EVBOX

Proposal for future approach to circular design engineering

August 2021

Circular design engineering

This booklet has been created to support circular practices within EVBox as a part of the graduation thesis 'Towards circular EV chargers: Assessing and improving the circularity of EVBox's commercial AC chargers'. The booklet provides a basic explanation of the circular economy, why it is important for EVBox to go circular and how to put it into practice by providing examples and methods from the thesis and other sources. The findings of the thesis and this booklet serve as a basis for future circular practices.

"A sustainable business is a circular business."
(EVBox, 2018)

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Definitions

For consistency, the following definitions are used throughout this booklet.

Maintain/Prolong is defined as
"the performance of inspection and/or servicing tasks that have been preplanned for accomplishment at specific points in time to retain the functional capabilities and cosmetic condition of products or systems." (Flipsen et al., 2016).

Repair is defined as
"repairability is the ability to bring a product back to working condition after failure in a reasonable amount of time and for a reasonable price." (Flipsen et al., 2016).

Reuse/Redistribute is defined as
"The use of a product again for the same purpose in its original form or with little enhancement or change." (Ellen MacArthur Foundation, 2013).

Refurbishing is defined as
"A process of returning a product to good working condition by replacing or repairing major components that are faulty or close to failure, and making 'cosmetic' changes to update the appearance of a product, such as cleaning, changing fabric, painting or refinishing. Any subsequent warranty is generally less than issued for a new or a remanufactured product, but the warranty is likely to cover the whole product (unlike repair). Accordingly, the performance may be less than as-new." (Ellen MacArthur Foundation, 2013).

Remanufacturing is defined as
"A standardized industrial process that takes place within industrial or factory settings, in which cores are restored to original as-new condition and performance or better. The remanufacturing process is in line with specific technical specifications, including engineering, quality, and testing standards, and typically yields fully warranted products. Firms that provide remanufacturing services to restore used goods to original working condition are considered producers of remanufactured goods." (International Resource Panel, 2018).

Recycling is defined as

- "Functional recycling. A process of recovering materials for the original purpose or for other purposes, excluding energy recovery.
- Downcycling. A process of converting materials into new materials of lesser quality and reduced functionality.
- Upcycling. A process of converting materials into new materials of higher quality and increased functionality." (Ellen MacArthur Foundation, 2013).

The circular economy

"A circular economy is based on the principles of designing out waste and pollution, keeping products and materials in use, and regenerating natural systems."

(Ellen MacArthur Foundation, 2021)

Currently, the global economy is based on a linear take-make-use-dispose system, which means that resources are taken from the Earth, made into products, used for a certain amount of time, and then thrown away. The linear economy draws from finite resources and is destructive to the Earth's ecosystems. Consequently, the linear economy is not sustainable.

A solution to the current linear economic system can be found in transitioning to the circular economy, which is restorative and regenerative by design.

The circular economy proposes a loop-based system visualised in the Butterfly Diagram, where product life is extended through repair, reuse, refurbishment, remanufacturing and recycling. These methods are only applicable for technical nutrients which are finite and man-made. As EV chargers are completely made from technical nutrients, it makes sense to focus on the technical side of the Butterfly Diagram. See figure 1.

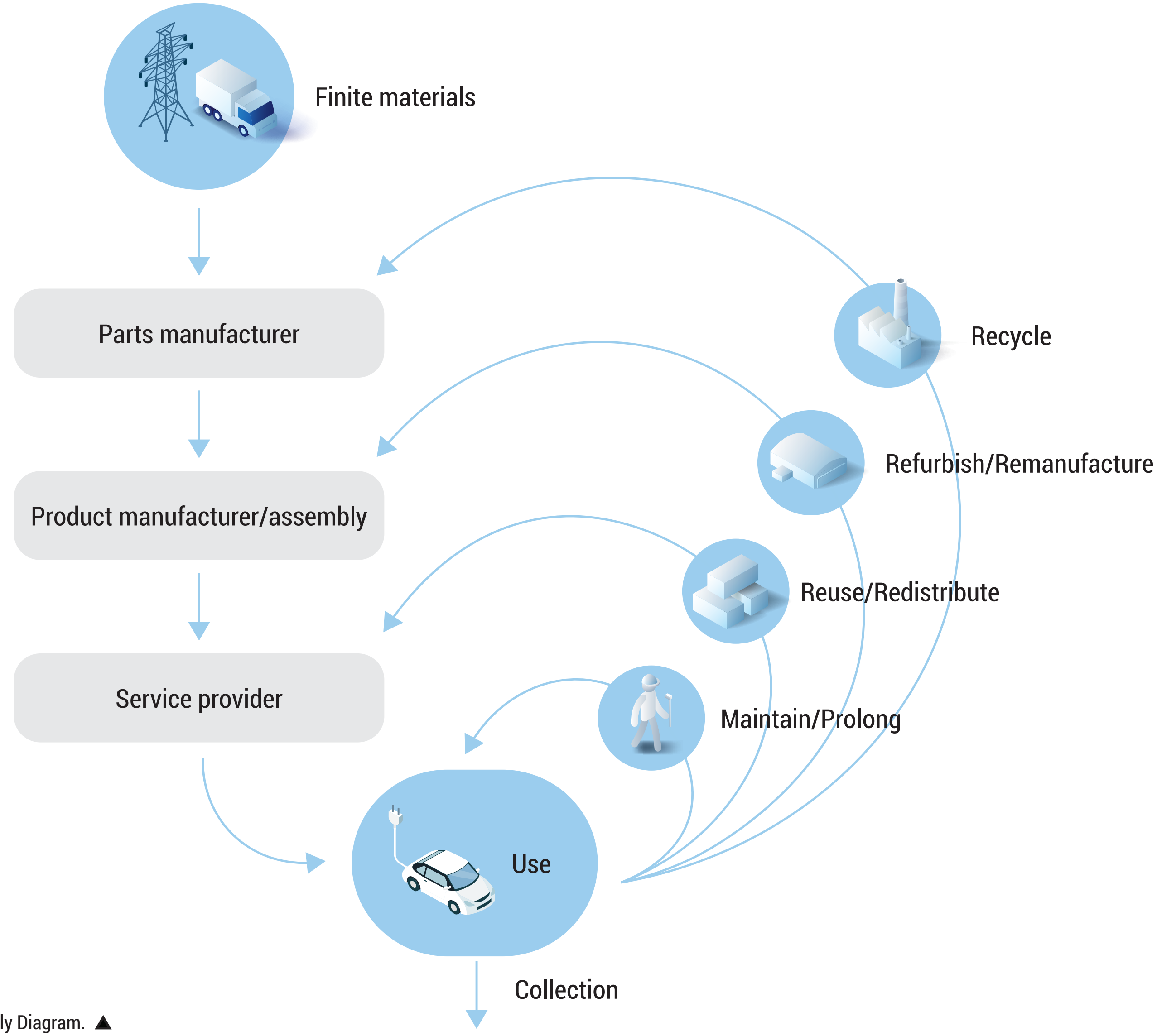


Figure 1. The technical cycles of the Butterfly Diagram. ▲

The value hill

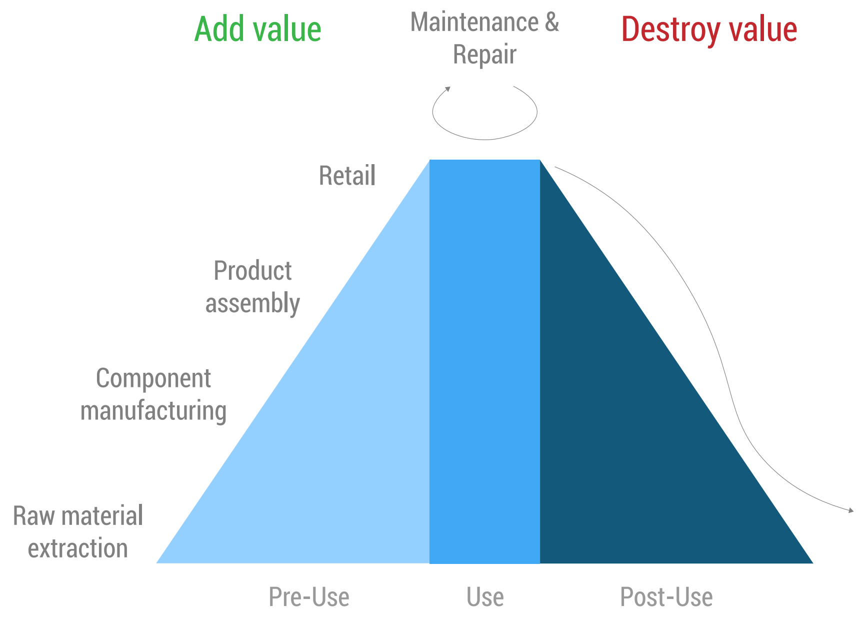
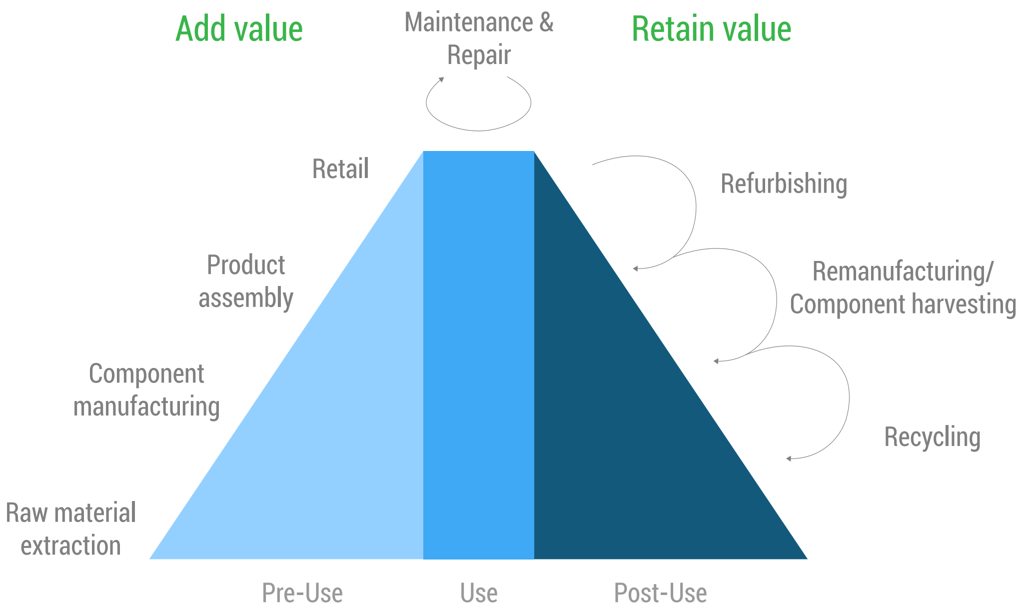


Figure 2. The Value Hill.

A

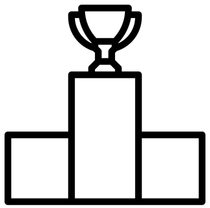
The Value Hill is a means of showing the addition and loss of value of products pre- and post-use, see figure 2, (Hinfelaar et al., 2016). On the left side the basic steps of product manufacturing are shown: raw material extraction, component manufacturing, product assembly and retail. In a linear economy this value is completely destroyed once products are disposed



B

of and incinerated or landfilled (figure 2 A). By implementing the strategies mentioned on the previous page value can be retained post-use. The value hill visualises how the most value can be retained on top of the hill by implementing strategies from the smallest loops where product and component integrity are maintained the most (figure 2 B).

Why going circular is important for EVBox



Becoming sustainability market leader

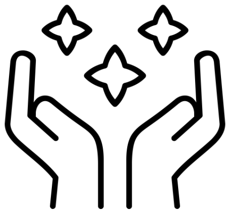
One of EVBox's main competitors offers charging as a service, which is a subscription-based model. Such a subscription model is an excellent example of keeping product ownership and is highly compatible with circular businesses.

Another big competitor's domestic EV chargers are made from recycled plastics and their chargers for urban areas are made using renewable energy. Furthermore, parts of the public chargers can be recovered and reused.

EVBox could differentiate in the EV supply equipment market by going circular, being able to show that they are not just a sustainable business, but a circular business.

