**1827**	*0.3 %*

Table 18: LED, scenario analysis with 10 percentage point steps to Load factor

Scenario	Transportation	Difference	Total	Difference
0.8	**68**	*12.3 %*	**1829**	*0.4 %*
0.9	**61**	*10.9 %*	**1822**	*0.3 %*
1	**55**	-	**1816**	-
1.1	**50**	*-8.9 %*	**1811**	*-0.3 %*
1.2	**46**	*-8.1 %*	**1807**	*-0.2 %*

Table 19: LED, scenario analysis with 10 percentage point steps to Usage hours per year

Scenario	Transportation	Difference	Total	Difference
0.8	**69**	*12.5 %*	**1830**	*0.4 %*
0.9	**61**	*11.1 %*	**1822**	*0.3 %*
1	**55**	-	**1816**	-
1.1	**50**	*-9.1 %*	**1811**	*-0.3 %*
1.2	**46**	*-8.3 %*	**1807**	*-0.2 %*

Table 20: LED, scenario analysis with 10 percentage point steps to Usage hours over lifetime

Scenario	Production	Difference	Total	Difference
0.8	**381**	*12.5 %*	**1892**	*2.3 %*
0.9	**339**	*11.1 %*	**1850**	*1.9 %*
1	**305**	-	**1816**	-
1.1	**277**	*-9.1 %*	**1788**	*-1.5 %*
1.2	**254**	*-8.3 %*	**1765**	*-1.3 %*

The compact fluorescent lamps have a similar division between different emissions, as shown by the Table 21 and Figure 21. All categories are higher than for the LED. The difference in total emissions is 879 gCO2e/Mlmh. In percentage the total difference is 49%, in production 27%, in transportation 55% and in use 53%.

Table 21: Compact fluorescent work site light, Ramirent Van

Ramirent					g CO2e/Mlmh
Transportation per year	**25.2**			Production	**387**
Transportation load factor	**0.1**			Transportation	**85**
Usage hours per year	**1902**			Use	**2231**
Usage hours over lifetime	**8000**			Total	**2703**

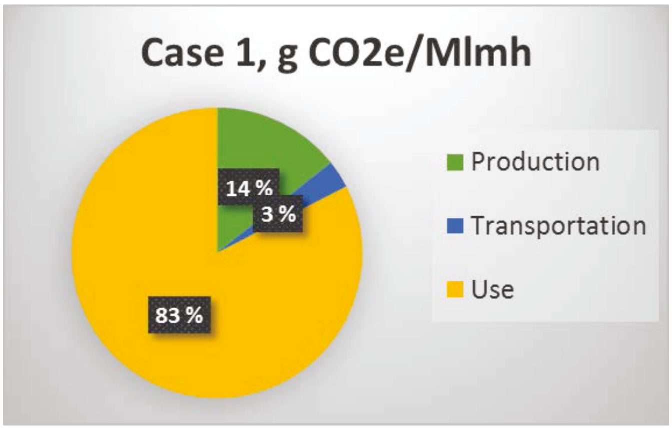

Figure 21: Compact fluorescent work site light, Ramirent Van

The compact fluorescent lamps have lower manufacturing emissions than the LEDs but that is overcompensated by a shorter lifetime. The transportation emissions are higher for the CFL because their light output per kilogram is lower. The usage emissions in turn are higher because the CFLs have lower luminous efficacy than the LEDs.

One suggested scenario was that construction companies tend to buy work site lights to projects because the CFL lamps are cheap enough. In essence, this means that the lights are used intensively for the six months. With an exaggerated scenario, the lamps are bought, used for 180 days, for 12 hours per day, and then discarded. The total usage hours over lifetime drop down to 2160. Effectively this lifetime decrease to one quarter increases the production emissions four-fold, roughly to 1500 g CO_2e/Mlmh. Now, this scenario would have the total emissions close to 4000 g CO_2e/Mlmh which is over twice the emissions of the LED with Ramirent profile.

The sensitivity analysis for compact fluorescent light is conducted exactly like for LED. The results, shown in Tables 22-25, are also similar. Both of which are explained in the LED part of this subchapter.

