RESEARCH REPORT

CARBON FOOTPRINT OF CONSTRUCTION EQUIPMENT

CE Delft

SGS SEARCH

Climate Neutral Group

for better business

Index

Executive summary

Introduction

The climate crisis is said to be one of the biggest challenges for humanity at this moment. The effects of global heating (natural disasters) show themselves more often and are getting more severe. Climate change comes from global warming which is directly related to a higher density of greenhouse gas emissions in the atmosphere.
185 World leaders gratified, on behalf of their countries, the Paris Agreement. The main goal of this agreement is working towards a net zero global carbon emissions economy in 2050 (only 30 years away!). All companies must have mostly eliminated their carbon footprint by then.

Circular economy

Besides legal measures; strategies are designed to lower the carbon footprint of the economy in general or for companies specifically. The philosophy of the circular economy is one of those strategies. The circular economy names seven principles that enhance circularity for a company, often referred to as the 7R's: Rethink, Reduce, Re-use, Repair, Refurbish, Recover and Recycle. Basically, aiming for an efficient use of materials and products, and by doing so avoiding environmental impact.

Rental

Rental for one represents this circular philosophy by organizing the handling of their assets in the most effective way possible. As a result, we can assume that rental contributes to lower emissions and a lower environmental impact. This assumption is the starting point for this research project:

"How does equipment rental contribute to avoiding carbon emissions?"

Research partners

This research was performed by **SGS Search**, **CE Delft** and **Climate Neutral Group**. Three independent, internationally operating and renowned research companies.

SGS SEARCH
Climate Neutral Group
CE Delft

Scope and methodology

To answer the research question a selection of 10 pieces of construction equipment is made representing the portfolio of rental companies in Europe. The selection of products studied has been guided by the principle that they are all machines that are frequently both rented and owned by contractors. Next the carbon footprint is made of these machines. The carbon footprint exists of three phases: the production phase, the use phase and the end of life phase. Rental impacts mainly the use phase and the end of life phase. For the total footprint of the chosen products, we used the representing figures from the rental practice to calculate the footprint of the use phase. Research shows that 5 parameters have the biggest effect on the carbon footprint in use phase and the end of life phase: 1. intensity of use; 2. Energy consumption; 3. Transportation; 4. Recycling and 5. Innovation. *Paragraph 7.2* from this research shows the effect of these parameters for the different machines.

Results and conclusions

The main conclusions from the Life Cycle Assessments (LCAs) are: i. the use of fossil fuel has a significant impact on the total carbon footprint of a product - to the extend that it in case of the generator, fuel overshadows the impact of all other factors. ii. In general, the heavier the machine, the bigger the carbon footprint is of the production phase; iii. there is a lot to be won using recycled materials in the production phase; iv. recycling the product, parts of the product, or materials from the parts positively influences the carbon footprint; and v. after energy, production and recycling the fourth biggest impact factor is transport.

Based on the LCA information a carbon calculator is built that allows for the parameters to be filled in using different variables, calculating the total carbon footprint of the machine in different user scenarios. Using the information from qualitative interviews a user scenario is constructed that interprets the way rental organizes the handling of its equipment. Interviews provided also information on examples of handling that show less efficient practices. For exercise purposes this report shows five of those theoretical user cases. Comparing these theoretical user cases with the user case from the rental industry it shows per situation an indication of the benefits gained by adopting the more effective practice we encountered at rental companies.

We conclude that rental as a business model embodies factors that contribute to lowering carbon emissions. The two main factors contributing to these reductions are i. avoiding the production by facilitating shared use and ii. efficiently organizing the handling of construction equipment.
A carbon calculation tool was developed as a second product on top of this report, to precisely predict the difference in impact between the rental practice and other user cases. This tool makes it possible for users to fill in the different parameters reflecting their own practice and compare that to the rental practice inspired user case.

Recommendations

The researchers recommend that this carbon calculation tool is further developed and then released for the rental and construction industry to be used. Much alike the way the *Total Cost of Ownership Calculator* on the website of the ERA is there to fuel the conversations on determination in which situations rental is the best option to make use of specific construction equipment but, in this case, from an environmental, carbon impact perspective.

Introduction

3.1 Climate change and the Paris Agreement

Industrialization has given our societies tremendous amounts of wealth, improving living standards, life expectancy, among many other benefits. Fossil fuels are mainly responsible for driving this progress: coal, oil, and gas use make up about 85% of the total energy used by the entire human civilization (Statistical Review of World Energy (June 2016)). As fossil fuels are burned up, greenhouse gas emissions are released into the atmosphere, increasing the concentration of carbon dioxide and other gases (such as methane and nitrous oxide) and consequently warming the atmosphere. As we have seen in the past years, the effects of climate change are becoming more and more intense, with extreme weather events, flooding, droughts, ocean acidification and coral bleaching.

Acknowledging this challenge, world nations signed the Paris Agreement in 2015 with the central aim of strengthening the global response to the threat of climate change by keeping a global temperature rise this century well below 2 degrees Celsius above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius (UNFCCC, 2018). Further reports by the Intergovernmental Panel on Climate Change sharpened the reduction targets that we have to reach in order for this to happen: global emissions have to drop by approximately 50% by 2030 and reach net-zero emissions by 2050 in order to limit warming to 1.5 degrees above pre-industrial levels (IPCC, 2018)[2].

Actors from the public, private and civil society sectors are working together and individually to determine the implication of these targets for their own scopes. Governments are setting their own Nationally Determined Contributions, national emissions reduction goals, while companies are working with voluntary reduction targets that express their own ambition. Each of these vary tremendously, but one thing is for certain: if we want to limit the costly impacts of climate change, all actors have to get serious about reducing our reliance on fossil fuels and accelerate the transition to a net-zero carbon economy.

3.2 The construction industry and it's impacts

Industry (including construction) contributes about 25% of the world gross domestic product (GDP)[3]. The construction sector is responsible for about a fifth (20%) of the global emissions[4,5]. In Europe, the construction industry contributes 9% to the GDP[6]. And is responsible for approximately 13% of the carbon emissions.

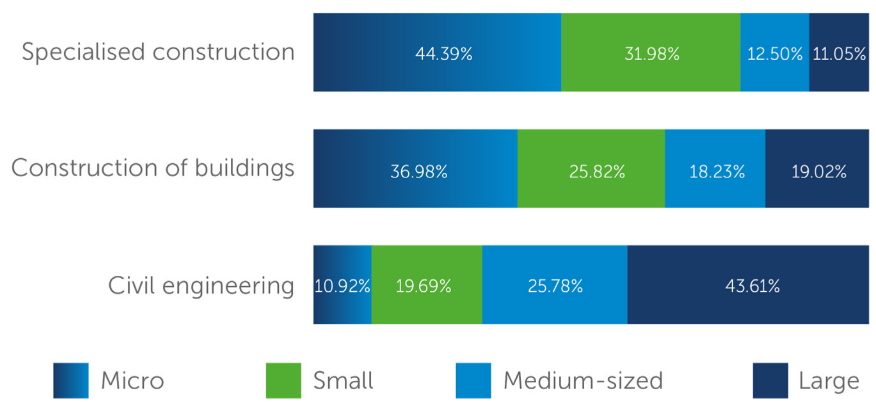
Analyzing the carbon footprint/ life cycle of a building can be divided into the following phases: extraction of required raw materials; processing and manufacturing of construction materials and building components; transportation and installation of building materials and components; operation, maintenance, and repair of building; and, finally, disposal of materials at the end of the building lifecycle. Each phase demands energy, material and other resources to produce the required input for a successive phase to complete the cycle[7]. In all of these phases, the use of equipment is needed, with most weight accounted to the total production phase and end of life phase.

The rental industry comes into play in exactly this part of the carbon footprint of construction projects (the equipment, transportation of the equipment and handling of the construction equipment).

Construction industry and the use of equipment

Company size within the construction sector varies highly, with a handful of large companies and thousands of smaller companies. Some larger construction companies have an equipment department that rents out their own equipment. Others like to rent their equipment from rental companies. This decision is based on different arguments in terms of Total Cost of Ownership, taking into account capital costs, transportation, operation, maintenance. After the contributions of this project, the carbon impact might also one day play a role in the decision between buying or renting.

Distribution of companies by sector in the construction industry



The market for rental equipment in the construction sector has been growing steadily during the last decade. In the EU-28 and EFTA countries, equipment rental companies (11.200 companies[8]) providing rental services generated a total rental turnover of more than EUR 25.7 billion, with average construction industry penetration of 1.5%[9].

Considering the significant impact of the construction industry, it also has a responsibility to take action and reduce its emissions if, we as a society want to reach the internationally agreed upon goals to limit the effects of climate change.

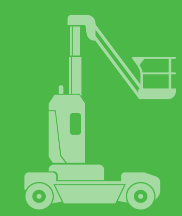
3.3 Using circle economy principles to reach this goal

Circularity is one of the tools that can be used to avoid carbon emissions, especially in a production branch like construction. A central role in the circular economy is to implement seven circular principles (7S model): Rethink, Reduce, Re-use, Repair, Refurbish, Recover and Recycle, in order to strive for economic prosperity and environmental quality (Kirchherr et al., 2017)[10]. Recently, The Ellen MacArthur foundation and TNO[11] analyzed the potential impact of CO_2 reduction as a result of adopting the circular economy. They found that transforming the current linear economic model to a 100% circular economy has the potential to reduce the carbon footprint of a country by 10%. As such, circular business models have the potential to significantly contribute towards the Paris Agreement climate targets of limiting global warming to 1,5-2°C by 2050.