Legislation

The European Commission is shifting towards a circular economy and is gradually implementing legislation for its members to follow. Examples are the European Green Deal (2019) and the Circular Economy Action Plan (2020). These documents propose milestones and a framework for the European Union to gradually shift towards a circular economy. One of its main goals is the decoupling of resource use from economic growth and being emission-free in 2050. The Commission proposes a sustainable products policy to ensure that product lifespan is elongated for as long as possible, having products cascading to the next cycle only when necessary. Strengthening of extended producer responsibility is also part of the agenda.



Value capturing

As mentioned before, value can be captured and retained by implementing the circular strategies presented in the Butterfly Diagram. However, as of now the life cycle maps of EVBox's chargers is linear. This means that the embedded value of these products can be recaptured. Figure 3 on the next page shows the linear life cycle map and potential value retention strategies to implement.

In the next chapter a tool called Reversed Logistics Mapping is presented, which was used during the thesis to estimate the economical viability of the aforementioned strategies.

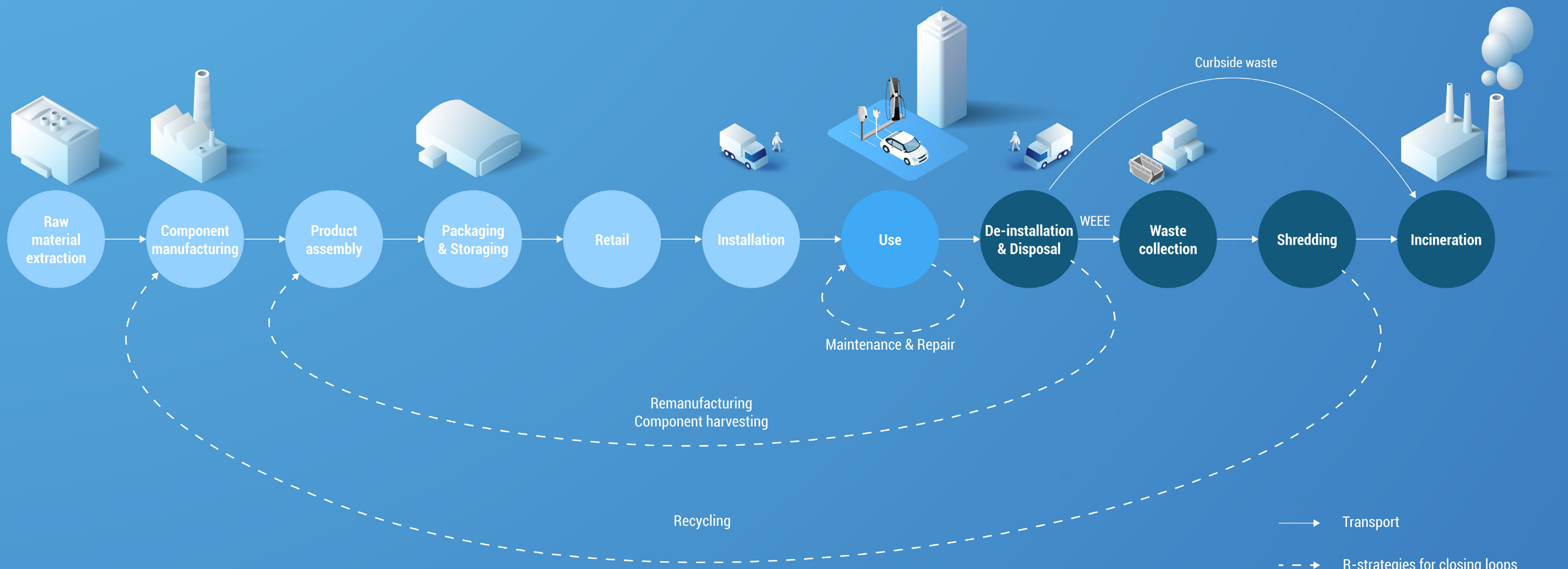

Raw material extraction
Component manufacturing
Product assembly
Packaging & Storaging
Retail
Installation
Use
De-installation & Disposal
WEEE
Waste collection
Shredding
Incineration
Curbside waste
Maintenance & Repair
Remanufacturing
Component harvesting
Recycling
Transport
R-strategies for closing loops

Figure 3 visually represents the stages a charger will go through during its life. Beginning with raw material extraction and component manufacturing. Component manufacturing and assembly is outsourced to multiple third parties.

Product assembly is done by assembly partners and potentially disassembly partners such as CMM in Amersfoort and VDL in Eersel, after which the products are stored and transported to resellers by EVBox's third party logistics provider Kuehne+Nagel. Installation is done by a third party or by the reseller themselves in case they offer installation services.

EVBox's AC chargers have an estimated commercial lifetime of 8 years, after which they will be de-installed and brought to special waste collection points by an installer party. Then, they will be disposed of following the WEEE directive, for which EVBox pays a tax. Eventually, this still means that the products are shredded. Valuable materials such as copper in the cables and metal parts are collected and recycled, but others will be incinerated.

As can be seen in the figure, the life cycle map of EVBox's chargers is linear, which means that potential value is lost as shown in the value hill in figure 2A. Through application of one or more value retention strategies from the butterfly diagram in figure 1 the value of these products can be captured. They are represented in figure 3 by arrows that loop back to earlier stages in the charger lifecycle.

◀ Figure 3. The linear life cycle map of EVBox's chargers.

Putting circularity into practice

This chapter shows how circular design was achieved during the thesis. The used methods, namely Reversed Logistics Mapping and the Disassembly Map are explained and the results are shared. Then, a proposal for fututre circular design practices based on the experiences of the whole project is presented.

Methods used during the thesis

EVBox's circularity was assessed on a strategic level with a tool called Reverse Logistics Mapping and on a product level with a tool called the Disassembly Map (De Fazio, 2018).

The Disassembly Map tool is ideal for making the disassembly (improvements) of these complex types of products visually comprehensible. The product's target components are identified, as well as product architecture and tools needed for disassembly. This way opportunities for improvement become clear, after which the tool can be used to guide and support redesign activities.

Improving ease of disassembly will only help when the envisioned activities are truly undertaken. Through Reverse Logistics Mapping, which is the identification and visualisation of necessary steps and processes in the ecosystem to take back the products, the economic viability of implementing one or more of the value retention strategies is identified.

Strategic level - Reverse Logistics Mapping

Reverse logistics is defined as 'moving goods from their place of use, back to their place of manufacturing for re-processing, re-filling, repairs or recycling/waste disposal' (Deloitte Consulting, 2014).

The Ellen MacArthur Foundation stated the following on reverse logistics, (2016):

"Just as important as forward logistics, which powers global trade through the transport of materials, goods and information from start to (literally) finish, is reverse logistics. It is a key step in capturing the value of end-of-life goods and facilitating the reuse and recycle pillars of the circular model. This covers not only the collection and transport of materials and products but value-added activities such as testing, sorting, refurbishing, recycling and redistribution."

A 'mapping' activity was added to the identification of reverse logistics steps which entails visually representing all steps, stakeholders and related costs and benefits. It can be considered a tool for finding and communicating fruitful circular strategies to stakeholders.

By visually mapping the reverse logistics steps and calculating the costs connected to its activities it was possible to estimate which value retention strategy can be best implemented by EVBox in the future as a potential business plan. Combined with the product-based Disassembly Map findings, guidelines for improvement can be made for a redesign for this specific strategy.

The four potential strategies that were considered in this analysis are:

- Maintenance and repair
- Remanufacturing
- Recycling
- Component harvesting

Applying one of the strategies does not exclude implementation of others; in a truly circular construct products can cascade through multiple loops by being reused, repaired, refurbished, remanufactured and finally, recycled. A cascading strategy would allow EVBox to add up all benefits calculated in this chapter, leading to the most lucrative scenario. Furthermore, once the reversed logistics for one of the strategies has been set up, the step to applying others is relatively easy to make since all strategies consist of partially the same parties.

Additionally, products that are brought back can consist of components that require different treatment. For example, after 8 years Iqon's side panels would be suitable for reconditioning in a remanufacturing scenario but the top cover would be more suitable for recycling. Furthermore, the kWh-meters, for example, can not be recalibrated and can thus only be considered refurbished instead of remanufactured after going through a value retention process. These examples show that the distinction between the different strategies can appear to be quite vague and that it might be necessary to apply them in parallel.

Maintenance and repair

Product life extension is a means to keep products in use for longer periods of time. This can be done by servicing activities such as repair, replacement and cleaning. EVBox chargers have an average commercial lifetime of 8 years, of which 3 years are covered by legal warranty. This warranty can be extended to 5 years. The warranty implies that the product should be working normally within this period of time and, in case parts failure and errors due to wrong assembly occur, it will be covered by EVBox. Labour costs of the repair professionals are not covered by EVBox. EVBox will be influenced if products are designed badly for repair, since the products have a warranty: customer satisfaction might decrease since customers do not expect the product to break within this period and repair costs will increase. An additional reason for wanting better repairable chargers came to surface through conversations with the EVBox Product Management Department: products that are more serviceable are more attractive to installers and repair professionals. These are often part of the reseller company and influence the purchase of a specific EV charger brand. In short: EV chargers that are easy to service are preferred over other chargers.

EVBox does not have in-house (de-)installation- and service technicians. After the products are sold to charging port owners maintenance is done by EVBox trained installation parties such as ENGIE affiliates or other installers such as Laadpunt.nl, Justplugin and VeBe in the Netherlands. For big contracts EVBox cooperates with third parties for service and maintenance to be able to offer one turn-key solution to customers.

Only when issues appear to be too complex to resolve on-site, the faulty components or station are disassembled and taken back to CMM or another assembly partner.

Additionally, CMM takes back faulty products through Return Merchandise Authorization (RMA) orders. The most common reasons for sending a product back are 'wrong item delivered' and 'wrong item ordered'. CMM does not take back products that need to be repaired; this is done on-site by the aforementioned third-party specialists.The CEO of CMM explained that in case of an RMA, products will undergo a physical quick check and be reboxed and re-sent when the box is unopened upon arrival. When the box is opened by a customer, the products will undergo a full check, including cleaning and replacement of parts where needed. Then the products will be reboxed and re-sent.

These and the aforementioned efforts indicate the possibility of a larger-scale repair service where more components are available as spare parts and a continuous in- and outflux of to be repaired and repaired products is constituted.

Product life extension in itself may not provide any extra income, as product sale is still just once per product. Extra income may come through increased customer loyalty, sales and the reduction of servicing costs under warranty. Servicing and repair packages can be provided to customers for a certain price guaranteeing product repair within a certain number of days. Maintenance and repair can be a lucrative strategy when the income made from selling these servicing and repair packages to customers exceeds the servicing and repair costs. A calculation was done based on collected data and assumptions which can be seen in the reverse logistics map in figure 4. The figure shows the benefits versus costs regarding this scenario: it is estimated that profits in a maintenance and repair scenario are equal to 8% of the costs. The calculation shows that transport costs are low compared to the labour costs. The biggest expenses come from labour and spare parts. The latter being heavily dependent on which part(s) needs to be replaced. For example, the replacement of Iqon's entire installer- and chargerbox assembly is roughly ten times more expensive than the replacement of the kWh-meter alone. The yearly servicing of all stations amounts to the biggest expenses. As of now, there are only about 20 Iqons in the field; this number is expected to grow. Which means more servicing and repair has to be done for this product, and more servicing and repair packages can be sold.