Table 22: CFL, scenario analysis with 10 percentage point steps to Transportation per year

Scenario	Transportation	Difference	Total	Difference
0.8	**68**	*-11.1 %*	**2686**	*-0.3 %*
0.9	**76**	*-10.0 %*	**2695**	*-0.3 %*
1	**85**	-	**2703**	-
1.1	**93**	*10.0 %*	**2712**	*0.3 %*
1.2	**101**	*9.1 %*	**2720**	*0.3 %*

Table 23: CFL, scenario analysis with 10 percentage point steps to Load factor

Scenario	Transportation	Difference	Total	Difference
0.8	**105**	*12.3 %*	**2724**	*0.4 %*
0.9	**94**	*10.9 %*	**2712**	*0.3 %*
1	**85**	-	**2703**	-
1.1	**77**	*-8.9 %*	**2696**	*-0.3 %*
1.2	**71**	*-8.1 %*	**2689**	*-0.2 %*

Table 24: CFL, scenario analysis with 10 percentage point steps to Usage hours per year

Scenario	Transportation	Difference	Total	Difference
0.8	**106**	*12.5 %*	**2724**	*0.4 %*
0.9	**94**	*11.1 %*	**2712**	*0.3 %*
1	**85**	-	**2703**	-
1.1	**77**	*-9.1 %*	**2695**	*-0.3 %*
1.2	**70**	*-8.3 %*	**2689**	*-0.2 %*

Table 25: CFL, scenario analysis with 10 percentage point steps to Usage hours over lifetime

Scenario	Production	Difference	Total	Difference
0.8	**484**	*12.5 %*	**2800**	*2.0 %*
0.9	**430**	*11.1 %*	**2746**	*1.6 %*
1	**387**	-	**2703**	-
1.1	**352**	*-9.1 %*	**2668**	*-1.3 %*
1.2	**323**	*-8.3 %*	**2639**	*-1.1 %*

5.4 Sensitivity analysis

In the model, data of various quality is used, ranging from specific process data to best estimates made by the author. Sensitivity of the profile variables are explained in the results of a specific product. The sensitivity of the background data is analysed in this subchapter.

Table 26: Sensitivity of the model

Data	Uncertainty
Emissions of manufacturing (all products)	mediocre
Transportation vehicle emissions	very low
Boom lift use emissions	low
Plate compactor use emissions	very low
LED and CFL electricity consumption	very low
Value conversion; from €, year 2014, to $, year 2002	low

On the model, the emissions of manufacturing are the most uncertain value: EIO-LCA gives only aggregate values of industry and the manufacturing emissions of LED and CFL work site light are estimated with respective household lights. For the other parts of the model, the data can be considered of reasonably good quality. Therefore, the model is considered to be trustworthy for calculations identifying the scale of emissions and the division to three emission sources.

In this study the electricity production mix of Finland is used. Finland has a somewhat low emissions of electricity production because there is considerably large amount of nuclear, hydro and bio power. Should, for example, the respective emissions of OECD average of European countries be used the emissions of electricity would be more than three-fold. Only for work site lights electricity emissions are relevant, but for them production and use are both dependants. Therefore, the actual emissions difference between LED and CFL would roughly three-fold also, when using OECD Europe electricity production emissions.

6 Discussion

The main objective of this thesis was to investigate whether the construction equipment rental is sustainable: in comparison to owning. This chapter examines how the objectives and thesis questions are answered. Also the results are discussed a bit further and an interesting correlation found between mass-to-power ratio and relative importance of transport and use emissions is explained.

Four questions and one objective was stated in the beginning of this thesis:

1. Does literature support the notion of rental being sustainable?
2. How does the life cycle of construction equipment used through owning and through renting differ?
3. What are the life cycle CO_2-equivalent emissions of construction equipment?
4. What kind of utilization scenarios are beneficial through renting?
5. To develop a model to illustrate the findings for various customer cases.

For the main objective, to investigate **the sustainability of rental**, the results are inconclusive. Nevertheless, through the questions and the objective set, the discussion on the subject was carried further. Rental definitely holds the possibility to relative sustainability but either through the literature reviewed or the calculations conducted the possibility cannot be generalized.

For the first question, the conducted **literature review** revealed that rental can be considered as a part of the sharing economy and as a sustainable business model. However, the sharing economy and the sustainable business models were found to be lacking in the evidence of their sustainability. Nonetheless, the potential of sustainability in both of the concepts is strong.