Europe is leading in defining circularity. Both in the public and private sector the concept is finding its way into policies and business models. But whilst some countries, such as Norway and the Netherlands have made significant steps, the concept is still in early stages. Best practices and success stories are slowly being developed. And while the concept is attractive from a theoretical point of view, evidence-based examples of successful implementation are needed further the implementation.

The rental industry - by definition - operates in a circular business model. As such, rental companies avant la lettre contribute to the transformation towards a more circular economy. By optimizing the utilization rate of equipment, minimizing idle and unused equipment, and optimizing re-use & re-cycling, the sector likely contributes significantly to overall carbon reduction. Sharing/rental can increase the efficiency of use of tools. Each user of construction equipment is aware that some machines are used quite efficiently, while other are sitting idly for most of their lifespans. There is, thus, a tremendous amount of differences in usage that has not been comprehensively mapped and quantified. There have been a number of case studies done, in particular for consumer rental products, e.g. Leisman (2013)[12], but not to the extent that compares inefficient versus efficient use of construction equipment.

Furthermore, companies are increasingly expanding into rental business models and also providing products as a service, as a way to respond to the challenges of the circular economy. This trend goes beyond the construction sector but illustrates how the economy is shifting to different business models such as rental. An interesting example is how the Phillips company offers light as a service to the Dutch airport, Schiphol. The airport no longer buys lightbulbs, instead Phillips remains the owner of the equipment, is responsible for installation and maintenance, and receives periodic payments for the "service"of light[13]. This gives an incentive to Phillips to design the most efficient and longest lasting products.



The following section explains the objective of this study, within the context of reducing carbon emissions from the construction sector, by adopting effective rental practices.

4 Objective

The goal of this study is to research the benefits of rental on the life cycle carbon footprint of equipment used in construction and other industries.

This is done i. by calculating the effects that the rental business model has on the efficiency of use during the first technical life span of ten pieces of equipment; and ii. by researching upon the potential avoided emissions by applying the sharing principle.

5 Scope and boundaries

5.1 Scope

To define the environmental benefits of rental for the environment, this study researches the impact of the rental practice on the carbon footprint of construction equipment. Even though the majority of the machines researched are used as construction equipment, the scope of utilization of these machines is broader than construction. The carbon footprint is measured during the three stages of the Life Cycle of these machines.

The production phase covers the upstream impacts such as extraction of raw materials, production of parts, assembly, and delivery of the finished product. The use phase covers operation of the machine as well as transport to job sites. The end of life phase covers the downstream impacts including the disassembly, transport and processing of waste of the product.

In other words, the carbon footprint analysis covers the product's carbon lifetime impacts from cradle to grave. The diagram below describes the scope of the analysis.

From the earlier interviews maintenance wasn't brought forth as one of the main factors impacting the carbon footprint. That's why maintenance is excluded from the LCAs.

Figure 2. Scoping

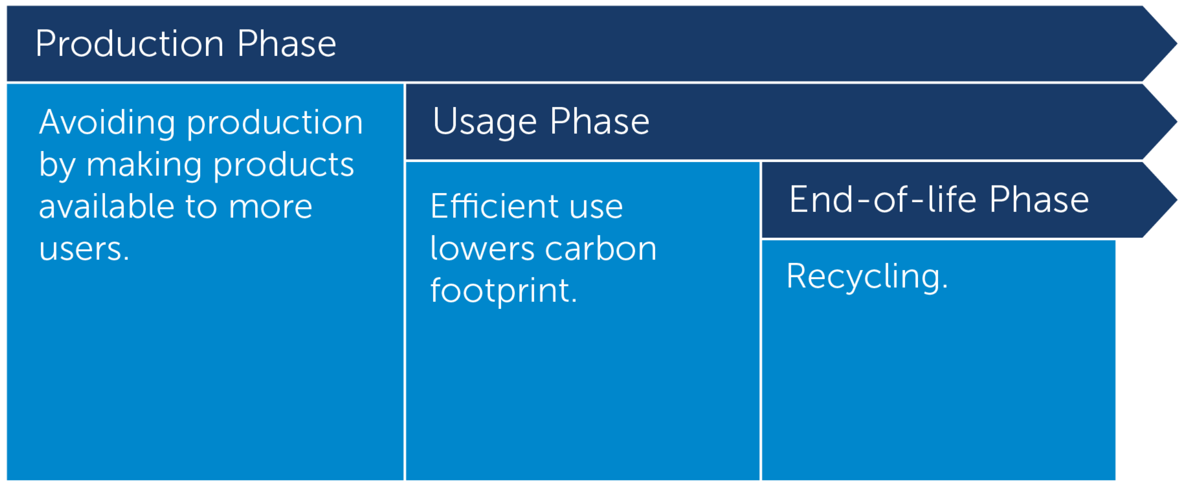
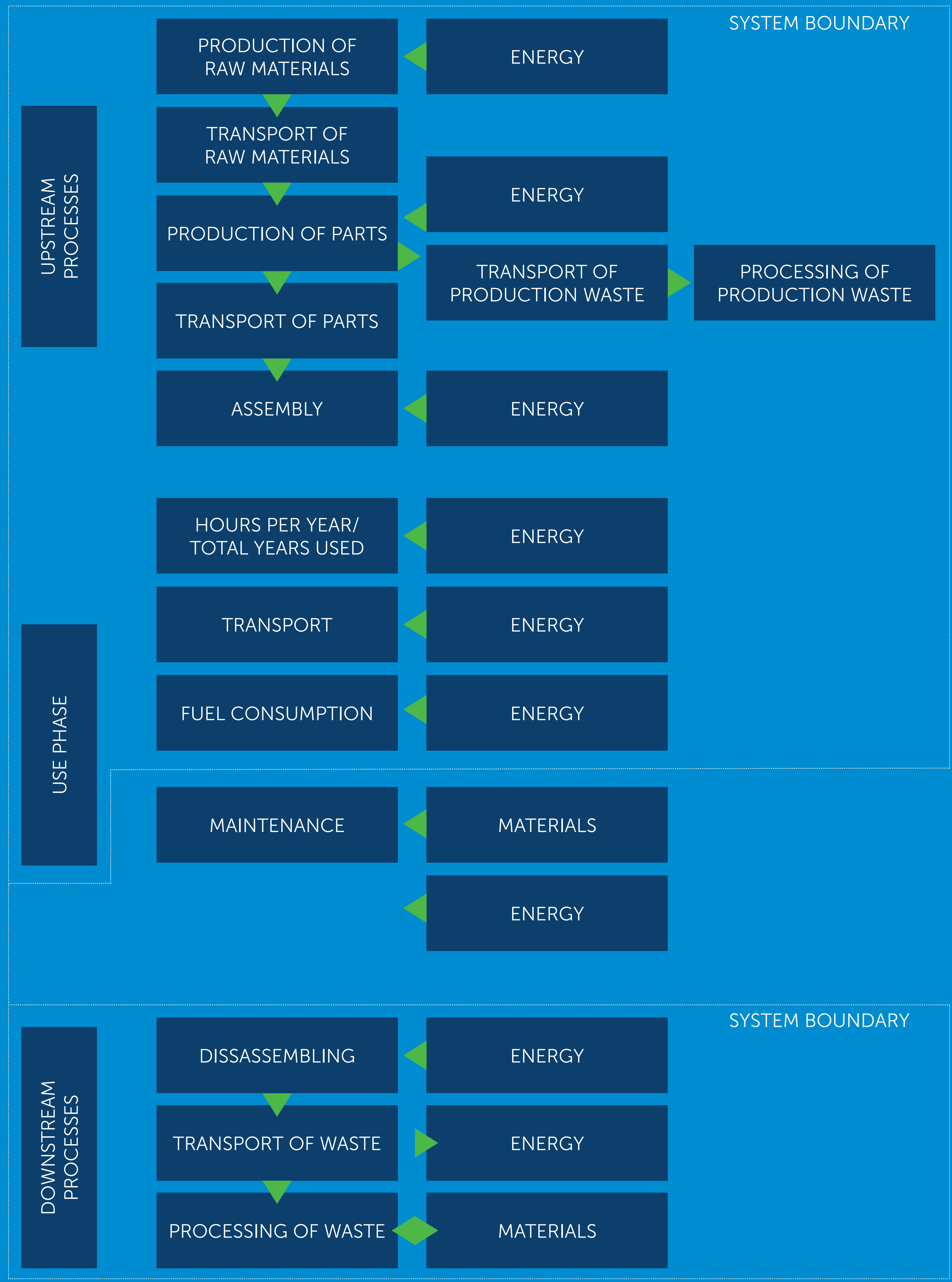


Figure 3. Process diagram for scoping



[2]https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_SPM_version_report_LR.pdf
[3]https://data.worldbank.org/indicator/nv.ind.totl.zs
[4]https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions
[5]Huang, L., Renewable and Sustainable Energy Reviews (2017), http://dx.doi.org/10.1016/j.rser.2017.06.001
[6]https://ec.europa.eu/growth/sectors/construction_en
[7]https://www.researchgate.net/publication/273693109_Estimating_energy_consumption_during_construction_of_buildings_a_contractor's_perspective
[8]Austria, Belgium, Czech Republic, Denmark, Finland, France Germany, Italy, The Netherlands, Norway, Poland, Spain, Sweden, Switzerland, United Kingdom – ERA Market Report 2018
[9]ERA Market Report 2018
[10]https://www.sciencedirect.com/science/article/pii/S0921344917302835
[11]https://www.tno.nl/media/8551/tno-circular-economy-for-ienm.pdf
[12]http://www.mdpi.com/2079-9276/2/3/184/pdf
[13]https://www.ledsmagazine.com/leds-ssl-design/modular-light-engines/article/16695809/lighting-as-a-service-poised-to-deliver-the-circular-economy-magazine

5.2 Boundaries

Rental companies offer a broad portfolio of machines and equipment used in the construction industry and beyond. To keep this research practical, a selection of products was made. The portfolio of rental companies in Europe can be roughly divided in five product categories: i. earth moving, ii. material handling, iii. power, iv. access and v. tools. This study focuses on ten products covering these five categories. A second criterion used was the difference in product specifications on the energy use and size of these machines. These variations enable showing the effect of different user scenarios on the total footprint of these machines.