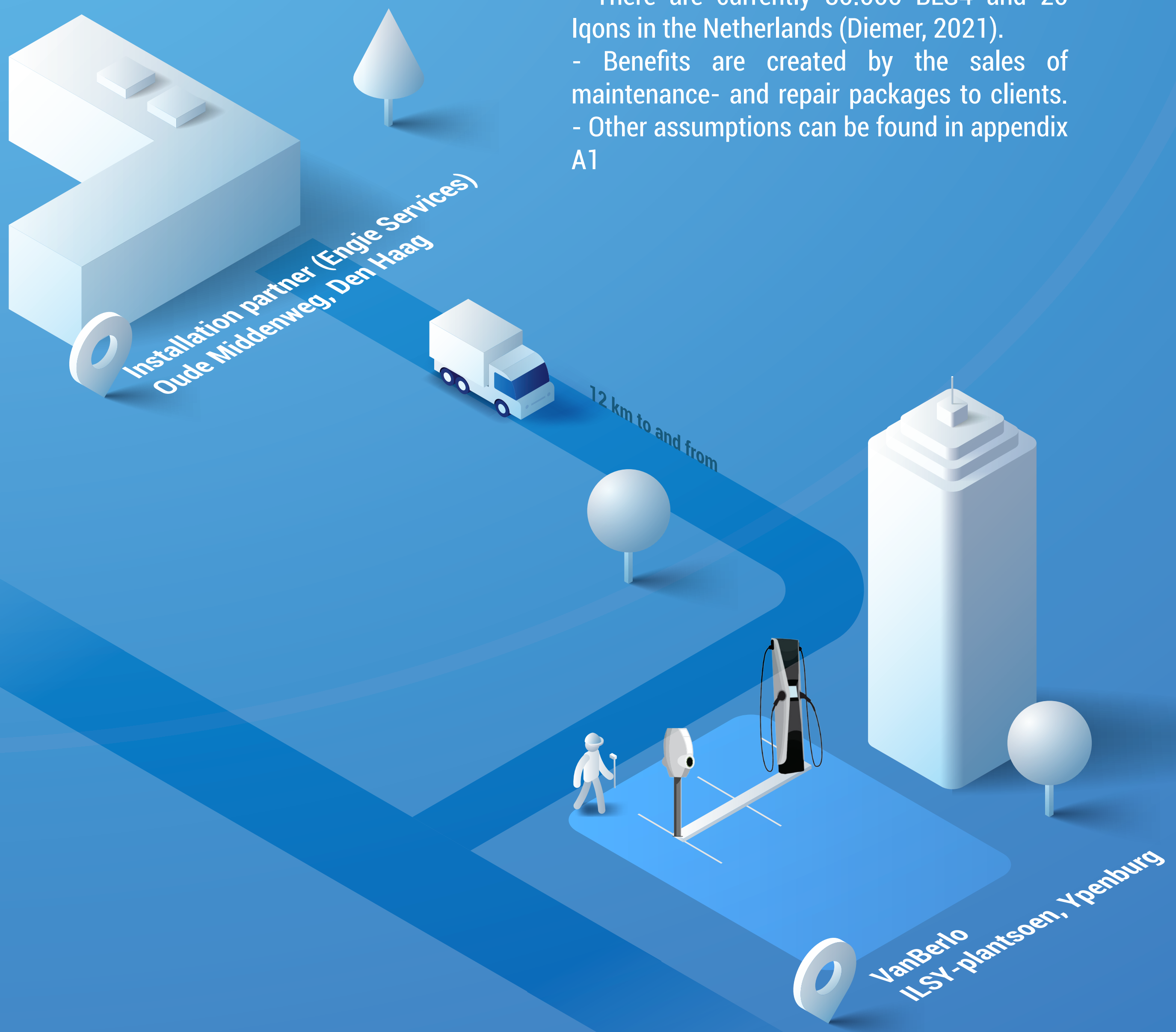
Figure 4. Reverse logistics map of a maintenance and repair scenario.▶

Maintenance and repair scenario

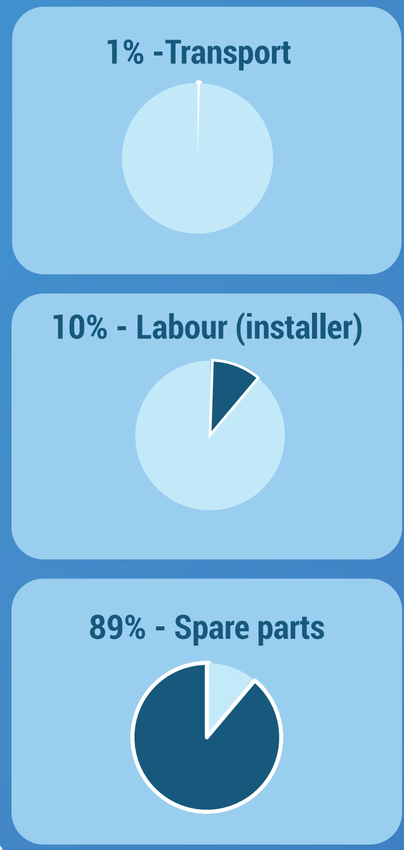
An Iqon/BLG4 at the parking lot on the ILSY-plantsoen in Ypenburg is serviced by Engie services located at the Oude Middenweg in Den Haag.

Key assumptions

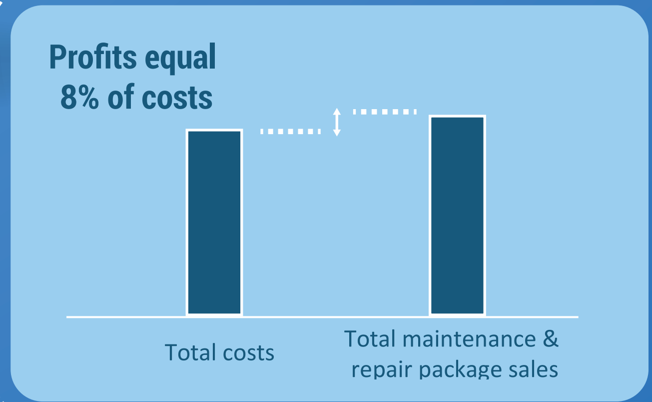
- All servicing and repair is done on-site
- Servicing is done once a year (VeBe, 2021)
- Transport happens with a Diesel van with fuel consumption ratio 1:10
- There are currently 30.000 BLG4 and 20 Iqons in the Netherlands (Diemer, 2021).
- Benefits are created by the sales of maintenance- and repair packages to clients.
- Other assumptions can be found in appendix A1



Average total repair costs of BLG4 and Iqon



Costs versus benefits per year



Remanufacturing

Remanufacturing is a potentially valuable strategy for EVBox, as EV chargers are durable and made of high-end materials, (Gray, C, Charter, M., 2007; Hatcher, Ijomah, Windmill, 2011). Additionally, as EVSE sales are growing and EVBox production is being upscaled the reverse flow of used products will also grow, which can enable sufficient product inflow for remanufacturing (Gray, C, Charter, M., 2007; Ayres, R. et al., 1997).

Applying a remanufacturing strategy would mean taking back products from the field to CMM or another (re)manufacturing partner which will be done by an installer party and Kuehne+Nagel. Upon arrival, the process of running entrance diagnostics on electronics, disassembling the products, thorough cleaning of parts, inspecting and sorting parts, remanufacturing suitable components/replacing components that are unsuitable for remanufacturing, reassembling products, final testing and finally selling the reassembled products is done (Steinhilper, R., Butzer, S., 2016). Reassembled products consist of a combination of new and remanufactured parts.

From a financial perspective, this could be a viable strategy when the benefits made from selling remanufactured products is higher than the costs of taking back the chargers and remanufacturing them. Additionally, remanufacturing would lead to material and cost savings.

A scenario calculation was done based on the assumptions shown in the reverse logistics map in figure 5. In this scenario it becomes clear that transport costs amount very little to the overall costs. De-installation of all stations is expensive due to the labour costs of installers.

Components have been divided into three groups: wear parts/obsolete parts, reconditionable parts and harvestable parts. The component category percentages are visualised under the 'Component harvesting' subchapter. In case the main frame, top frame, CMS guide frame, side panels, pulley system, aluminium heatsink and DIN rails in Iqon are reconditioned, 35% of the total production costs can be saved. It is estimated that 48% of total production costs needs to be invested in replacing wear parts with spare parts, which amounts to 88% of the total costs of remanufacturing. Overall, it is estimated that profits in a remanufacturing strategy amount to 54% of the costs, rendering remufacturing a lucrative strategy.

As of now, there are only about 20 Iqons in the field; this number is expected to grow, which means more remanufacturing has to be done and more remanufactured products can be sold.

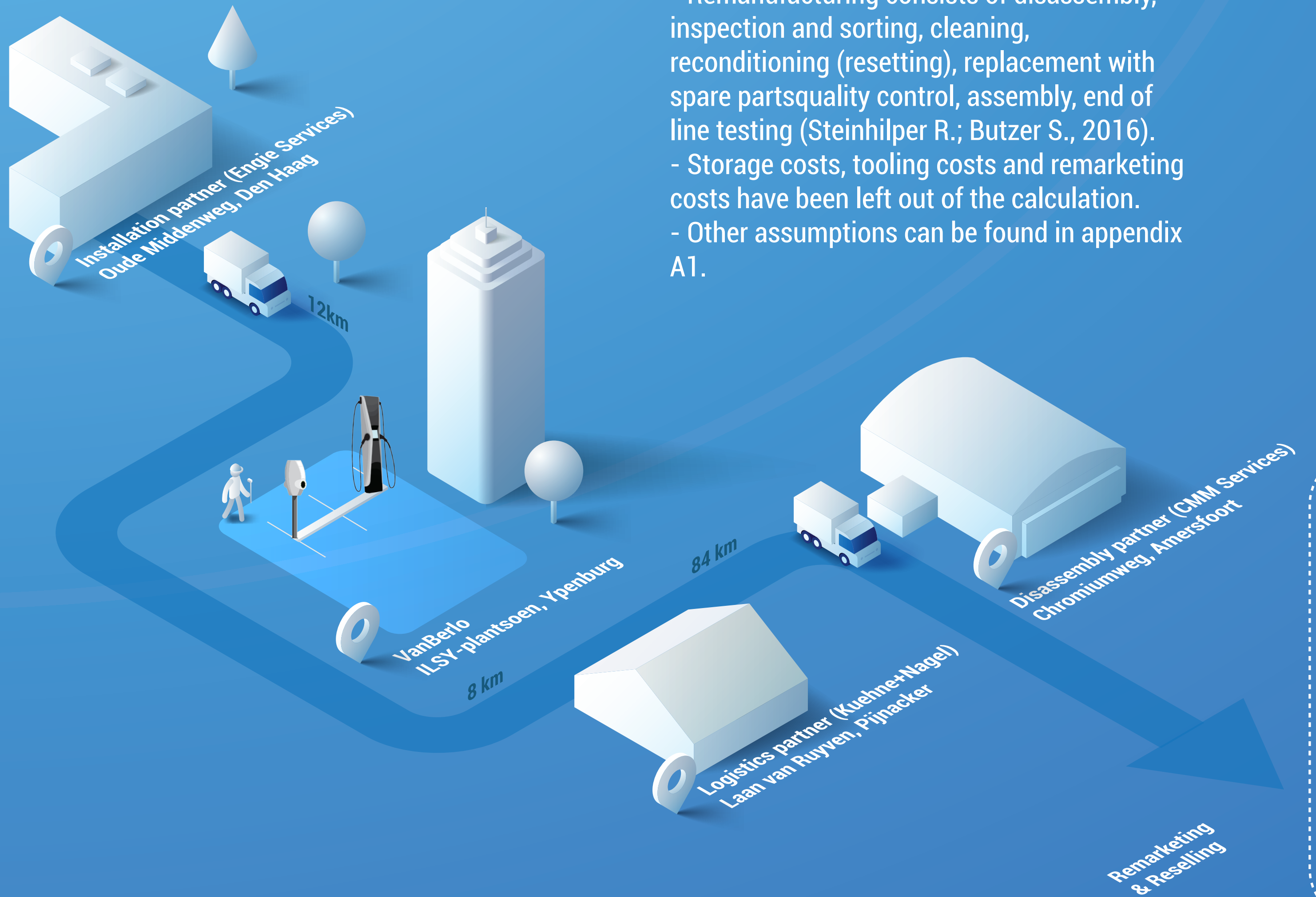
Figure 5. Reverse logistics map of a remanufacturing scenario. ▶

Remanufacturing scenario

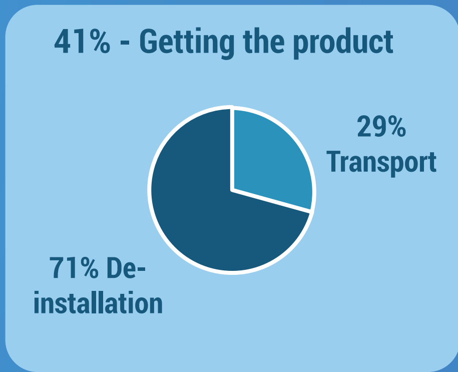
An Iqon/BLG4 at the parking lot on the ILSY-plantsoen in Ypenburg is at its EoL. It is de-installed by an EVBox partner and stored at a Kuehne+Nagel warehouse. Then it is brought to CMM, where it will go through the remanufacturing process. Afterwards, the remanufactured product will be remarketed and sold as new.