Over the **construction equipment life cycles** the differences between owning and renting are mostly in the use phase of equipment: How it is used, transported, stored and maintained. The beginning and the end of the life cycle, planning and production and end-of-life activities, are similar but the difference there can be found in volume of activities. This second question is answered in detail in the subchapters 3.3 Life cycle of construction equipment and 3.4 Comparison of rental to owning.

The question number three, **the life cycle CO_2e emissions**, is answered for the products studied, and the results are further discussed in the coming paragraphs. The answer to the fourth question, **beneficial utilization scenarios of renting**, was only partially identified. The same discussion as for the question two, explores the possible scenarios but the empirical evidence could not be completed.

Finally, for the fifth question, a functioning **model** was developed. Though, the easy applicability of it in the possible customer conversation is hindered by the absence of the user profiles. Furthermore, it was identified through the interviews that, for the owners, it is very hard to provide the data on the annual transportation needs and the annual usage hours of a specific piece of equipment.

With the model the emissions of rental (represented by Ramirent) of construction equipment were calculated. An important notion can be made regarding the division of emissions. For **the boom lift**, it is clear that to manage them sustainably, all the phases, manufacturing, use and transportation are important and therefore, it is important to optimize the transportation and the maximizing the lifetime. Rental companies with big fleets are adept at these optimization problems and big construction companies are emulating them because of that. Smaller companies then hardly can manage their fleet as efficiently.

The plate compactor under study is relatively small and cheap machine which has high power-to-mass ratio because of which the portion of usage emissions is dominant. To reduce the emissions the main thing is to optimize, minimize, the usage. Optimizing the usage is an activity of the user first and foremost, but nevertheless the cost structure of renting, pay by the time needed, is an incentive to efficient utilization.

For **the LED** and **the CFL** work site lights, the emissions of use are highly dominant and as such the potential to operate them more sustainably is not that strong. However, it must be noted, that should the operable lifetimes be noted as much shorter, the portion of manufacturing emissions will rise to a high relevancy. It is hinted that for construction companies lighting is a minor cost which leads to not optimized use of lights. Whereas for rental company it is important to maximise the utilization of all items.

Compared to the LED and CFL LCAs by Tähkämö (2013), I initially thought that with my analysis the portion of transportation would be considerably higher as the transportation between the work sites is completely different from the households where the lights in general are not transported between usage periods. However, the usage data from Ramirent showcased that the usage periods of lights in work sites are typically several months and even some years and as such, the results from Tähkämö are quite similar.

Throughout the study, **the usage hours over lifetime** were considered to be a key variable in assessing the sustainability of the construction equipment rental. However, in many points it was deemed hard to assess or quantify. Even if, values of an average were available in a few sources, the variables for them were not discussed. Moreover, the construction companies found it very hard to estimate the hours, suggesting that they are not tracking the actual usage hours of their equipment.

On the other hand, the dispersion of telematics to a growing number of equipment holds the promise of better data in the future. Already, many of the heavy equipment have hour meter and so does boom lifts. Though, the boom lift manufacturers whom I asked, gave no estimates on how many hours their machines should run. I was able to get from Ramirent the data concerning the usage hours of their boom lifts, but then there was the problem of assessing the lifetime of a machine after Ramirent sells it. If systematically establishing rental as a sustainable option in general, the usage hours over the lifetime is a key problem to assess. Possibly, added telematics in the future will solve part of that.

As the boom lift is a heavy equipment but with relatively low nominal power, and the lights are devices with a small mass, so relative to that high power, an idea rose. What does the **mass-to-power ratio** say? Power is the key factor in the usage emissions and the mass is an important factor to the transportation emissions. Table 27 shows the mass-to-power ratios of all examined products and in Table 28 there is the respective ratio for the transportation and usage emissions.

Table 27: Mass-to-power ratios

PRODUCTS	Mass, Kg	Power, W	Mass-to-power
Boom lift	12000	37000	0.32
Plate compactor	100	4000	0.03
LED&CFL	1	21	0.05

Table 28: Transportation and Use emissions and the ratio of Transportation to Use

PRODUCTS	Transportation	Use	Transportation/Use
Boom lift	3936	9799	0.40
Plate compactor	81	2437	0.03
LED	55	1456	0.04
CFL	85	2231	0.04

The values of mass to power and the ratio of transportation emissions per use emissions suggest relatively strong correlation between these numbers. This ratio indicates the relative importance of transportation emissions. Still, transportation has many other variables, such as the distance transported and the load factor. Therefore, this correlation may be most useful for pre-study analyses. In essence, it is an indicator of the need for further calculations.