The table below gives an overview of the specific type of products that are analysed.

Product category	Category	Size	Power source
Earth moving	Mini excavator Excavator Wheel loader	2.5t 8 to 14t 1 to 1.3 m^3	Diesel Diesel Diesel
Material handling	Telehandler	14m	Diesel
Power	Generator	60 KVA	Diesel
Access	Mast boom lift Electric scissor Electric articulating boom lift	8m 12m	Electricity Electricity Electricity
Tools	Breaker Battery drill	10kg	Electricity Electricity

Table 1. Overview of products

Products are often, after reaching their technical lifespan, sold to second hand markets. These second and often third lives are left out of scope of this research because it is difficult or impossible to keep track of these machines. Due to this reason, the research only takes the first technical life span into account.

6 Methodology

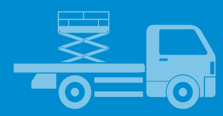
In this research, a four-step approach is taken to answer the research question.

1. Carbon footprint measurement for upstream processes (production phase) and downstream processes (end-of-life phase).
2. Definition of four parameters that influence efficiency during use phase as well as carbon footprint for use phase. Development of a carbon footprint tool that incorporates the life cycle carbon emissions from all stages and allows for adjustment of parameters during use phase and end-of-life phase.
3. Comparison of ten user cases, two per product category that compares rental-inspired efficient use with theoretical inefficient use. These user-scenarios are built to demonstrate the effect of the different parameters on the carbon LCA of a product.
4. Briefly researching the implications of avoided production due to sharing of equipment.

Since this research is commissioned by the European Rental Association (ERA), the impartiality of the outcomes must be guaranteed by the independency of the parties executing the research. Climate Neutral Group, as an independent research company, was selected to manage the project and independently verify the results of all stages of the research, which was done with two additional expert parties. SGS Search was responsible for calculating the carbon LCA according to the ISO14040 and ISO14044 standards (step 1) and CE Delft for defining the use phase parameters, building the carbon footprint tool (step 2) and building the user scenarios (step 3). The following sections elaborate the different steps.

6.1 Carbon life cycle assessment (LCA)

Measuring the carbon footprint of each piece of equipment requires making an inventory of all materials and energy use needed for its production. The scope for this is the upstream impacts (production phase) as well as the downstream impacts (end-of-life phase). Usually, a life cycle assessment considers several impact categories, however for the purpose of this study only the global warming potential (GWP), measured in kg CO2 equivalents (CO2e) per functional unit, is considered. CO2 equivalents is a practical metric that also takes into account other greenhouse gases such as methane, nitrous oxide, and fluorocarbons. This metric is the most standard form of measurement when comparing the impact of fossil



fuels and how they contribute to global warming.
Original Equipment Manufacturers (OEMs) of the different products provided information on the products. This information was gathered and assessed by SGS Search. In case of missing information this was complemented by information from the Ecoinvent database, an internationally known LCA database with information of the environmental impact of the various materials.

To add impartiality to the research, Climate Neutral Group carried out an independent verification of each carbon LCA, critically reviewing the analysis according to the ISO14040 and ISO14044 standard.

6.2 Definition of the parameters on efficiency and carbon footprint tool

Definition of parameters
The rental industry, due to the way it is organized, is able to have a strong influence on the use phase of products. The following section of the research focused on defining parameters that influence efficiency.

To establish how construction equipment is typically used, for instance in terms of lifetime, utilisation rate or transportation, 30 companies were contacted, of which 20 provided useful data. These include the original equipment manufacturers (OEMs), rental companies, and contractors. Through an extensive questionnaire and follow-up interviews, data on all relevant parameters was gathered. This was done separately for each equipment type.

A gross list of parameters influencing the efficiency usage of the equipment was derived from these conversations. The parameters were tested in calculation models in order to define the parameters that had the most effect on efficiency. These are described below:

1. Lifetime and utilization: this parameter captures how often (hours per year) a piece of equipment is used during its life-time (total years in first technical life).
2. Energy consumption: this parameter focuses on the energy use, in terms of fuel or electricity consumption per hour.
3. Transport: Pieces of equipment have to be transported from construction site to storage and again to the next location. Parameters that influence the CO2 impact during its life cycle include distance between storage and job site, load factor of transport vehicle, the loading factor on the return of the transport vehicle (sometimes it can be empty, increasing the emissions for that journey), and the type of vehicle that is used..
4. Re-use/recycling: Proper recycling of the product at the end of its life reduces the total impact of the product, because recycling saves new (virgin) materials.

Each of these parameters was selected based on the goal of attempting to differentiate various types of inefficient and efficient use of construction tools. Based on research, there

Lifecycle Stage	Description	Included in Scope
Upstream processes	Production of raw materials	Yes
	Production of parts	Yes
	Transport of raw materials and parts	Yes
	Assembly	Yes
Use phase	Hours per year	Yes
	Transport during use	Yes
	Fuel consumption	Yes
	Maintenance and parts/oil	No
	Equipment training	No
	Equipment replacement due to innovation	No
Upstream processes	Disassembly	Yes
	Transport of waste	Yes
	Processing of waste	Yes

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were significant variations of use that could affect the total carbon footprint. Other influencing factors such as innovation (when replacing a product by a newer and more energy efficient model, CO2 emissions are reduced), fleet management (optimization), maintenance, waste management and recycling, equipment use training, were left out of scope due to lack of data. The table below gives an overview of the scope.

After defining the parameters, CE Delft built a Carbon Footprint Calculator in which the effects of the different parameters can be input individually and combined to determine the life time carbon emissions of the selected pieces of equipment.

Carbon Footprint Calculator

The purpose of the Carbon Footprint Calculator is to show how different parameters and user scenarios can affect the carbon footprint of construction equipment. The carbon footprint is calculated using the LCA method, and includes the following life cycle phases: production of the equipment, energy consumption during use, transport to/from construction sites, and treatment at end-of-life.

The tool compares two different scenarios, called Scenario 1 and Scenario 2. Scenario 1 corresponds to realistic, efficient use of the construction equipment, as inventoried by CE Delft via interviews with diverse companies[14].

After reviewing the received data, the default parameters for Scenario 1 were selected. This was done by considering all data points and their apparent quality. Furthermore, in establishing the default parameters of Scenario 1, the aim was to combine matching data (e.g. for utilisation rate and energy data) wherever possible. The following part of this section explains how specific data points were selected.

[14] *OEMs, rental companies and contractors*

These efforts to find the most representative data notwithstanding, it should be noted here that establishing realistic user scenarios is not straightforward. For example, different interpretations of 'use' exist (e.g. equipment is rented out, equipment is on-site, equipment is switched on, equipment is actively using energy, etc.). Furthermore, the energy use of equipment can strongly depend on how it is used. For example, the amount of diesel that an excavator uses per hour depends on how intensively it is used, whether it is moving or digging, how much load it is carrying, etc. For these reasons, there is a degree of uncertainty in the carbon footprint results that are obtained when the default Scenario 1 parameters are used.

The selected data on user scenarios was combined with LCA results on the production and end-of-life of the construction equipment as provided by SGS Search.

6.3 Use cases – the effect of the combined parameters

Ten user cases were designed for this study. Two per each product category: one as an example for efficient use of the product based on the practices learned from the interviews and inspired by the rental industry and the other as example for inefficient use.

The user cases are based on hypothetical scenarios. This means that the cases are fictional, but parameters used are based on interviews and actual data received from companies, owners, rental companies, end users, and additional research. The cases are constructed to give a balanced insight into the full spectrum between the interview-based estimates for inefficient use and efficient use.

6.4 Research on avoided production

Interviews were held and databases of rental companies searched to establish how much production can be avoided by offering construction equipment for rent.
Two main questions were researched:

1. What are the main drivers for users to rent instead of purchasing a piece of equipment; and
2. How much production related emissions are actually avoided.

6.5 Assumptions and limitations

The carbon footprint calculator is based on the assumption that a specific piece of equipment has only one owner, thus the lifetime impacts are for the first technical life span (the first owner). Often when machines reach the end of their technical life span, they are sold to secondary use markets, and manufacturers and rental companies lose track of these machines. Since it is not possible to measure the extra hours of use in these markets, it is left out of scope.