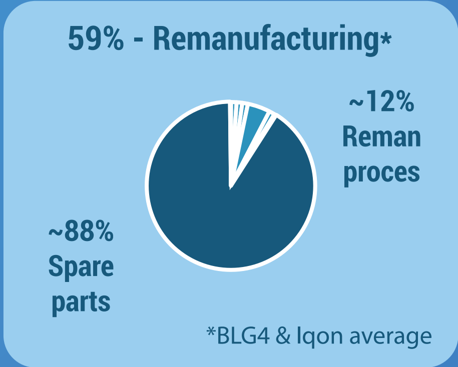
Key assumptions

- Transport happens with a Diesel van with fuel consumption ratio 1:10.
- There are currently 30.000 BLG4 and 20 Iqons in the Netherlands (Diemer, 2021).
- 50% of brought back Iqons and 25% of BLG4's will be remanufactured and resold.
- Remanufactured products are sold for 2/3rd of the original price, business model still to be further developed.
- Remanufacturing consists of disassembly, inspection and sorting, cleaning, reconditioning (resetting), replacement with spare partsquality control, assembly, end of line testing (Steinhilper R.; Butzer S., 2016).
- Storage costs, tooling costs and remarketing costs have been left out of the calculation.
- Other assumptions can be found in appendix A1.

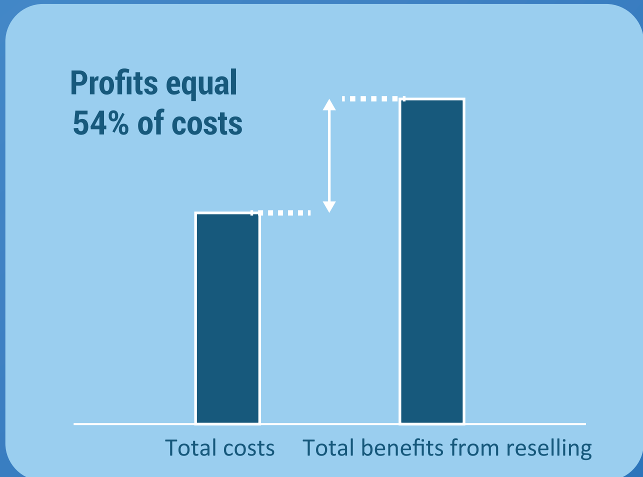


Average total remanufacturing costs





Costs versus benefits



Recycling

Recycling is a strategy that affects component integrity the most: components are collected, liberated, concentrated and reprocessed, (Tempelman, 2014). After reprocessing, the materials can be reused in other applications. Recycling should only be done when other strategies that better preserve product/component integrity are not viable. A recycling strategy should therefore only be chosen as a last resort.

The correct collection of chargers that have reached EoL is the first step in this process. In a business scenario, the facility manager is responsible for the disposal of the charger. He or she would have to call an installer to de-install the charger, who would then transport or send the charger to a specific collection point. From there on the charger will have to be transported to a special sorting centre, where the product will be disassembled and separated into specific waste streams to be processed at specialised processing centres, (WEEE Nederland, 2021). There, the streams are separated and shredded as mentioned above resulting in feedstock for new products. Any residual waste is incinerated.

Recycling is an economic activity (Tempelman, 2014). As shown in the reverse logistics map in figure 6, it is unlikely that EVBox will be able to profit from income made from reselling recycled materials, as it will be captured by the recycling centre. This calculation does show, however, that EVBox chargers contain lots of precious metals: value which should be captured, rather than given away. This emphasises the importance of implementing other R-strategies before recycling.

It should be noted, however, that upcoming European regulations will make correct recycling of products mandatory as mentioned in the European Green Deal (2019) and the Circular Economy Action Plan (2020). Producer responsibility will have to be strengthened. Therefore, it could be worthwhile to form one or more partnerships with third-party recycling plants. Assembly partner CMM is currently working with recycling partner HKS, which could perhaps be investigated further to explore possibilities of upscaling recycling activities when reverse logistics activities are upscaled.

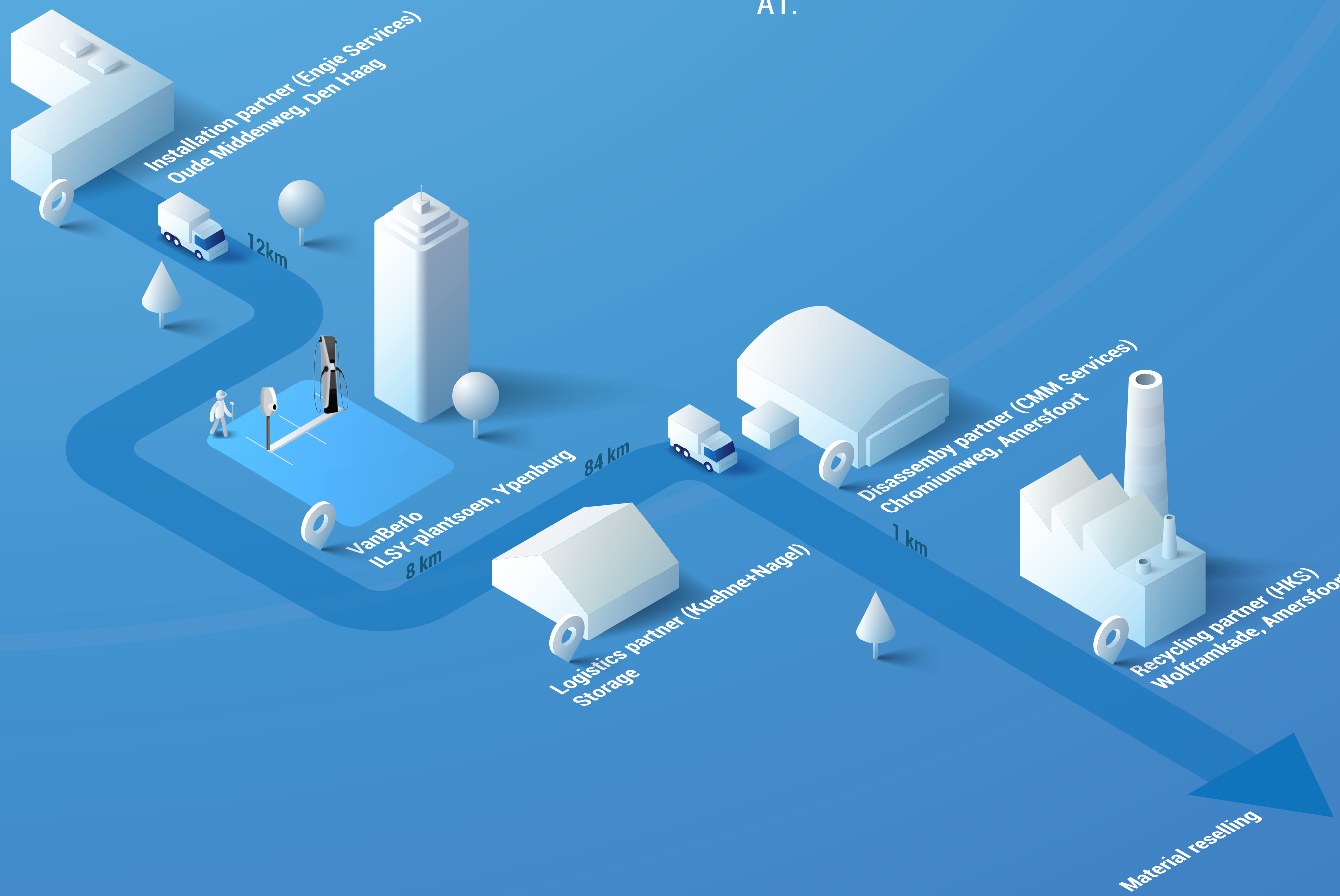
Figure 6. Reverse logistics map of a recycling scenario. ▶

Recycling scenario

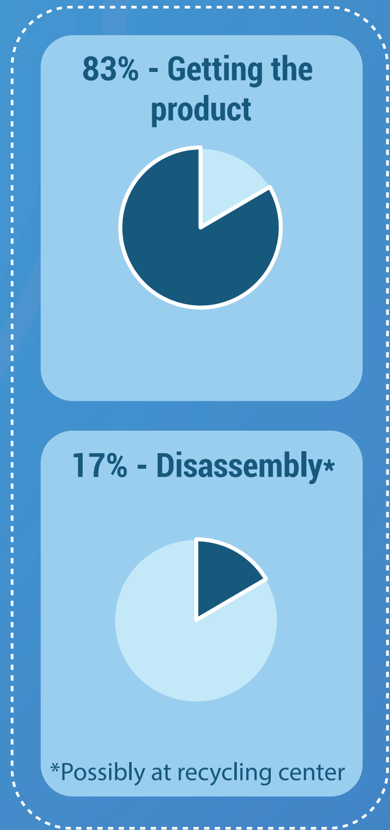
An BLG4/Iqon at the parking lot on the ILSY-plantsoen in Ypenburg is at its EoL. It is de-installed by a EVBox partner and stored at a Kuehne+Nagel warehouse. Then it is brought to CMM for disassembly and picked up by a recycling partner for further processing.

Key assumptions

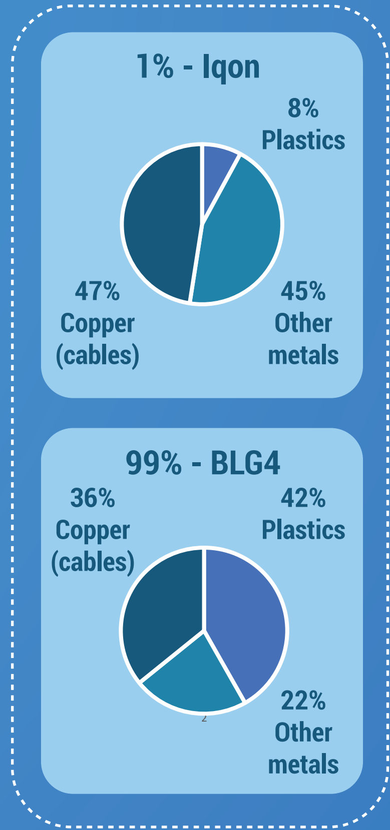
- Transport happens with a Diesel van with fuel consumption ratio 1:10.
- There are currently 30.000 BLG4 and 20 Iqons in the Netherlands (Diemer, 2021).
- 90% of chargers is reclaimed from the field.
- A material recovery rate of 60% is used.
- Shredding costs: €25 / ton for coarse shredding and €50 / ton for fine shredding (Tempelman, 2014).
- Other assumptions can be found in appendix A1.



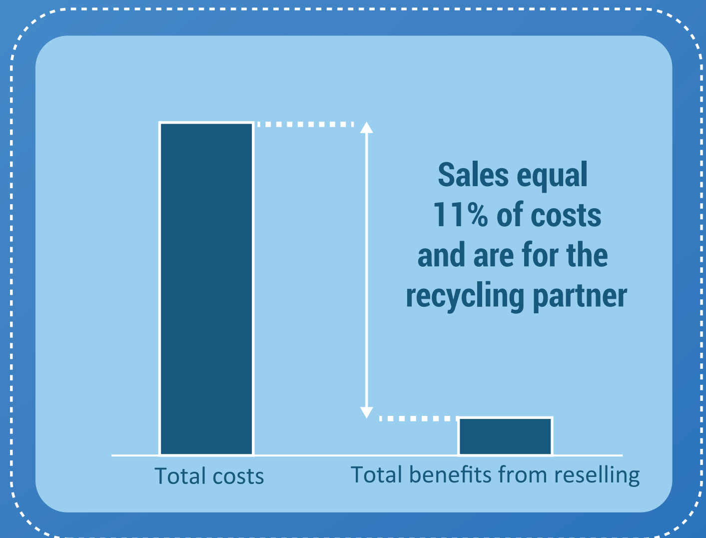
Average total costs of recovery



Reselling materials (recycling partner)



Costs versus benefits



Component harvesting

Component harvesting can be implemented for reusing suitable components. It is often done in combination with other strategies such as repair, refurbishing and remanufacturing. Harvested components can be used in new as well as second-hand products, eliminating the need to buy the components as new, resulting in cost savings. Component harvesting can be done instead of manufacturing new parts. This is an interesting strategy when combined with, for example, repair and remanufacturing as the products need to be disassembled anyway to implement those strategies. Furthermore, money can be saved when harvested parts are used instead of new parts.