During the study there came up possibilities for **further investigation**, especially two of them worth mentioning. Firstly, connecting the environmental calculations such as my modelling to the economical calculations of renting. How strongly do these correlate? For the rental business it is also beneficial to minimize the transport costs and maximize the utility of the equipment. On the other hand there are variables like labour costs which could twist the relation. A strong correlation between the economic and environmental costs would prove rental business to be sustainable.

Secondly, the most of building LCAs I reviewed during the study had dismissed machine work as insignificant emission source, and in others it was only considered through the fuel and electricity consumed. As indicated by the results on boom lift, machine emissions can be much higher than just the fuel consumed. It would be interesting to further investigate how much a model, like the one in this thesis, could provide for building LCAs.

7 Conclusions

The sustainability of construction equipment rental is researched in this thesis. Connecting literature from the topics of “sharing economy” and “sustainable business models” is reviewed. The empirical research part of this thesis included making a model to estimate the construction equipment life cycle emissions. The model was supposed to be based on rental data from Ramirent and owner data from construction companies. However, the interviews conducted with the construction companies did not provide adequate information about the transportation and the usage hours per year of an equipment group. The presented results, therefore mainly explore the environmental impacts (GWP) of construction equipment based on characteristics of which the comparison between is renting and owning is analysed.

The literature review concludes that rental belongs to both of the aforementioned concepts but the sustainability of neither is generalizable. For the boom lift, all phases, the production, the transportation and the usage, are all important, with the relative shares of 30%, 20%, 50%. Optimizing the life cycle emissions, therefore, need a combined effort in all of the phases. For the overall optimization bigger fleet, and larger volume of use is beneficial. In this aspect rental, and large construction companies, are in better position to achieve sustainable utilization.

For the rest of the products, the usage phase is the dominant emissions source (80%-90% of total GHG emissions). The transportation emissions with plate compactor and work site lights have a marginal (3%) impact on the total emissions. For the plate compactor the most important way to minimize emissions is to minimize the usage of such an equipment, a goal of which the rental pay-per-time consumed cost structure is incentive for.

For work site lights the key notion is to maximize the useful lifetime as the theoretical lamp lifetimes is suggested to be high compared to actualized lifetimes in certain scenarios. The business model of rental makes them tuned to optimize the utilization of every product, lights included. In comparison, for the construction firms the lights are only relatively minor cost for the core business of construction and as such not always managed most efficiently.

With all of the products, the mass-to-power ratio is found to correlate well with the ratio of transportation emissions to usage emissions.

To produce the owner data, the interviews should have been developed with a deeper thought on who actually are owning these products. Furthermore, the construction companies deemed the information for the profile as hard to provide. Nevertheless, a lot of effort was used to formulate the profile variables in such a way that it would be feasible for the construction companies to provide them.

Sustainability has been studied and discussed rigorously since the publishing of Silent Spring by Rachel Carson and The Limits to Growth by Club of Rome over forty years ago but the real change still has not materialized. As Assadourian (2010) highlights, despite all the work conducted in the academia, by the governments, by the nongovernment organizations, and by the business community, to understand and change unsustainable practices, such practices still persist and are being amplified by the continued growth of the global economy. Nevertheless, understanding is fundamental for changing the behaviour. This thesis is one more drop to that sea of understanding.

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Appendices

Appendix 1: Values used in the model

The values used in the model are presented below.

Construction machines	Acquisition value, €	Mass, t	Nominal power, kw
Telescopic boom lift 20m	49000	12	37
Plate compactor petrol round 100 kg	1300	0.1	4

Table A 1: Construction machines, sources: (Dynapac, 2015; Ramirent, 2014a)

Work site lights	Primary energy consumption per lamp [13W], MJ	Life of lamp, h	Luminous efficacy, lm/W	Light output, lm	Mass, t
LED site light (Mberg)	343	35000	95	2000	0.001
Compact fluorescent (Goljat)	65	8000	62	1300	0.001

Table A 2: Work site lights, sources: (Ramirent, 2015a; Schneider Electric, 2015; Tähkämo, 2013)