7 Results

7.1 LCA results

7.1.1 LCA results for upstream and downstream impacts (Capital goods)

The table below gives an overview of the total and net carbon footprint (in kg CO2e) for all pieces of equipment analysed. The total figures represent the emissions for a piece of equipment without proper disposal, while the net figure represents the emissions that take into account proper recycling.

The table below shows the importance of recycling materials when a product reaches the end of its lifecycle. Properly disposing of and utilizing materials from equipment can significantly reduce its carbon footprint. Depending on the size and material composition, reductions can vary from -21% to -54%. Setting up closed-loop ownership cycles, together with design for disassembly, will improve recycling rates and further reduce the carbon impact of the construction sector.

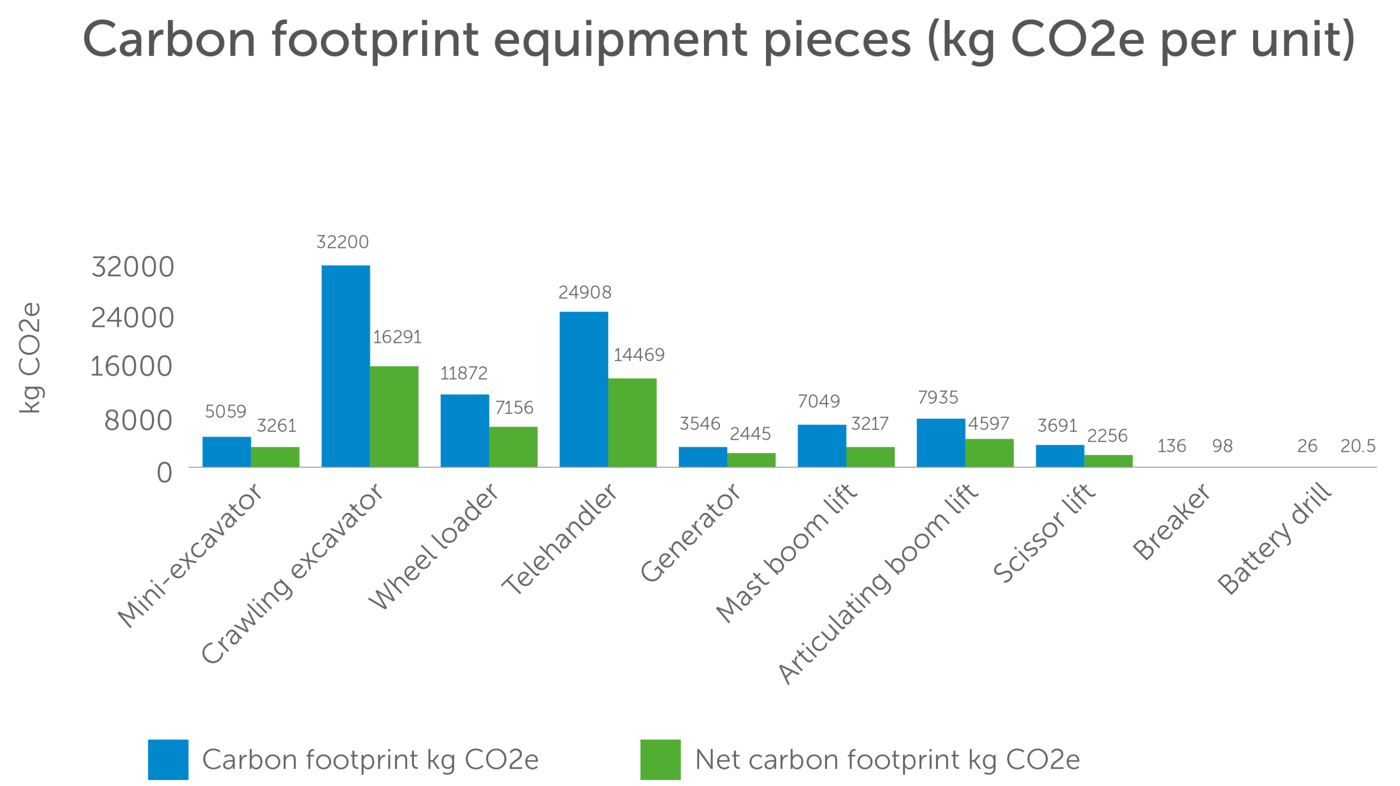


Figure 4. Overview of total and net carbon footprints.

	Mini-excavator	Crawling excavator	Wheel loader	Tele-handler	Generator	Mast boom lift	Articulating boom lift	Scissor lift	Breaker	Battery drill
Carbon footprint kg CO2e	5059	32200	11872	24908	3546	7049	7935	3691	136	26
Net carbon footprint kg CO2e	3261	16291	7156	14469	2445	3217	4597	2256	98	20
% change if properly recycled	-36%	-49%	-40%	-42%	-31%	-54%	-42%	-39%	-28%	-21%

Table 2. Difference between up-stream and down-stream effects.

Sensitivity analyses

Another result from the carbon LCA's performed by SGS Search were sensitivity analyses. These analyses made theoretical calculations to assess the impact on the carbon footprint of the production stage by replacing primary material with secondary or recycled materials. The table below shows that the footprint of all products can be significantly reduced when secondary materials are used. The first line shows the amount of primary steel content, with a lower figure meaning there is more secondary steel used. The second line represents the amount of recycled plastic in the product.

It becomes clear from the analysis above that companies can significantly (from 15-34%) cut their carbon emissions by choosing secondary materials for the construction of their products.

Assumptions for end of life

After use, the machines are disassembled. Commonly in Europe the materials will be sent to end-of-life treatment. The end-of-life scenarios used for these LCA are based on EU averages as presented in Table 5. This distribution is applied to all materials of the machine except the engine oil. Assumed is that the oil is 100% incinerated and has a net calorific value of 11MJ/kg. Moreover, it should be mentioned that, data from automotive products are used and that it is assumed that the same applies to machinery, although EU directives do not mention this explicitly.

	Mini-excavator	Crawling excavator	Wheel loader	Tele-handler	Generator	Mast boom lift	Articulating boom lift	Scissor lift	Breaker	Battery drill
Primary steel content (%)	10%	31%	14%	8.5%	0%	41%	10%	6%	N.A.	N.A.
Recycled plastic content (%)	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	100%	100%
Reduction of upstream impacts (%)	24%	20%	21%	32%	15%	15%	17%	15%	34%	25%

Table 3. Sensitivity analyses on primary and secondary materials
N.A. = not applicable

Table 4. End-of-life scenario's

Product	Recycle	Incineration	Landfill	Reference
Plastics**	95%	3,5%	1.5%	Eurostat ELV[15]
Tyres	57.5%	42%	0.5%	Eurostat ELV
Metal	99%	0%	1%	Eurostat ELV
Glass	99%	0%	1%	Eurostat ELV
Electronics	83%	9.5%	7.5%	Eurostat WEEE[16]
Battery (metal)	95%	0%	5%*	Eurostat battery[17]
Battery (plastic)	47.5%*	47.5%*	5%*	Eurostat battery

[15]Eurostat 2016 data: https://ec.europa.eu/eurostat/web/waste/key-waste-streams/elvs
[16]Eurostat 2016 data: https://ec.europa.eu/eurostat/web/waste/key-waste-streams/weee
[17]Eurostat 2017 data: https://ec.europa.eu/eurostat/web/waste/key-waste-streams/batteries

** Assumption, no data available*
*** Except glass reinforced plastics, those are considered non-recyclable and therefore assumed to go to incineration and landfill*
[18]CE Delft, 2017; STREAM Goederenvervoer 2016: Emissies van modaliteiten in het goederenvervoer – Versie 2; CE Delft, Delft, January 2017. Tables 29, 30 and 31.

7.1.2 Results life cycle including operation

The graph below represents the main findings of the first life cycle carbon footprints for all analyzed products. It shows how complex the relation between impacts and life-cycle phases can be. For example the use phase is most dominant in the generator, excavator and wheel loader, while the access category is impacted more by transport and production.

7.2 Comparative analysis

7.2.1 Effects of parameters on efficiency

This section describes how the Carbon Footprint Calculator expresses the effects of the different parameters. Here we elaborate on what we have learned on the parameters.

mix vs electricity from renewable sources), as well as stand-by time, when a machine is turned on but not being used.

Note: The calculator does not yet enable calculation of the change in impact from switching from diesel to electric power (for the same type of equipment). This is included in the recommendations (Chapter 9). Changing to electrically powered equipment may in the future lead to near-zero emission for energy consumption, when the electricity is generated from renewable sources. Certificates of Origin can in these cases guarantee the source and origin from energy used. Nowadays, though, the electricity mixes in most EU countries is still carbon intensive, being partly generated with coal and gas. Still, the average impact of electricity is lower than the impact of diesel. Calculations of the switch from diesel to the average EU mix show a reduction in impact by 20-25% (CE Delft, 2017[18]). Of course this switch requires a change of motor type and redesign of the equipment.