Previous research by VanBerlo has shown that some parts in the chargers are overengineered and have long shelve lives. It would be a waste to incinerate them when a charger becomes defective or reaches its EoL. One of those parts is the kWh-meter, located in the installerbox. Based on this information, a videocall with two employees of ABB, the manufacturer of the kWh-meters, was set up to further investigate this matter.

During the call, the employees indicated that the lifetime of the meters is 7 years longer than the expected 8 years of Iqon, resulting in a total expected lifetime of 15 years. Furthermore, the innovation rate of these meters is slow: the current model was designed in 2012. These factors show there is potential for a second life. However, during the call it also became clear that the meters can not be recalibrated to zero. Within a remanufacturing scenario, this could be problematic as components have to become as new. On the other hand, this does not have to be bad news necessarily. The meter's value could act like the mileage in a second-hand car and give an indication of past usage, which is also valuable information. A harvested meter that is not recalibrated can not be classified as remanufactured but is classified as refurbished. As mentioned in chapter 3.2, for a component to be remanufactured, it has to be brought back to an as-new state. Thus, for the kWh-meters to be remanufactured, they would have to be recalibrated to zero.

Additionally, kWh-meters have a calibration warranty. When the components are disassembled (for example, for a quality check), the kWh-meter loses its warranty. As far as the ABB employees knew, disassembly of the kWh-meter with the intend of reusing has never been done before. There is a 1 year warranty in the Netherlands on these components.

Based on the abovementioned findings, one could argue that similar electronic components, for example those that also measure and take action based on electric attributes such as current/voltage/power, will have a similar expected lifetime which is longer than the expected lifetime of the charger as a whole. Further research into the harvesting of, for example, the RCBO and solenoids, could substantiate this claim.

The reverse logistics map in figure 7 shows that savings created by harvesting suitable components equal 21% of total remanufacturing costs. The Iqon component categories mentioned under 'Remanufacturing' have been used in this calculation. Based on assumptions, the harvestable parts in Iqon amount to 6% of total production costs.

Figure 7. Reverse logistics map of a component harvesting scenario. ▶

Component harvesting scenario

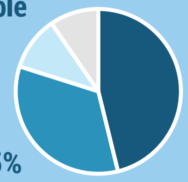
A BLG4/Iqon at the parking lot on the ILSY-plantsoen in Ypenburg is at its EoL. It is de-installed by a EVBox partner and stored at a Kuehne+Nagel warehouse. It is then transported to an assembly partner where functional components are harvested for reuse in refurbished/remanufactured products.

Key assumptions

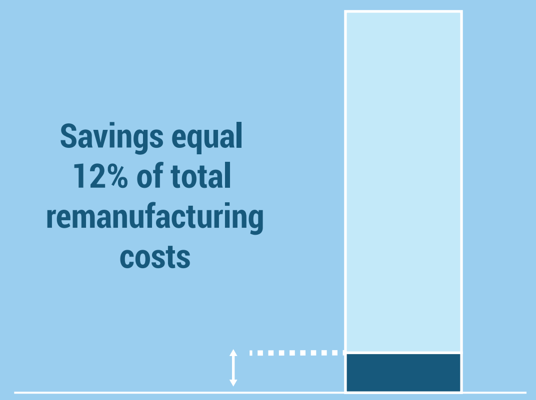
- Transport happens with a Diesel van with fuel consumption ratio 1:10.
- There are currently 30.000 BLG4 and 20 Iqons in the Netherlands (Diemer, 2021).
- 50% of brought back Iqons and 25% of BLG4's will be remanufactured and resold with harvested components.
- Component harvesting is done as an additional activity next to refurbishing/remanufacturing, thus disassemblyreconditioning costs have not been taken into account.
- Other assumptions can be found in appendix A1.