#333920: Material handling equipment manufacturing

Total for all sectors	Total t CO2e	CO2 Fossil t CO2e	CO2 Process t CO2e	CH4 t CO2e	N2O t CO2e	HFC/PFCs t CO2e
$1M 2002	747.00	496.00	185.00	42.70	5.16	18.00
€1M 2014	**613.73**	407.51	151.99	35.08	4.24	14.79

Table A 3: Boom lift production emissions, total of €1M 2014 is used, source: Carnegie Mellon University Green Design Institute. (2015) Economic Input-Output Life Cycle Assessment (EIO-LCA) US 2002 (428 sectors) Producer model [Internet], Available from: <http://www.eiolca.net/> [Accessed 13 Feb, 2015]

#333120: Construction machinery manufacturing, $1M

Total for all sectors	Total t CO2e	CO2 Fossil t CO2e	CO2 Process t CO2e	CH4 t CO2e	N2O t CO2e	HFC/PFCs t CO2e
$1M 2002	651.00	465.00	123.00	44.60	6.09	12.30
€1M 2014	**534.86**	382.04	101.06	36.64	5.00	10.11

Table A 4: Plate compactor manufacturing emissions, total of €1M 2014 is used, source: Carnegie Mellon University Green Design Institute. (2015) Economic Input-Output Life Cycle Assessment (EIO-LCA) US 2002 (428 sectors) Producer model [Internet], Available from: <http://www.eiolca.net/> [Accessed 13 Feb, 2015]

Semi-trailer articulated lorry, Total weight 40 t, Max payload 25 t

CO2e [g/km]	empty	max payload
Highway	766	1041
Street	1181	1736

Table A 5: Semi-trailer articulated lorry per kilometer emissions, source: TYKO 2012, VTT Technical Research Centre of Finland

Van, diesel, Total weight 2.7t, Max payload 1.2t		
CO2e [g/km]	empty	max payload
Highway	212	233
Street	245	292

Table A 6: Van per kilometer emissions, source: TYKO 2012, VTT Technical Research Centre of Finland

	Usage factor
Average of drivable diesel machines	**0.3**
Plate compactors	**0.6**

Table A 7: Usage factors, the average of drivable diesel machines is used for boom lift. Source: TYKO 2012, VTT Technical Research Centre of Finland

CO2e/kWh	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Average of drivable diesel machines	840	839	839	838	838	829	825	824	823	812
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
	812	807	808	808	808	808	808	808	809	809
	2020	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**
	809	809	809	809	809	809	809	809	809	809

Table A 8: Average of drivable diesel machines specific emissions in years 2000-2029. Chosen representative of boom lift. Source: TYKO 2012, VTT Technical Research Centre of Finland

CO2e/kWh	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
Plate compactor, petrol	1433	1433	1433	1433	1435	1422	1408	1394	1333	1279
	2010	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
	1267	1217	1200	1183	1135	1125	1100	1078	1044	1011
	2020	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**
	995	996	996	997	998	998	999	999	999	999

Table A 9: Plate compactor, petrol, specific emissions in years 2000-2029. Source: TYKO 2012, VTT Technical Research Centre of Finland

Ramirent	**Boom lift**	**Plate compactor**	**LED work site light**
Transportation per year	1404.7	263.9	25.2
Usage hours per year	<u>383</u>	211.1	1901.5
Utilization efficiency	<u>60.4</u>	<u>20.7</u>	<u>60.8</u>
Average rent length	<u>5</u>	<u>4</u>	<u>125</u>
Utilization efficiency base	<u>255</u>	<u>255</u>	<u>365</u>
Average two-way distance	<u>45.6</u>	<u>20</u>	<u>14.2</u>
Usage hours over lifetime	5170.5	3800.5	-
Average age	<u>6</u>	<u>6</u>	-

Table A 10: Ramirent profile data, the underlined values are data gathered from Ramirent, and the rest are derivative.

Appendix 2: Theory and Method behind EIO-LCA

Theory and method behind EIO-LCA as explained by Green Design Institute, Carnegie Mellon University (available at: http://www.eiolca.net/Method/eio-lca-method.html):

Combining life cycle assessment and economic input-output is based on the work of Wassily Leontief in the 1930s. Leontief developed the idea of input-output models of the U.S. economy and theorized about expanding them with non-economic data. But the computational power at the time limited uses of the Economic Input-Output method that required matrix algebra.