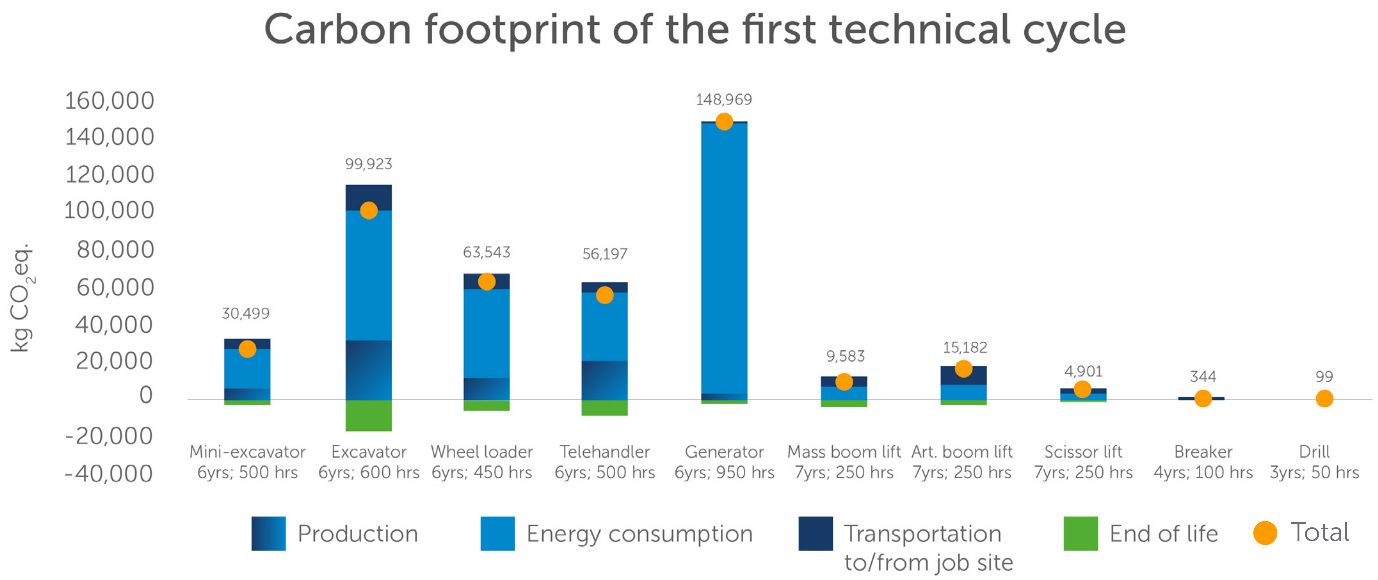


Figure 5. Life cycle carbon footprint of all products

Intensity of use

This parameter is defined by hours of use per year and the total amount of years that it is used during its first technical life span. The impact of producing the machine (and its end-of-life) is spread out over the number of hours it runs during its life. To lower the equipment's carbon footprint at the level of emissions per hour of use, it can be kept in use for longer (increasing the lifetime) or it can be used more intensively (higher utilisation rate).

Energy consumption

Energy consumption is defined by the amount of fuel or energy consumption per hour of use. The tool enables inserting the type of fuel (conventional vs biofuel) or electricity (average EU

Transportation

The parameter for transportation of a machine, to reach the customer or a job site and to bring it back, is the most complex of all: it depends on load factor, return load factor, distance to the job site, vehicle type used, and fuel type.
By optimization of logistics, avoiding unnecessary transport as much as possible, CO2-emissions can be avoided. Combined transport for multiple products increases the load factor, avoids empty rides and may shorten the total transportation distance.

Selecting the right size truck for the transport is important. Large trucks have a lower impact than small trucks per ton transported weight, but only if the load capacity of the truck is indeed utilised. It is better to choose a smaller truck of which the load capacity can be fully utilised, rather than a large truck only partly utilised.

Empty rides

Ideally, equipment is transported to and from the job site while bringing and picking up other equipment. If an empty transport movement occurs, the impact of the empty ride is attributed to the equipment, although it is not being transported.

Calculation example:

The excavator is the heaviest piece of equipment selected in this project: it weighs 15 (metric) tons.

For this, we have constructed an efficient transportation scenario:

A large truck and a trailer are used for transportation, having a load capacity of 28 ton of cargo. 80% of this load capacity is utilised, meaning that not only the excavator is transported, but also other cargo. No empty rides occur, meaning that the company has an efficient logistics, bringing and taking other pieces of equipment to the job site(s) as well.

The excavator is used at 15 jobs per year and a one-way transport average distance is 60 km.

The table below shows the effect of changes, of less efficient transportation

Scenario (change)	Result per job (kg CO2-eq.yr) (from calculation tool)	Result per year (kg CO2-eq) At 15 jobs/yr	Difference with baseline per year (kg CO2-eq.)
BASELINE, EFFICIENT SCENARIO	76	1.140	-
Empty rides	132	1.980	840
Lower load factor: 53%. Only the excavator is transported with the large truck/trailer	104	1.560	420
Lower load factor: 53% AND empty rides	188	2.820	1.680
Much lower truck with a load capacity of 40 ton, but only the excavator is transported. No empty rides.	121	1.815	675

Recycling

The tool allows to choose from three options for recycling. The first uses the European averages for recycling as explained in the methodology section. The second considers a higher-than average (100%) recycling rate assuming that the product is fully disassembled when properly disposed of. The third option is no recycling at all, which is chosen when the product is sold to a second-hand market.

7.2.2 Comparison of user scenarios

Out of the 10 pieces of equipment, 5 were chosen because they have similar use patterns and are therefore representative for their category. The following selection was made for each product category:

- Earth moving: Mini-excavator
- Material handling: Telehandler
- Power: Generator
- Access: Mast boom lift
- Tools: Breaker

The following user scenarios are presented in three parts (per product category). The first table gives an overview of the average data that was gathered for the rental-inspired scenario (Scenario 1). The graph under the table gives a representation of the carbon footprint in kilograms per hour of use, comparing the rental inspired use case (Scenario 1) and the theoretical inefficient case (Scenario 2). Then the explanation below the graph indicates which parameters were changed to demonstrate the effect on the carbon footprint. The user case concludes with an example of inefficient use and the possible effects of avoided productions.

Earth moving: Mini-excavator

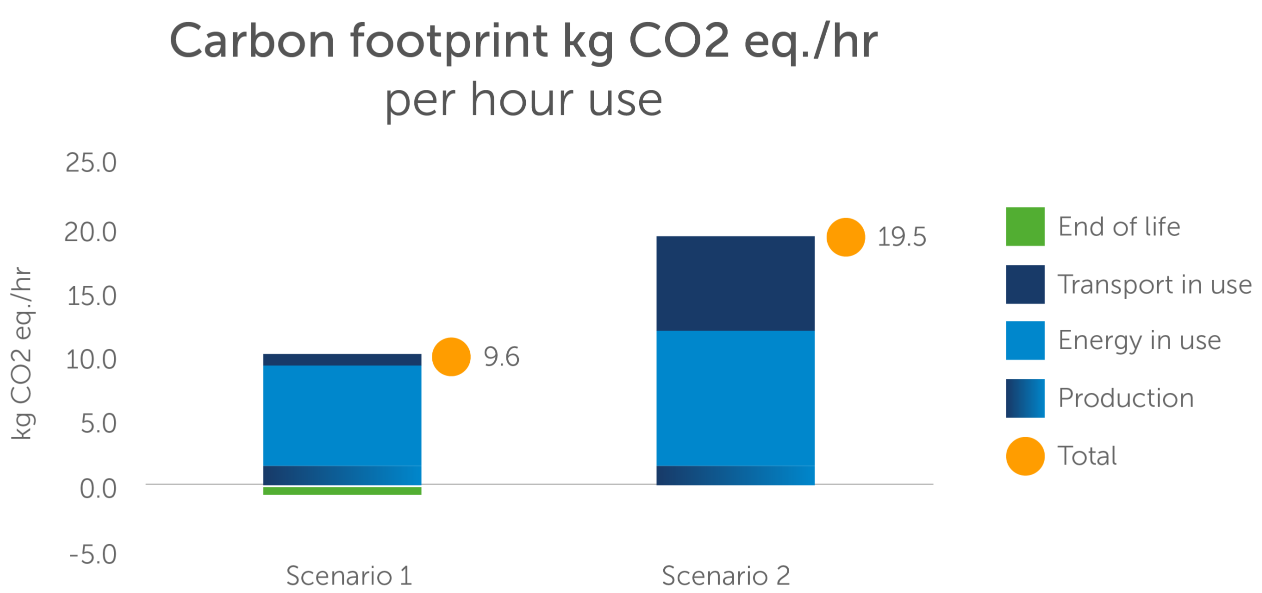
Rental inspired scenario

Scenario 1 represents rental-inspired scenario and scenario 2 is a theoretical inefficient scenario where transport is farther away, uses a larger type of transport vehicle, where there are less hours of use and a longer life span. Also, the product is sold off at the end of its life cycle so it is uncertain if it will be recycled.

Considering an inefficient scenario for the mini-excavator

Parameter: Hours of use. A (large private) land owner buys a mini-excavator for irregular (garden) maintenance, such as shrub clearing, soil levelling or digging for tree planting. The impact of one excavator is about 3.250 kg CO2-eq. (incl. end-of-life treatment), which would be saved if the landowner would rent instead. Provided that the rented excavator is used at other clients as well.