Iqon component categories

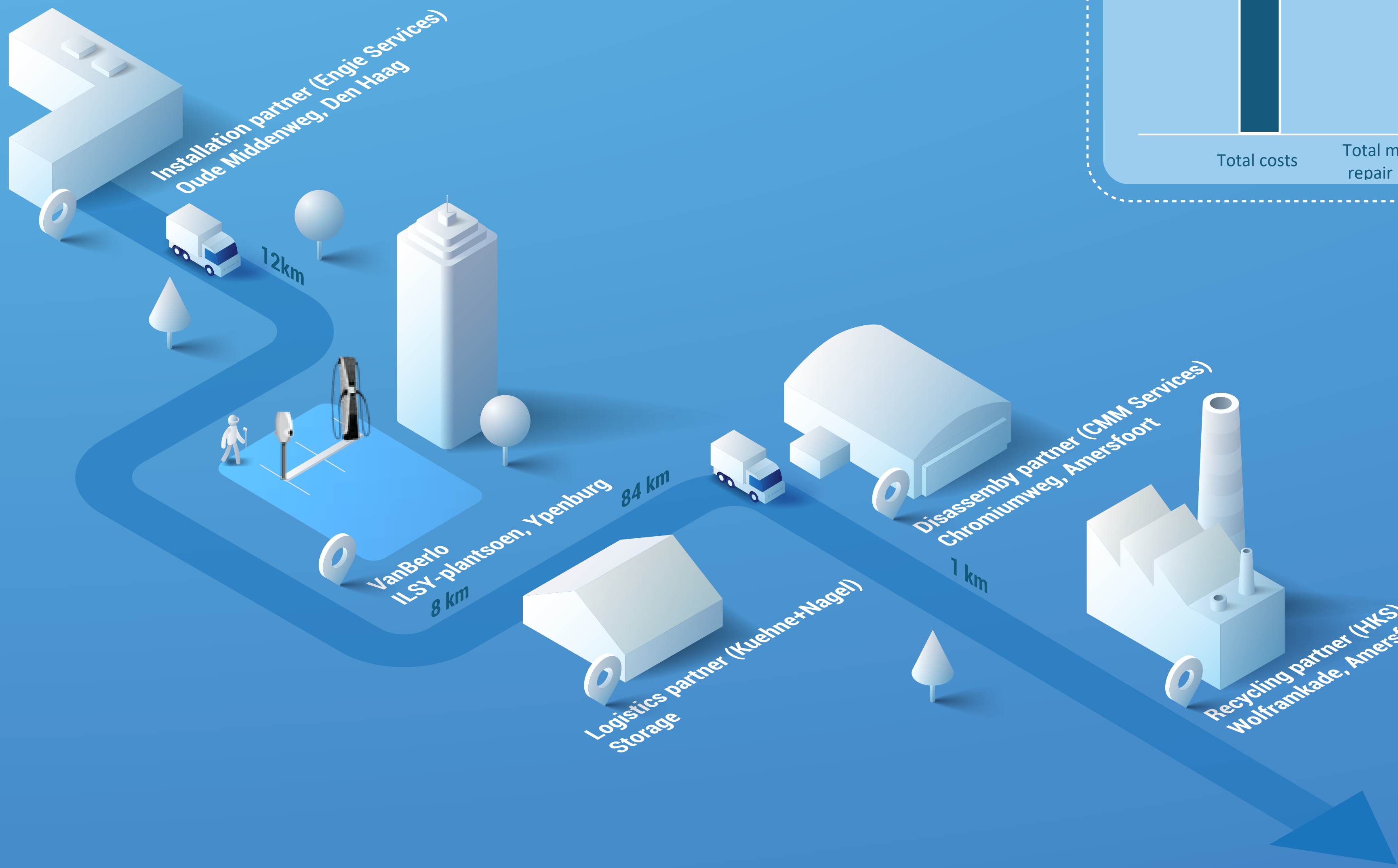
% Of total production costs



Iqon costs versus benefits

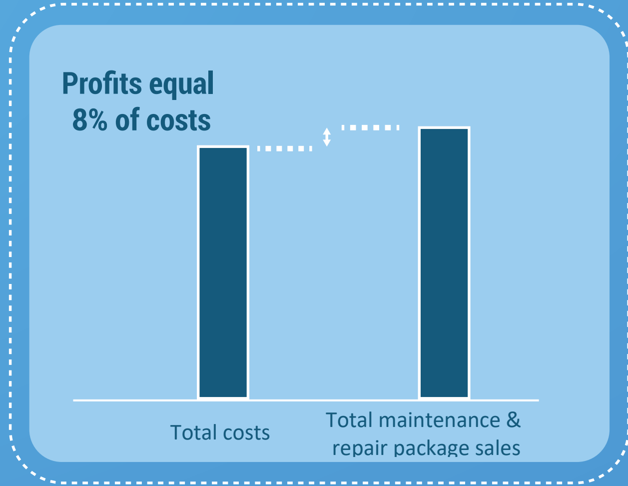


Total reverse logistcs overview of value retention strategies



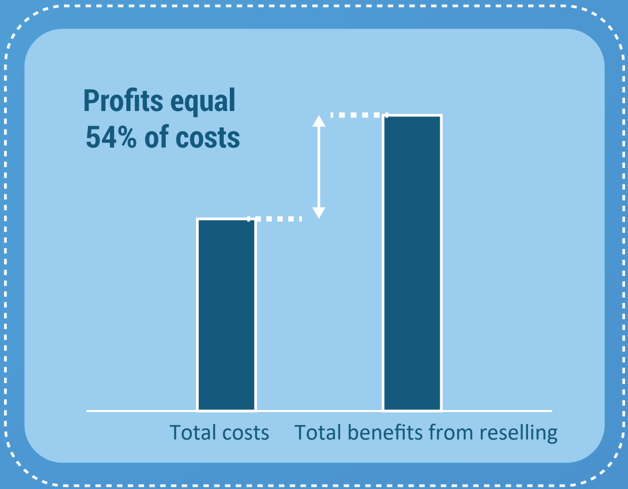
Maintenance and repair scenario

Costs versus benefits per year



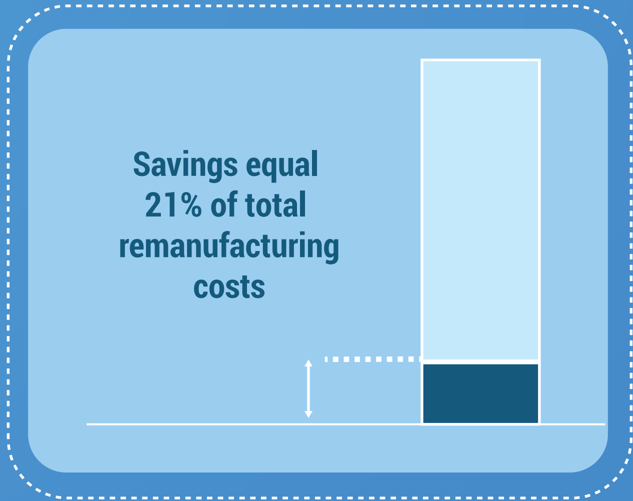
Remanufacturing scenario

Costs versus benefits



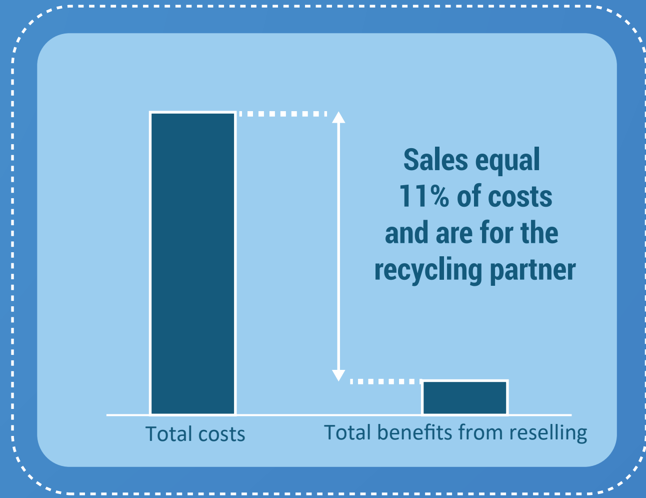
Component harvesting scenario

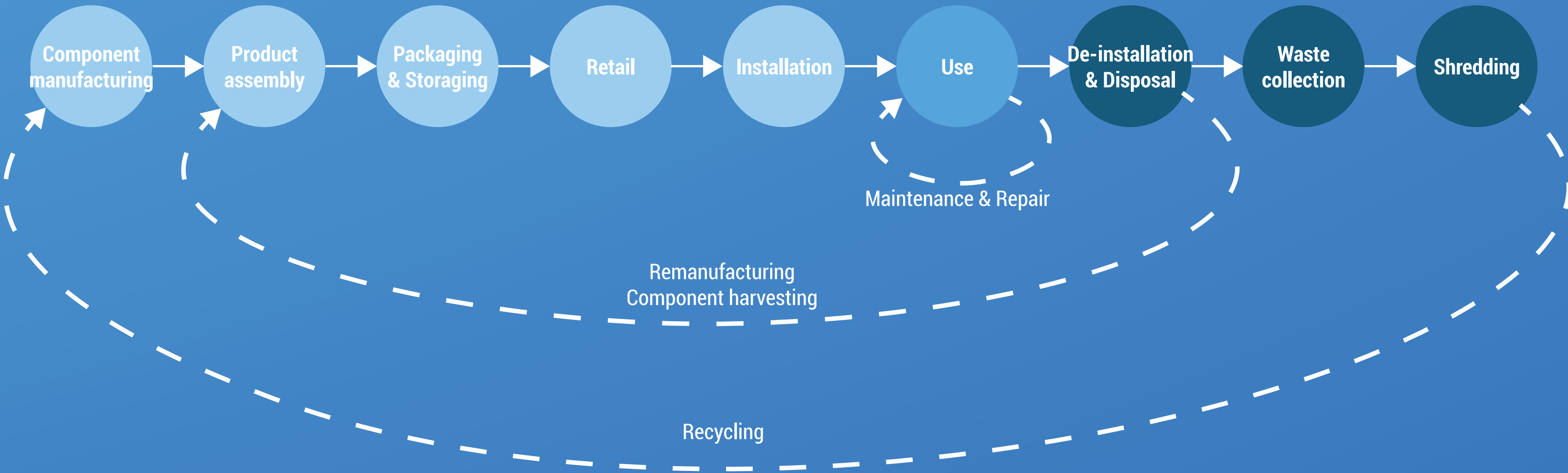
Iqon costs versus benefits



Recycling scenario

Costs versus benefits





Product level - The Disassembly Map

A product's ease of disassembly correlates to product lifetime extension strategies. Improved component accessibility facilitates reuse, repair, refurbishment, remanufacturing and recycling, (Vanegas et al., 2017). The Disassembly Map was used on EVBox's commercial AC chargers, because it provides insights in the current state of affairs and the product's potential for lifetime extension strategies. Furthermore, the tool is ideal for making the disassembly of these complex types of products visually comprehensible.

Through the use of the Disassembly Map the ease of disassembly is assessed based on the disassembly depth and sequence, type of tools used, fastener reusability and reversibility and the disassembly time. The method visually maps the disassembly of a product, showing different routes to target components. Stated by De Fazio et al., (2020) and Flipsen, (2020) target components are the components that contain:

- the highest failure rates and functional importance, which is important for product repair and upgradeability;
- the highest economic value, mass and remaining useful life, which is important for components harvesting and refurbishing;
- the most embodied environmental impact, which is important for recycling purposes.

The Disassembly Mapping methodology is based on standardized logic representations derived from a combination of previously established methods, (Ishii et al., 1996; Vanegas et al., 2016; Zandin, 2003). Relations and dependencies of components are described as either sequence dependency, sequence independency, multiple dependency and components clustering. They are shown in figure 8 A, B, C, D and E, respectively. Once a component has been completely liberated, it is represented in the tool by a light blue component circle. Sequence dependency, as the name suggests, entails the possibility of disassembly of one component after complete disassembly of another. With sequence independency, two components can be disassembled after disassembly of one component. The opposite is true for multiple dependency, which is when two components must be disassembled before another component can be disassembled. Component clustering is represented in the tool by a bigger circle; it entails the disassembly of multiple components at once, for example a subassembly. Such as subassembly can be further disassembled, which is depicted in figure 8-E.

In between component circles action labels represent the necessary steps to achieve component liberation. Action labels are either square-shaped in case of a single motion action, or hexagon-shaped in case of a multiple motion action. See figure 9. As the names suggest, single motion actions require one single loosening or fastening movement, whereas multiple motion actions require multiple loosening or fastening movements, such as unscrewing a screw with a screwdriver. Different colours are used to represent if an action is done by hand (green for single motion actions and aqua for multiple motion actions) or with the use of a tool (orange for single motion actions and magenta for multiple motion actions). Colour intensity correlates to the force intensity needed for completing the action. See figure 10. Text inside the action blocks indicate the type of activity (such as a removal action or unscrewing) and the type of tool used (such as torx or spudger).

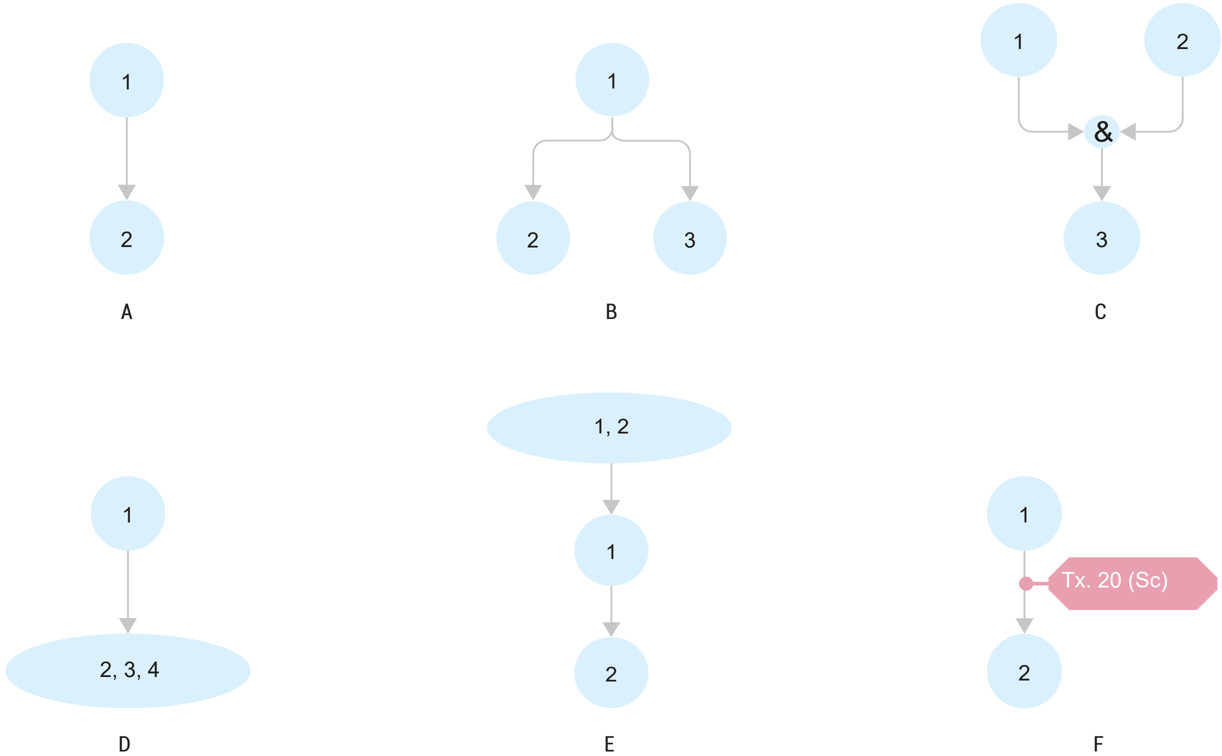
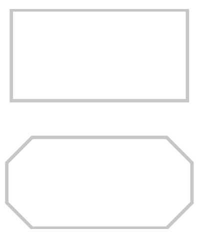
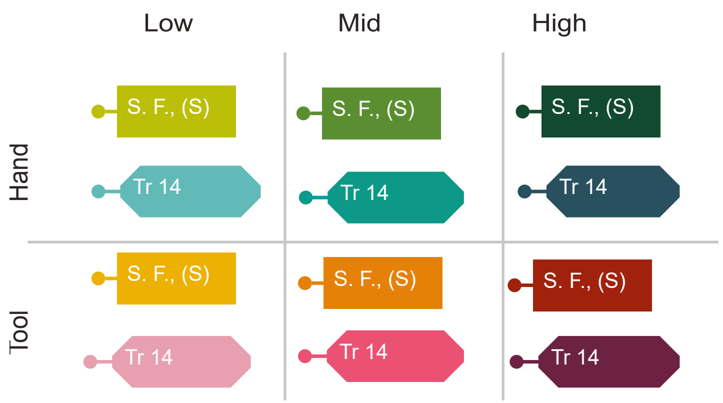


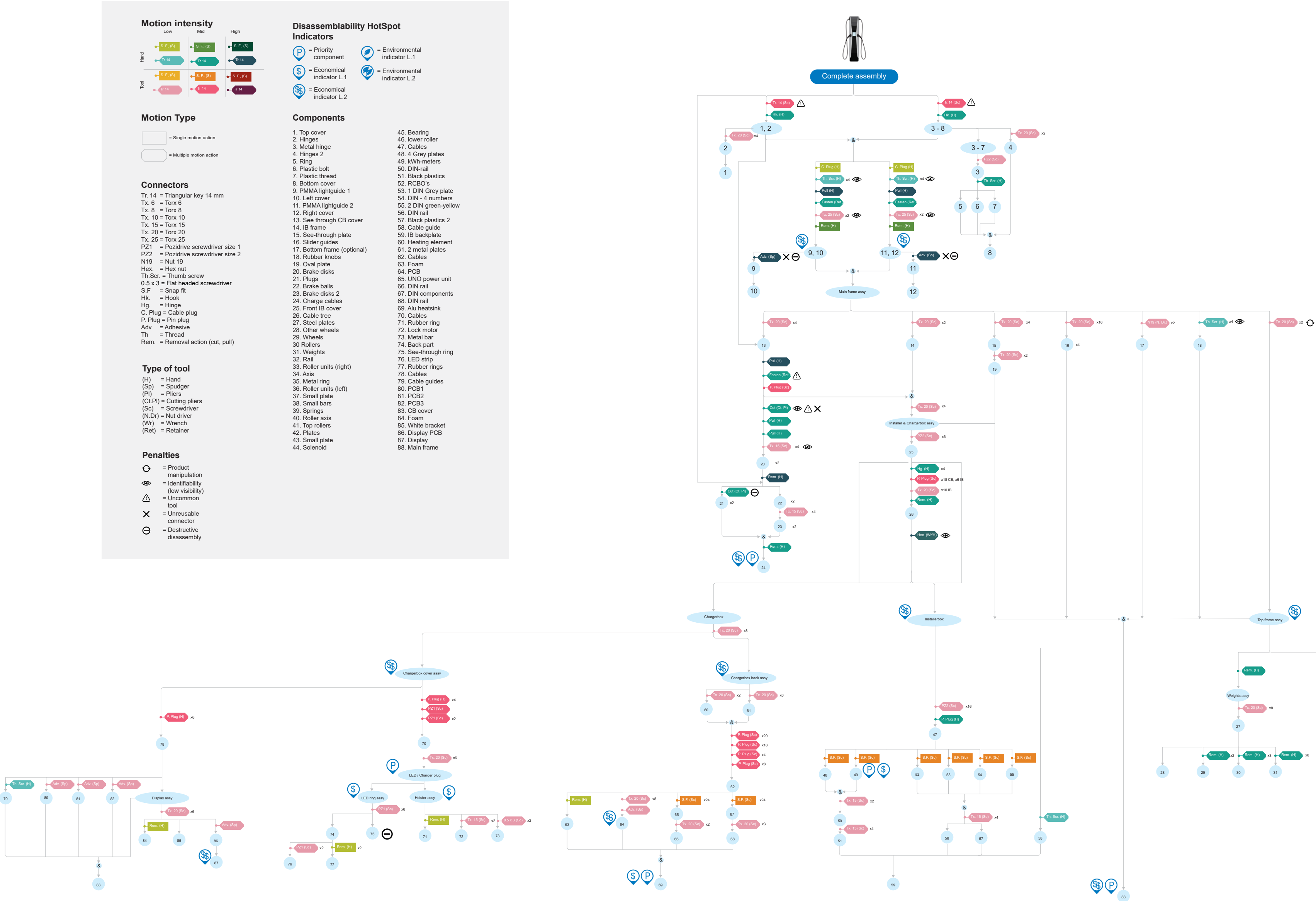
Figure 8. A. Sequence dependency; B. Sequence independency; C. Multiple dependency; D. Components clustering; E. Components declustering; F. An activity label. ▶



◀ Figure 9. Single motion action (square) and multiple motion action (hexagon).