From the Input-Output accounts a matrix or table **A** is created that represents the direct requirements of the intersectoral relationships. The rows of **A** indicate the amount of output from industry *i* required to produce one dollar of output from industry *j*. These are considered the direct requirements – the output from first tier of suppliers directly to the industry of interest.

Next, consider a vector of final demand, **y**, of goods in the economy. The sector in consideration must produce $\mathbf{I}\times\mathbf{y}$ units of output to meet this demand. At the same time $\mathbf{A}\times\mathbf{y}$ units of output are produced in all other sectors. So, the result is more than demand for the initial sector, but also demand for its direct supplier sectors. The resulting output, $\mathbf{x}_{\text{direct}}$, from the entire economy can be written

$$\mathbf{x}_{\text{direct}}=(\mathbf{I}+\mathbf{A})\mathbf{y}$$

This relationship takes into account only one level of suppliers, however. The demand of output from the first-tier of suppliers creates a demand for output from *their* direct suppliers (i.e., the second-tier suppliers of the sector in consideration). For example, the demand for computers from the computer manufacturing sector results in a demand for semiconductors from the semiconductor manufacturing sector (first-tier). That in turn results in a demand for electricity from the electricity generation sector (second-tier) to operate the semiconductor manufacturing facilities. The second-tier supplier requirements are calculated by further multiplication of the direct requirements matrix by the final demand, or $\mathbf{A}\times\mathbf{A}\times\mathbf{y}$. In many cases, third and fourth or more tiers of suppliers exist. The supplier requirements are calculated similarly with further multiplication of the direct requirements matrix by the final demand. To determine the total output then requires a summation of many of these factors calculated as:

$$\mathbf{X} = (\mathbf{I} + \mathbf{A} + \mathbf{AA} + \mathbf{AAA} + \ldots)\mathbf{y}$$

where **X** (with no subscript) is a vector including all supplier outputs. The output demanded from these second-tier sectors and beyond is considered indirect output. So, **X** includes total output, both direct and indirect.

The expression $(\mathbf{I} + \mathbf{A} + \mathbf{AA} + \mathbf{AAA} + \ldots)$ can be shown to be equivalent to $(\mathbf{I} - \mathbf{A})^{-1}$, which is called the total requirements matrix or the Leontief inverse. The relationship between final demand and total output can be expressed compactly as:

$$\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1}\mathbf{y} \text{ or } \Delta\mathbf{X} = (\mathbf{I} - \mathbf{A})^{-1}\Delta\mathbf{y}$$

where the latter expression indicates that the EIO framework can be used to determine relative changes in total output based on an incremental change in final demand. Typically, the values in the matrices and vectors are expressed in dollar figures (i.e., in the direct requirements matrix, **A**, the dollar value of output from industry *i* used to produce one dollar of output from industry *j*). This puts all items in the economy, petroleum or electricity or pickles, into comparable units.

The economic input-output analysis can then be augmented with additional, non-economic data. One can determine the total external outputs associated with each dollar of economic output by adding external information to the EIO framework. First, the total external output per dollar of output is calculated from:

$$R_i = \text{total external output} / X_i$$

where R_i is used to denote the impact in sector *i*, and X_i is the total dollar output for sector *i*.

To determine the total (direct plus indirect) impact throughout the economy, the direct impact value is used with the EIO model. A vector of the total external outputs, $\mathbf{B}i$, can be obtained by multiplying the total economic output at each stage by the impact:

$$\Delta \mathbf{B}_i = \mathbf{R}_i \Delta \mathbf{X} = \mathbf{R}i(\mathbf{I} - \mathbf{A})^{-1} \Delta \mathbf{y}$$

where $\mathbf{R}_i$ is a matrix with the elements of the vector R_i along the diagonal and zeros elsewhere, and **X** is the vector of relative change in total output based on an incremental change in final demand. A variety of impacts can be included in the calculation – resource inputs such as energy, electricity, or water; or environmental burdens such as criteria air pollutants, global warming gases, or hazardous wastes.

Appendix 3: The interviewed companies and organizations

Consti Oy
Destia Oy
Fira Oy
Lemminkäinen Oy
Normek Oy
Puolustushallinnon rakennuslaitos (the Construction Establishment of Defence Administration)
Rakennus Finrem Oy
Rakennusliike Lapti Oy
Rakennustoimisto Nousiainen Oy
Skanska Rakennuskone Oy
YIT Oy