Section	Detail	Value	Justification/source
Transport	Load capacity and truck size, tonne	28 (large truck + trailer)	Most frequently transported in heavy trucks with trailers (16-32 t) according to questionnaires.
	Distance, km	40	Rounded average based on data provided by 6 European rental companies and contractors. Data provided ranged roughly between 20 and 50 km. One outlier (5 km) not considered.
	Jobs per year	65	Based on a typical duration of use at one site of 4 days. Employment rate of 70% of the time, based on interviews with 2 rental companies.
Lifetime and utilisation	Utilisation rate (h/yr)	500	Rounded average based on data provided by 6 European rental companies and contractors. Data ranged from 300 h/yr to about 600 h/yr. Very high values (e.g. 1600 h/yr)were considered unrealistic and/or unrepresentative for the diesel consumption used, and have therefore not been taken into account.
	Life time (1st use), yr	6	Average based on data provided by 6 European rental companies and contractors. Data ranged from ~3 to 8 years.
Energy	Diesel consumption, l/h	2.4	Value provided by OEM and deemed representative for typical construction sites. Rental companies and contractors provided slightly higher values but did not indicate how these were derived.



Material handling: Telehandler

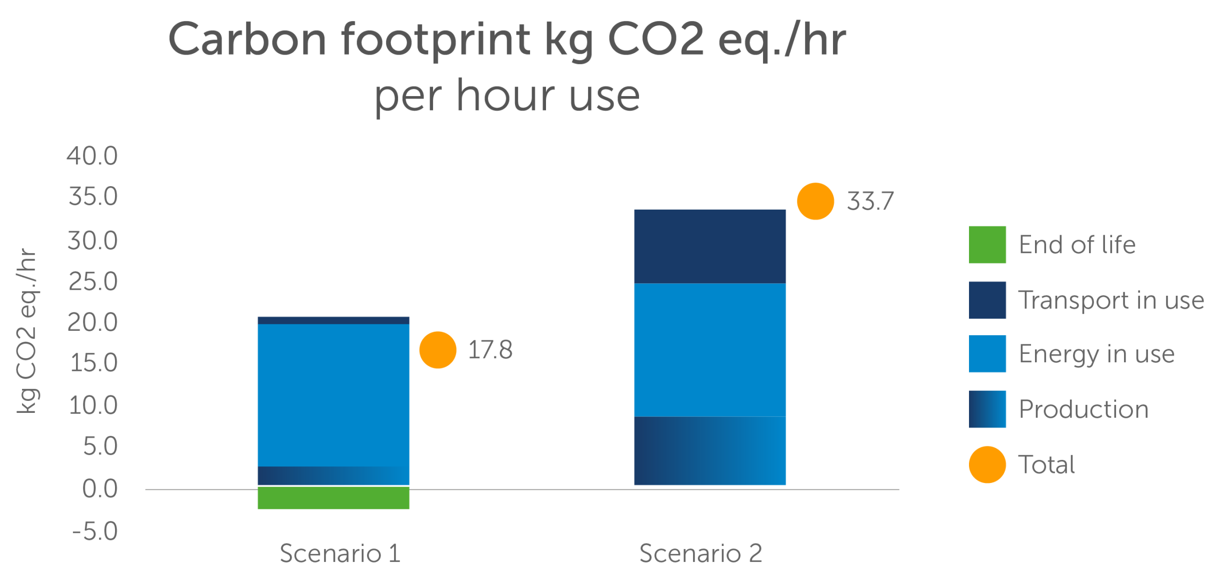
Rental inspired scenario

In the comparison below scenario 2 represents a theoretical inefficient scenario where transport is farther away (50 vs 75 km), uses a larger type of transport vehicle, and the delivery vehicle makes an empty return journey (both travel journeys are allocated to that machine). Additionally, in scenario 2 there are less hours of use and a longer life span. Also, the product is sold off at the end of its life cycle so it is uncertain if it will be recycled. In this case, because the telehandler has such a large footprint for its production, the recycling of metals would significantly affect the overall emissions if the machine is properly disposed of.

Considering an inefficient scenario for the telehandler

A farmer owns a telehandler to move bales of hay after harvest in the autumn. The rest of the year the telehandler is not used, or just very occasionally. The utilisation rate (hours per year) is low and the farmer could rent a telehandler instead. The impact of a telehandler is the highest of all assessed equipment types: over 12.000 kg CO2-eq. (incl. end-of-life treatment). By renting the telehandler, this impact would be avoided.

Section	Detail	Value	Justification/source
Transport	Load capacity and truck size, tonne	28 (large truck + trailer)	Most frequently transported in heavy trucks with trailers (16-32 t) according to questionnaires.
	Distance, km	50	Rounded average based on data provided by 5 European rental companies and contractors, ranging from 30 to 100 km.
	Jobs per year	10	Based on a typical duration of use at one site of 20 days. Employment rate of 70% of the time, based on interviews with 2 rental companies.
Lifetime and utilisation	Utilisation rate (h/yr)	500	Rounded average based on data provided by 4 European rental companies and contractors, ranging from 280 to 720 h/yr. Very high values (e.g. >1000 h/yr) were considered outliers that may not be representative for the energy use. These have not been taken into account.
	Life time (1st use), yr	6	Rounded average based on data provided by 7 European rental companies and contractors. Data provided varied between 3,75 to 10 years.
Energy	Diesel consumption, l/h	4	Value provided by OEM.



Power: Generator

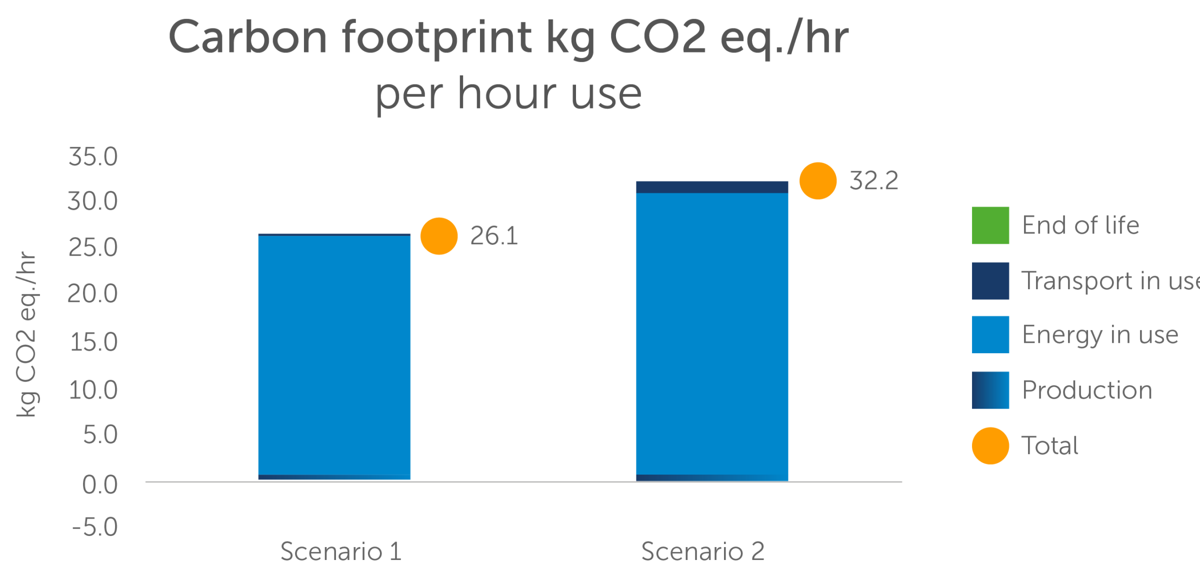
Rental inspired scenario

In the belowexamples, the parameters that have been shown in scenario 2 express the theoretical case where a larger vehicle has been used for transport, with a lower loading capacity (80% vs 11% loading factor), and a slightly longer distance (30 km vs 40 km). The utilization rate is lower and the life span is longer (6 vs 8 years), but the most important factor here is the energy consumption. With a slightly lower diesel use of 1,5 liters per hour, scenario 2 has a higher footprint. This is to demonstrate the importance of efficient machines when deciding which one to pick for a job.

Considering an inefficient scenario for the generator

Parameter: Hours of use. A generator is bought as a backup device at home, in case of power grid failure or outage. It is not in use. This generator can be replaced by a shared (rented) generator. This saves the impact of one generator: 2.450 kg CO2. Another case is that job sites usually order larger generators that provide excess energy that will not be used, burning more fuel than necessary. This can be avoided by advising clients on the right amount of energy use for a specific type of job.

Section	Detail	Value	Justification/source
Transport	Load capacity and truck size, tonne	28 (large truck + trailer)	Most frequently transported in heavy trucks (16-32 t) according to questionnaires.
	Distance, km	30	Rounded average based on data provided by 5 European rental companies and contractors, ranging from 15 to 50 km.
	Jobs per year	15	Based on a typical duration of use at one site of 15 days. Employment rate of 70% of the time, based on interviews with 2 rental companies.
Lifetime and utilisation	Utilisation rate (h/yr)	950	Rounded average based on data provided by 5 European rental companies and contractors, ranging from 500 to 1600 h/yr. Very high values (e.g. >1600 h/yr) were considered outliers that may not be representative for the energy use. These have not been taken into account.
	Life time (1st use), yr	6	Rounded average based on data provided by 7 European rental companies and contractors. Data provided varied between 4,4 to 8 years.
Energy	Diesel consumption, l/h	8	Value provided by OEM.