▶ Figure 10. Green and aqua represent actions by hand, orange and magenta actions with tools. Colour intensity correlates to motion intensity.




Motion intensity
Low
Mid
High
Hand
Tool
S. F., (S)
Tr 14
Disassemblability HotSpot Indicators
= Priority component
= Economical indicator L.1
= Economical indicator L.2
= Environmental indicator L.1
= Environmental indicator L.2
Motion Type
= Single motion action
= Multiple motion action
Connectors
Tr. 14 = Triangular key 14 mm
Tx. 6 = Torx 6
Tx. 8 = Torx 8
Tx. 10 = Torx 10
Tx. 15 = Torx 15
Tx. 20 = Torx 20
Tx. 25 = Torx 25
PZ1 = Pozidrive screwdriver size 1
PZ2 = Pozidrive screwdriver size 2
N19 = Nut 19
Hex. = Hex nut
Th.Scr. = Thumb screw
0.5 x 3 = Flat headed screwdriver
S.F = Snap fit
Hk. = Hook
Hg. = Hinge
C. Plug = Cable plug
P. Plug = Pin plug
Adv = Adhesive
Th = Thread
Rem. = Removal action (cut, pull)
Type of tool
(H) = Hand
(Sp) = Spudger
(Pl) = Pliers
(Ct.Pl) = Cutting pliers
(Sc) = Screwdriver
(N.Dr) = Nut driver
(Wr) = Wrench
(Ret) = Retainer
Penalties
= Product manipulation
= Identifiability (low visibility)
= Uncommon tool
= Unreusable connector
= Destructive disassembly
Components
1. Top cover
2. Hinges
3. Metal hinge
4. Hinges 2
5. Ring
6. Plastic bolt
7. Plastic thread
8. Bottom cover
9. PMMA lightguide 1
10. Left cover
11. PMMA lightguide 2
12. Right cover
13. See through CB cover
14. IB frame
15. See-through plate
16. Slider guides
17. Bottom frame (optional)
18. Rubber knobs
19. Oval plate
20. Brake disks
21. Plugs
22. Brake balls
23. Brake disks 2
24. Charge cables
25. Front IB cover
26. Cable tree
27. Steel plates
28. Other wheels
29. Wheels
30 Rollers
31. Weights
32. Rail
33. Roller units (right)
34. Axis
35. Metal ring
36. Roller units (left)
37. Small plate
38. Small bars
39. Springs
40. Roller axis
41. Top rollers
42. Plates
43. Small plate
44. Solenoid
45. Bearing
46. lower roller
47. Cables
48. 4 Grey plates
49. kWh-meters
50. DIN-rail
51. Black plastics
52. RCBO's
53. 1 DIN Grey plate
54. DIN - 4 numbers
55. 2 DIN green-yellow
56. DIN rail
57. Black plastics 2
58. Cable guide
59. IB backplate
60. Heating element
61. 2 metal plates
62. Cables
63. Foam
64. PCB
65. UNO power unit
66. DIN rail
67. DIN components
68. DIN rail
69. Alu heatsink
70. Cables
71. Rubber ring
72. Lock motor
73. Metal bar
74. Back part
75. See-through ring
76. LED strip
77. Rubber rings
78. Cables
79. Cable guides
80. PCB1
81. PCB2
82. PCB3
83. CB cover
84. Foam
85. White bracket
86. Display PCB
87. Display
88. Main frame
Complete assembly

Disassembly Map Iqon

Iqon's Disassembly Map in figure 11 shows that the architecture of the product is rather modular. The product consists of the main frame assembly, in and on which the side panel assemblies, charger- and installerbox assembly and cable management system assembly are constructed. However, the map clearly shows that before reaching these horizontally placed subassemblies some vertical and thus sequential steps have to be undertaken. Namely, the removal of the top- and bottom covers and side panels. Afterwards multiple loose parts have to be disassembled along with cable unfastening activities.

Iqon's modular subassemblies can be reached once several sequential activities have been completed. They are the removal of the top- and bottom covers, the side panels and detaching the installerbox from the chargerbox by unplugging wires. Removal of all subassemblies in addition to the disassembly of 8 'loose' parts and the removal of the charger cables will result in the liberation of the stainless steel main frame. This can be done in at least 21 steps. Most of the other priority components are located inside the subassemblies and require many steps before disassembly is possible: the charger cables can be liberated in 28 steps, the top frame assembly can be reached in 18 steps, separating the installerbox from the charger box would mean 28 disassembly steps need to be taken. The installerbox could also be reached in 18 steps, when it is not separated from the chargerbox. From there, it would take an additional 3 steps to liberate the kWh-meter. Liberating the heatsink in the chargerbox would take 32 steps and liberating the LED-/holster assembly would take 28 steps. Either side panel can be reached in 10 steps. Removal of the top- and bottom cover and both side panels would require the completion of 16 steps.

In addition to the specialty tool needed for disassembling the top- and bottom cover, a second specialty tool is needed for retaining the weights inside the product to ensure the safety of the repair-/installer professionals.

Penalties have been given for low visibility during disassembly of the side panels, cutting tie-wraps, unscrewing the stoppers and unscrewing the installer- and chargerbox fastener. Other penalties that have been given are the destructive disassembly- and unreusable tool penalties for the PMMA lightguides that are attached to the side panels, the cutting of tie-wraps to release the charger cables, the cutting of the plugs to separate them from the charger cables and the disassembly of the LED-ring and rollers in the cable management system.

◄ Figure 11. Iqon's Disassembly Map.

Redesigning for a cascading scenario with the Disassembly Map

Design for a cascading scenario means design for facilitating the cascading process. A flowchart of product value retention scenarios can be seen in figure 12. In this flowchart a distinction is made between two types of products that can come back to a (dis-)assembly partner of EVBox: products that are too broken to be repaired on-site and products that are returned after serving their estimated commercial lifetime of 8 years. Both consist of components that do not have remaining useful life and components that do. This leads to components being replaced/thrown away or components being harvested/reconditioned, respectively. A distinction is made between 3 types of components: wear parts, reconditionable parts and harvestable parts.

In the last chapter, the Disassembly Map was used as an assessment tool. However, it can also be used to guide redesign (brainstorm) sessions, which was done for the thesis.

A brainstorm session was held with VanBerlo employees with prior knowledge of Iqon. The aim of the session was to find solution directions for shortening disassembly time and decreasing the number of disassembly steps to reach critical components. They are the PMMA lightguides (for complete liberation and reconditioning of the sidepanels), the cables (for replacement) and the kWh-meter (for component harvesting). This was done by experimenting with the Disassembly Map to find redesign opportunities for a cascading scenario following the three methods of clumping, surfacing and trimming (Flipsen, 2020).

- **Clumping**: parts should be grouped according to their EoL scenario or other aspects, facilitating repair, refurbishing, remanufacturing, harvesting and recycling operations.
- **Surfacing**: priority parts should be the easiest and quickest to reach, placing them in the upper layers of the disassembly map.
- **Trimming**: omit or combine redundant components to minimize the number of components and disassembly steps.

Figure 12 shows potential solutions for improving ease of disassembly of Iqon in a cascading scenario. The redesigns serve as an example of how optimisation for circularity can be executed by EVBox if analyses are done on both strategic- and product level.

Figure 12. Redesign proposals in the value retention flowchart. ▶

Parts with remaining useful lifetime

Parts without remaining useful lifetime

Component harvesting

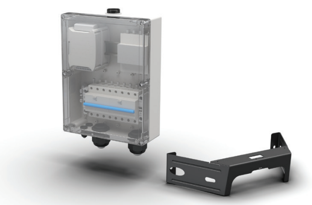
Reconditioning

Replaced with new parts & Thrown away

A redesigned installerbox that allows **harvesting** of the **kWh-meter**

Custom installerbox

Off the shelf installerbox and redesigned bracket



Mechanical fastening of the PMMA plates to completely liberate the **side panels** for **reconditioning**

Based on a weighted criteria matrix it was chosen to not develop this direction further.

A modified stopper (mechanism) to allow easier **replacement** of the **cables**

The form-fitted stopper

The fork mechanism

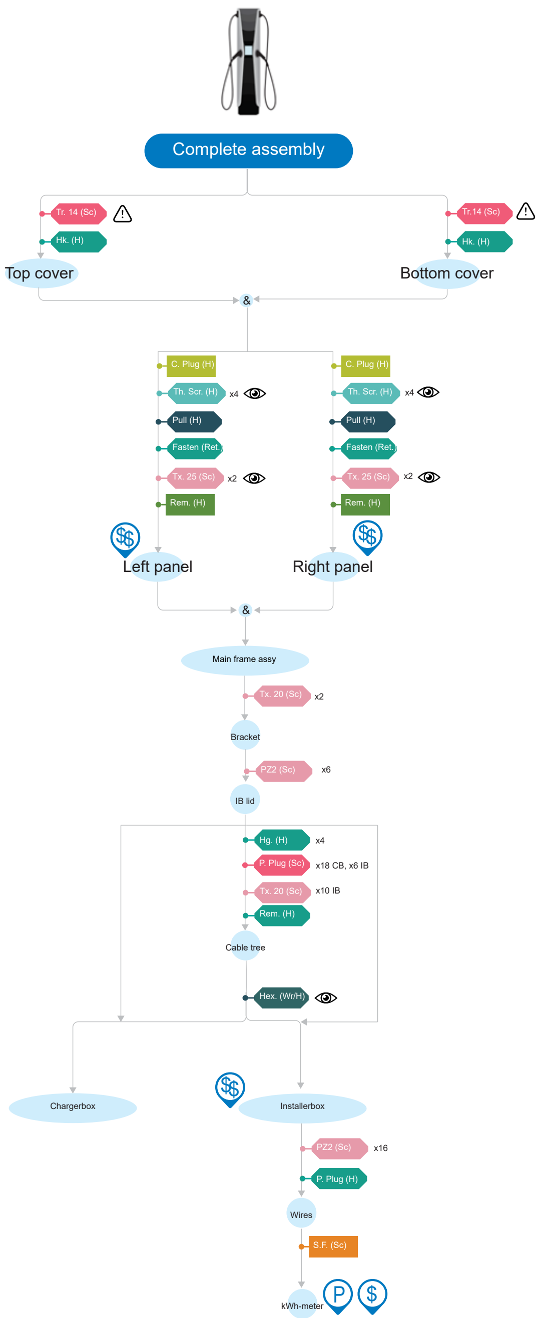
Redesign comparisons with the Disassembly Map

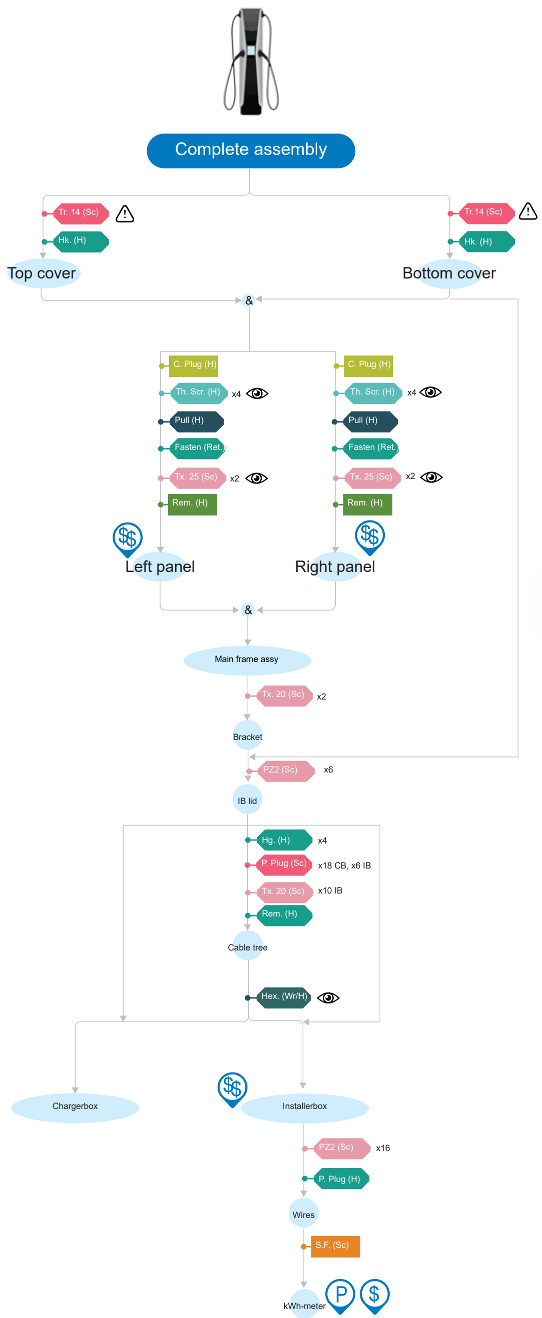
A redesign process for optimising disassembly can be structured with the use of the Disassembly Map. By identifying the purpose of the redesign, in this case improving disassembly of target components in a cascading scenario, brainstorm sessions can be guided and solution spaces can be found. Within the solution spaces several redesigns have been developed which allow for faster disassembly.