Access: Mast boom lift

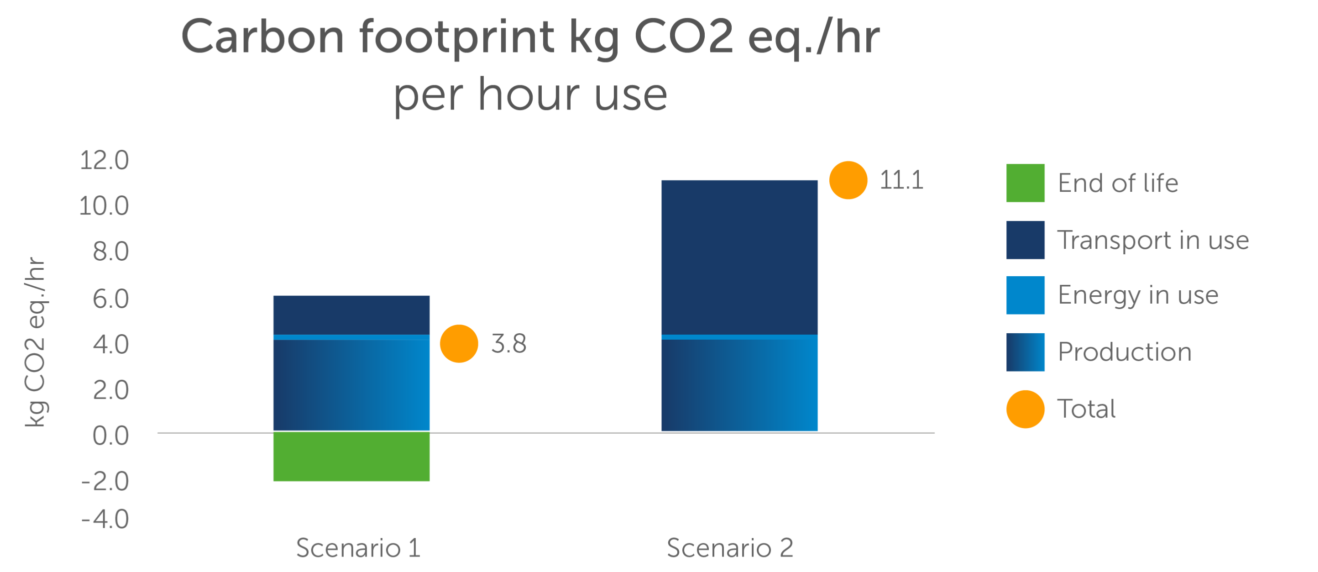
Rental inspired scenario

The comparison below shows the following parameters for scenario 2: Even though a better type of transport vehicle has been picked for scenario 2 (meaning a full loading capacity in comparison with 80% loading capacity in scenario 1), because distance is longer (40 km vs 100 km) and slightly more job site trips are made, the footprint is higher in scenario 2. Utilization rates and energy use for both are the same. Finally, the product is sold off at the end of its life cycle in scenario 2, so the benefits of recycling cannot be attributed.

Considering an inefficient scenario for the mast boom lift

Inefficient use: A municipality uses a lift only a few times per year, for instance for mounting and removing decorations in the streets. Another possibility is a (small) municipality that has a dedicated boom lift for replacing lights on lantern posts. The impact of a mast boom lift is about 3.200 kg CO2-eq. (incl. end-of-life treatment), which would be saved if the municipality would rent instead. Provided that the rented mast boom lift is used at other clients as well.

Section	Detail	Value	Justification/source
Transport	Load capacity and truck size, tonne	7,5 (medium truck)	Questionnaire data wildly varied (from 3,5t to 16-32t truck). As default value an value in the middle has been chosen.
	Distance, km	40	Rounded average based on data provided by 5 European rental companies and contractors. Data varied between 20 and 80 km.
	Jobs per year	20	Based on a typical duration of use at one site of 12 days. Employment rate of 70% of the time, based on interviews with 2 rental companies.
Lifetime and utilisation	Utilisation rate (h/yr)	250	Indication based on data by one rental company; and set similar to the other lifts. Interpretation is uncertain (whether this represents all functional hrs/yr or only hours at which energy is consumed; see also Ch.1)
	Life time (1st use), yr	7	Rounded average based on data provided by 6 European rental companies and contractors. Data provided varied between 3,5 to 10 years.
Energy	Electricity consumption, kWh/h	2	Questionnaire data varied from 1 to 4 kWh. The value is assumed to be similar to the articulating and scissor lifts.
	Hours of active use per year, h/yr	60	Based on the average value provided by 2 European rental companies that have chips installed to measure the hours of active use. The data ranged from 57-65 hours per year.



Tools: Breaker

Rental inspired scenario

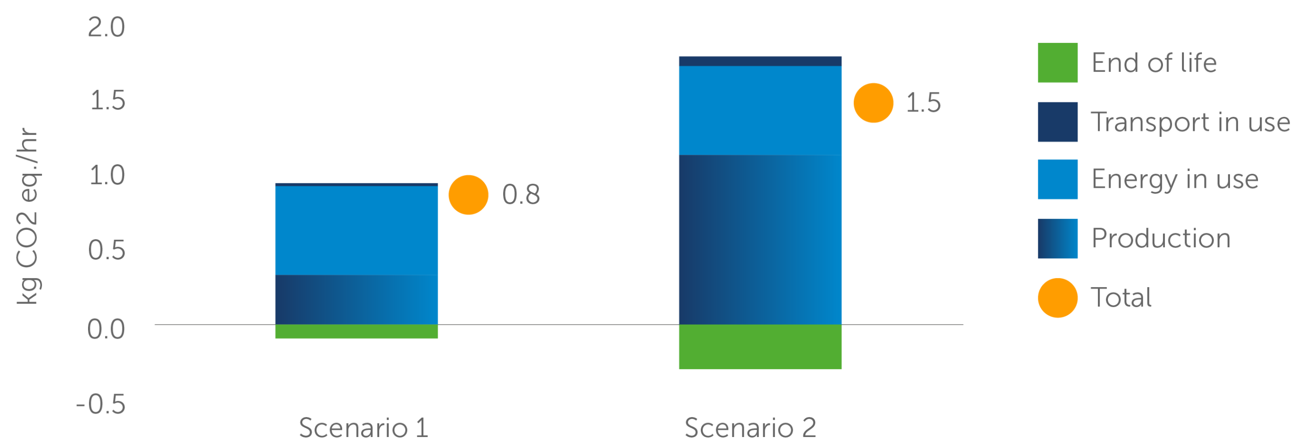
Scenario 1 represents the rental inspired scenario; scenario 2 is a theoretical inefficient scenario based on much less efficient use (around 1/5th of scenario 1). All other parameters are kept the same. The only difference is the total amount of hours the breaker is used in its first lifetime. The figure shows that the impact of production (and benefit of recycling) become much more prominent.

Considering an inefficient scenario for the breaker

Considering the most relevant parameter for this tool, hours of use: a breaker is bought as standard equipment by a construction company, and stored in a van, just in case it is needed. The impact of a breaker is 101 kg CO2-eq. (incl. end-of-life treatment).This would be saved if the construction company would rent instead. Provided that the breaker is used at other clients as well.

Section	Detail	Value	Justification/source
Transport	Load capacity and truck size, tonne	1.2 (large van)	Varied and limited data received. In general, smaller vehicles appear to be used compared to larger pieces of equipment.
	Distance, km	20	Based on data provided by 4 European rental companies. Data varied between 10 to 40 km.
	Jobs per year	7	Based on a typical duration of use at one site of 28 days. Employment rate of 50%, based on an indication by a large rental company. Uncertain data: another rental company mentions a 10% employment rate for small tools.
Lifetime and utilisation	Utilisation rate (h/yr)	100	Based on OEM-provided data on the time machines were in active use ('switch-on time'). High-end of provided range to correspond with efficient machine use.
	Life time (1st use), yr	4	Based on data provided by 4 European rental companies. Data varied between 2 and 5 years.
Energy	Electricity consumption, kWh/h	1.25	Data provided by rental company. Uncertain data: only one data point, which is not the OEM

Carbon footprint kg CO2 eq./hr per hour use



7.3 Avoiding production by sharing equipment

Rental is a prime example of the sharing economy. By using equipment for rent, users don't have to own equipment themselves. This avoids the production of these machines, and therefore avoids the carbon emissions related to the production and the end-of-life phases.

7.3.1 Drivers to choose rental above ownership

There are many factors that determine how rental is more effective than ownership. These factors also directly influence the rental rate/ penetration rate of the products.

Purchasing price versus rental price

Whether or not to choose for rental is above all a financial consideration. This shows the relevance of the TCO (Total Cost of Ownership) calculator on the ERA site[19]. Consider tools for example, which have relatively low retail prices: companies tend to buy these tools themselves. When products get bigger and prices are higher, companies look at the total costs of ownership more in depth, taking into account maintenance, security check-ups, use rate and other factors as mentioned below.

Availability and Risk management

Some machines are crucial for project continuity on a construction site. When such a machine is not available, the construction process is sometimes delayed to the extent that a project deadline is not made. The constructor is then often fined. So there is a financial risk by not having the right machine at the right moment on the construction site.

Supply of the right equipment

Some tasks need very specific tools/equipment. This was often encountered on the subject of access materials. Depending on how often these specific tasks occur became the basis for the decision for the users to rent and could explain why the access products group has a high penetration in rental.

7.3.2 Actual avoided production and hence avoided emissions

To provide input for the question of avoided production, researchers received data from a rental company showing that a mini-excavator was rented by ten different users in a year. We could argue, for sake of this study, that these ten users would otherwise have bought the mini-excavators. By using rental, the carbon emissions of the production and end-of-life phase are avoided for ten mini-excavators in this example. The carbon footprint of the production phase for a mini-excavator is approximately 5.000 kg of CO2 and if properly recycled, recycling reduces the carbon footprint by approximately 1.700 kg of CO2. In theory, adding up the net carbon emissions of 3.300 kg CO2 per avoided mini-excavator ten times adds up to a total of 33.000 kg CO2.

Note: because the clients in this case could not be interviewed it is impossible to confirm that all would have bought the machine if it was not offered for rent or that they would have filled in their need otherwise.

Working on the assumption that only 50% of the clients would have bought the mini-excavator in this case. With this taken into account we can say that with reasonable confidence that applying the rental practice in this case saved about 16.500 kg CO2 – for this one mini-excavator in one year.

7.4 Implications

The insights provided by this research lead to some additional implications for the future:
Considering that the use phase of these tools can have such a large impact, it is imperative that all OEMs and users of these tools work together to accelerate the transition to a low carbon economy and remove the dependency on fossil fuels. By being able to tweak fuel type and consumption in the tool, users can see the potential for emissions reduction by making responsible fuel choices.

Once this transition is made and energy plays a minor role, and in a future where materials (especially rare earth metals) become more scarce, the importance of designing for disassembly and recovering all the materials used in machines becomes clear. Companies will have an economic incentive to keep all their products within their control, to avoid the export of valuable materials to other parts of the world that will seek to increase the stockpile of their own strategic resources.
In the meantime, companies can unlock the tremendous potential for efficiency gains in energy use, further cutting costs in fuel and electricity by using telematics and developing increasingly efficient machines.

Further efficiency gains, not only in fuel use but in carbon reductions, can be made by optimizing logistics and transport during rental. This research has shed light on the strong effects that inefficient transport can have in the total life cycle emissions of products.

[19]*https://equipmentcalculator.org/en*

RESEARCH REPORT CARBON FOOTPRINT OF CONSTRUCTION EQUIPMENT
Climate Neutral Group

8 Conclusions

The climate crisis is said to be one of the biggest The climate crisis is said to be one of the biggest challenges for humanity at this moment. Global warming is directly related to a higher density of greenhouse gas emissions in the atmosphere. Besides legal measures, strategies are designed to lower the carbon footprint of the economy. The philosophy of the circular economy is one of those strategies. Rental, avant la lettre, is a circular business model and contributes to lower emissions.

The goal of this study is to find out how equipment rental contributes to avoiding carbon emissions of the life cycle carbon footprint of construction equipment.

Rental as a business model may ensure a highly efficient handling of the equipment. Various parameters can be subject to efficient handling. The parameters having pronounced influence on the carbon footprint of equipment are: 1. The intensity of use; 2. Energy consumption; 3. Transportation; 4. Recycling and 5. Innovation. Organizing equipment handling efficiently contributes, as is often key to the business model of a rental company, lowers carbon emissions.

Next follows an overview of the carbon footprints of the ten machines used for this research, including a realistic use scenario based on interviews.

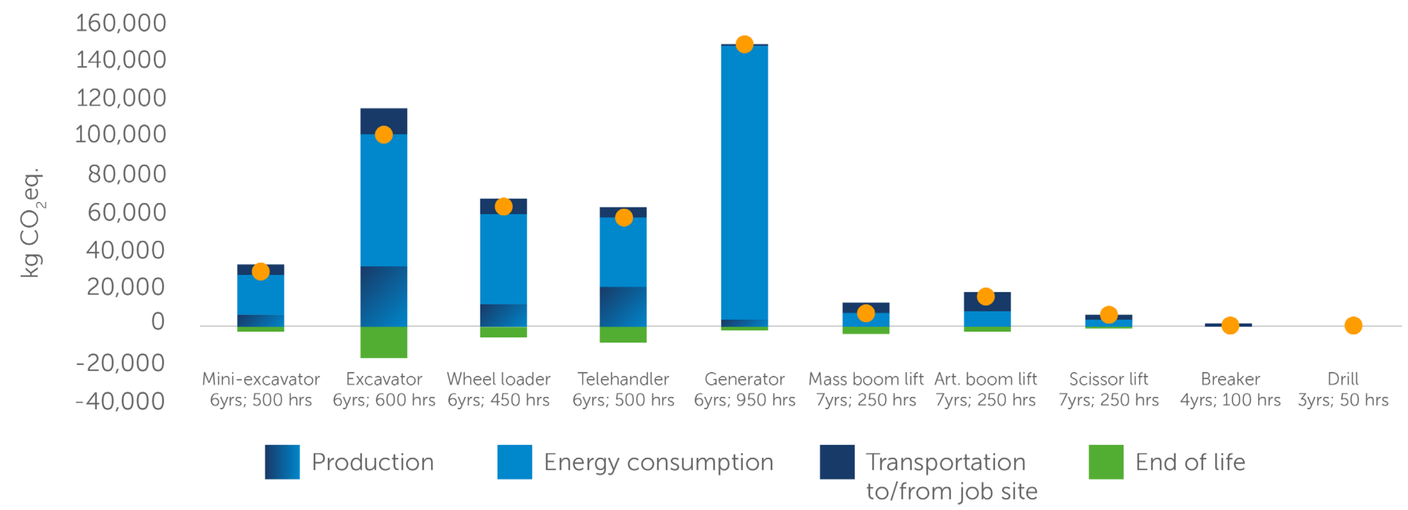
This graph shows that for the products using fuel, energy consumption is the largest part of the carbon footprint.
To the extent that for the generator the impact of energy consumption overshadows all other factors.

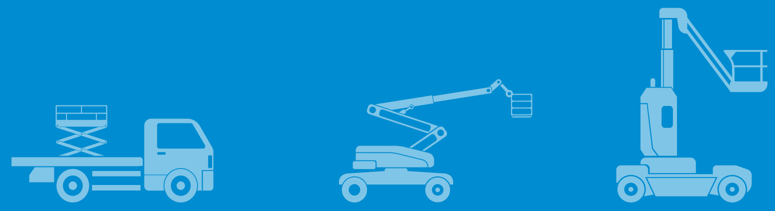
Rental contributes to lowering emissions by providing a wide range of products enabling the client to choose the best machine for the task, making sure that the machines are put to best practice, and have the most efficient fuel consumption per hour. Rental companies can also request the client to use biofuel (if technically possible), which lowers the carbon footprint significantly. Additionally, rental ensures proper maintenance of the products which leads to enduring optimal performance of the products.

For the electrically driven equipment, the impact of production and transportation is more prominent than the contribution of electricity. This is because this equipment generally has much lower utilization rates (hours of use per year) than the -- often continually working -- diesel powered equipment types.
The assessment shows that inefficient transport leads to a significantly higher total carbon footprint.

When fuel consumption is taken out of the equation, for instance when switching to renewable energy or biofuel, other components start weighting heavier on the carbon footprint. Especially then, transport becomes a major factor, an issue in which rental companies research optimization.

Carbon footprint of the first life cycle





Rental companies and their clients represent a big customer share for OEMs. Rental companies can influence their customers to choose more sustainable equipment and with that providing OEMs with the business case to produce more sustainable and electrically driven equipment. ERA can facilitate this process for its members are both rental companies and OEMs.

9 Recommendations

The following section briefly outlines some recommendations for the next steps after conclusion of this project.

1. Expand the functionality of the carbon calculator
    a. Option to compare diesel powered equipment with an electrical counterpart;
    b. Include oil consumption (maintenance)

2. Make the Carbon Footprint Calculator accessible for members to use in their sales pitches

3. Strive to accelerate the transition to electrical equipment that is based on renewable energy. That lowers the footprint of the use phase dramatically and gives more significance to the production and end-of-life phase, enhancing the positive effect of rental.

4. Increase use of telematics to get better insight in idle times, hours of use and total life-time of machines to increase accuracy of numbers in carbon calculator.

5. Carry out carbon footprint on different levels, to have more insights into the impact of the companies itself:
    a. Aim to calculate the footprint of the total fleet of companies
    b. Calculate the carbon footprint of the rental companies

6. Carry out a sector-wide research to determine how often rental is used and production emissions are avoided.

10 About

10.1 Climate Neutral Group

Climate Neutral Group (CNG) wants to accelerate the transition to a net-zero carbon economy. Founded in 2002, CNG is one of the longest established and most recognized providers of carbon management and offsetting services in the market. CNG offers its clients advice on how to fight climate change whilst strengthening their corporate strategies. Via services as carbon footprinting, life cycle analysis (LCA), emission reduction and carbon offsetting, organizations and their products and services become climate neutral.
Headquarters: Utrecht, Netherlands

10.2 CE Delft
Committed to the Environment

Through its independent research and consultancy work CE Delft is helping build a sustainable world. In the fields of energy, transport and resources our expertise is leading-edge. With our wealth of know-how on technologies, policies and economic issues we support government agencies, NGOs and industries in pursuit of structural change. For 40 years now, the skills and enthusiasm of CE Delft's staff have been devoted to achieving this mission.
Headquarters: Delft, Netherlands

10.3 SGS Search

SGS is the world's leading inspection, verification, testing and certification company and is recognized as the global benchmark for quality and integrity. With more than 95.000 employees, SGS operates a network of over 1.200 offices and laboratories around the world.
WHEN YOU NEED TO BE SURE
Headquarters: Amsterdam, Netherlands

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