- One option is creating a shortcut. The custom installerbox and off-the-shelf installerbox proposals allow de-installers to skip 15 steps in the disassembly process by making the internal components of the box accessible without having to disassemble the top cover, side panels and bracket. Instead, only the bottom cover and the installerbox lid have to be removed, which means it would only take 3 steps to open the installerbox and an additional 3 steps to liberate the kWh-meter. See figure 13.
- Another option is focusing on improving an activity label. In the case of the redesigned stoppers the activity no longer requires a tool but can be done by hand. Furthermore, the number of times the activity needs to be done is reduced: instead of unscrewing 2 screws per stopper, the 2 stoppers can be removed by unfastening the form fitted part. See figure 14.
- The fork mechanism shows that in order to optimise a system for disassembly the introduction of a new component might be necessary. Because the forks are located at a more accessible place, namely the frame instead of the stiff cables, these components are better identifiable, eliminating the penalty point given for the original design. Moreover, there is no need to pull out the cables to disassemble the stoppers anymore, as these are integrated onto the cable, eliminating a 'pull' activity label. See figure 15.

The solution spaces include, but are not limited to these redesigns. These are examples of how disassembly can be improved for a cascading scenario focusing on the identified priority components. During another (re)design process, other factors might be taken into account or weighed differently, resulting in different priority components and different redesign proposals. Even within the identified solution spaces in this thesis, different redesign proposals could be found but have not been pursued.

Figure 13. Disassembly Map comparison between the installerbox redesign and the original design. ▶


Complete assembly
Tr. 14 (Sc)
Hk. (H)
Top cover
Tr.14 (Sc)
Hk. (H)
Bottom cover
&
C. Plug (H)
Th. Scr. (H)
x4
Pull (H)
Fasten (Ret.
Tx. 25 (Sc)
x2
Rem. (H)
Left panel
Right panel
&
Main frame assy
Tx. 20 (Sc)
x2
Bracket
PZ2 (Sc)
x6
IB lid
Hg. (H)
x4
P. Plug (Sc)
x18 CB, x6 IB
Tx. 20 (Sc)
x10 IB
Rem. (H)
Cable tree
Hex. (Wr/H)
Chargerbox
Installerbox
PZ2 (Sc)
x16
P. Plug (H)
Wires
S.F. (Sc)
kWh-meter


Complete assembly
Tr. 14 (Sc)
Hk. (H)
Top cover
Tr.14 (Sc)
Hk. (H)
Bottom cover
&
C. Plug (H)
Th. Scr. (H)
x4
Pull (H)
Fasten (Ret.
Tx. 25 (Sc)
x2
Rem. (H)
Left panel
Right panel
&
Main frame assy
Tx. 20 (Sc)
x2
Bracket
PZ2 (Sc)
x6
IB lid
Hg. (H)
x4
P. Plug (Sc)
x18 CB, x6 IB
Tx. 20 (Sc)
x10 IB
Rem. (H)
Cable tree
Hex. (Wr/H)
Chargerbox
Installerbox
PZ2 (Sc)
x16
P. Plug (H)
Wires
S.F. (Sc)
kWh-meter

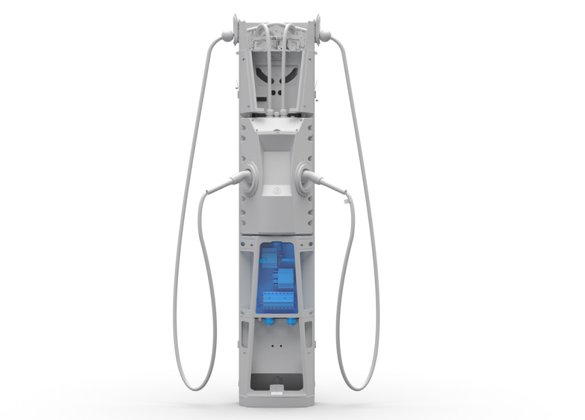


Figure 14. Disassembly Map comparson between the original (left) and redesign (right) of the stoppers. ▼

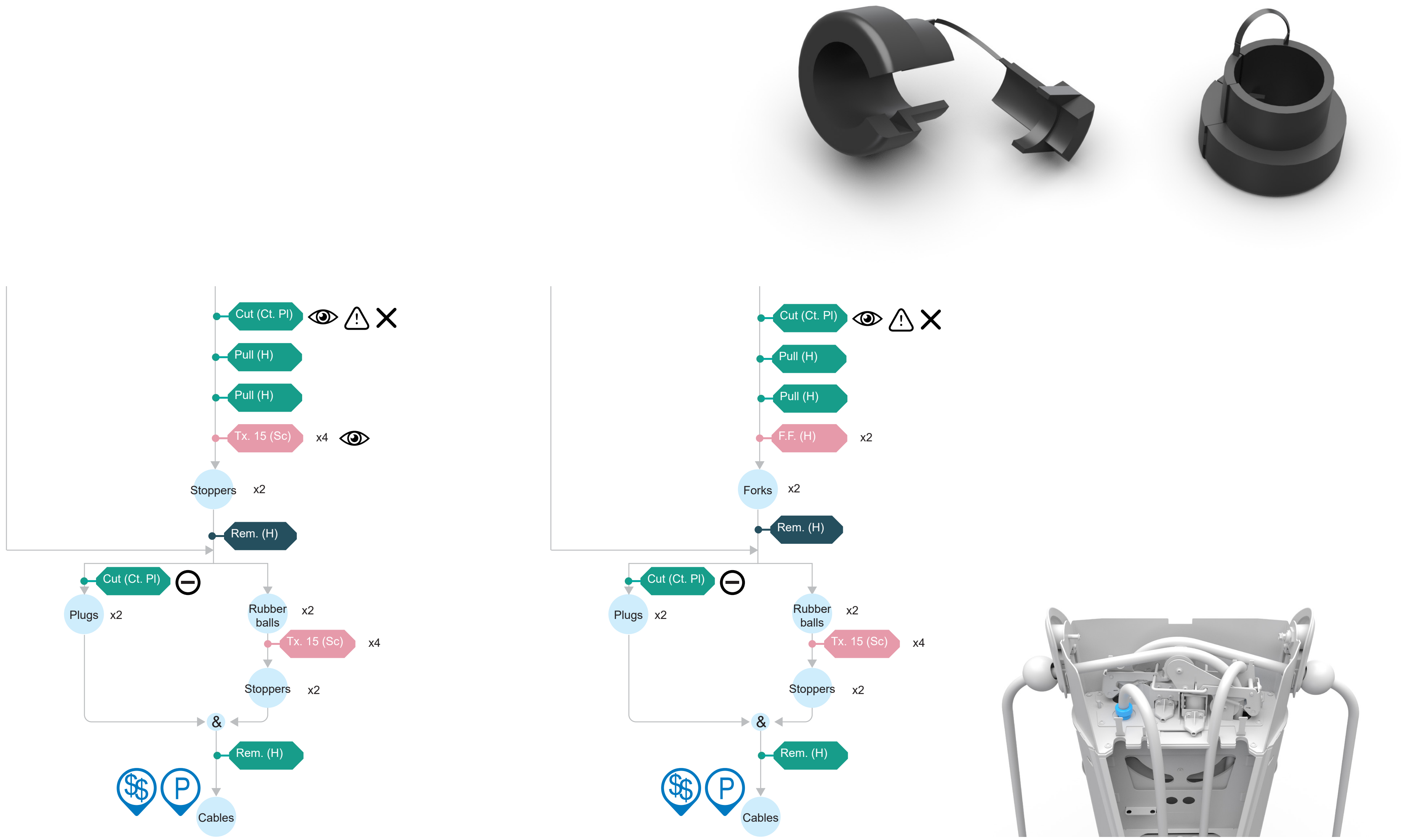
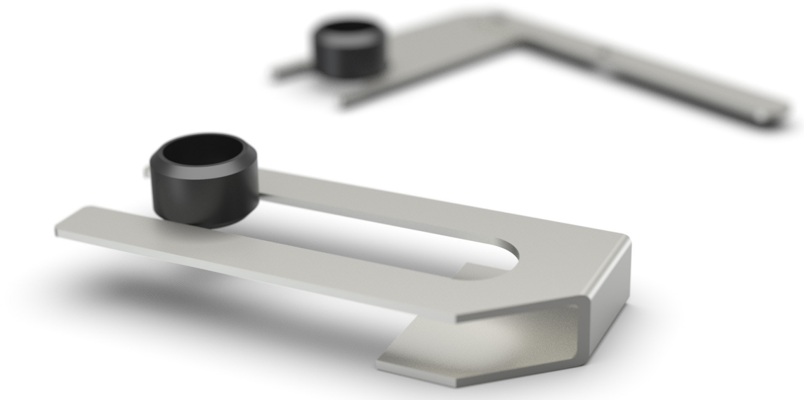
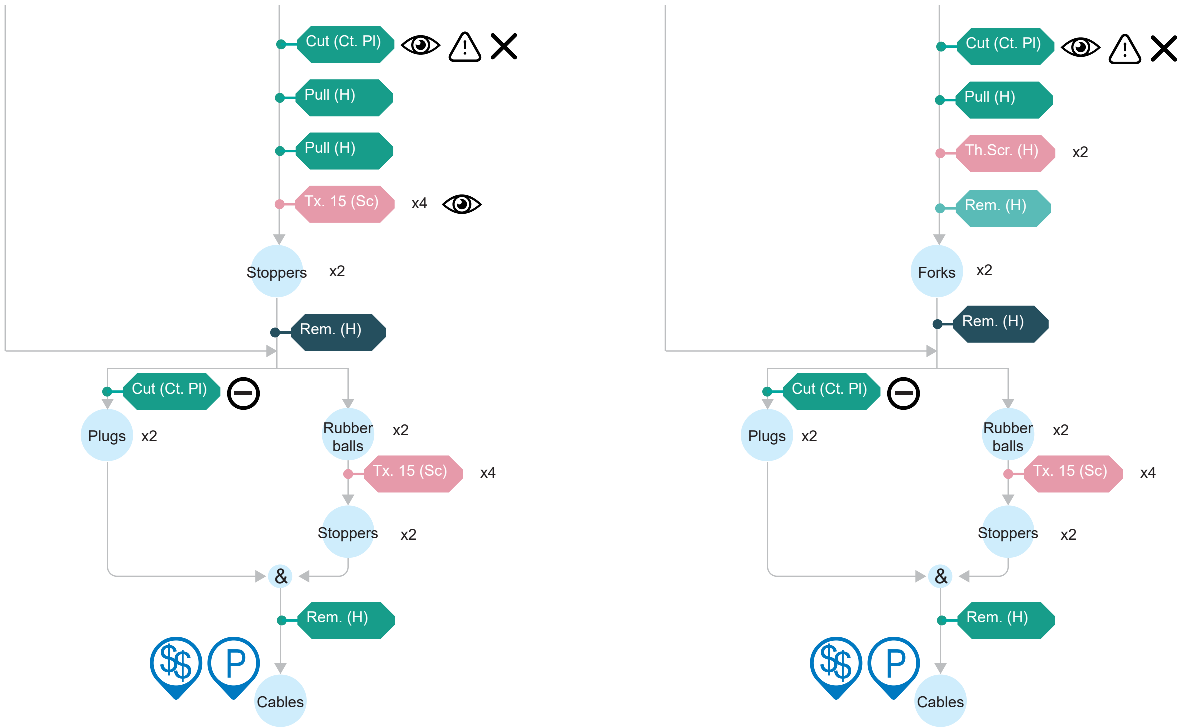
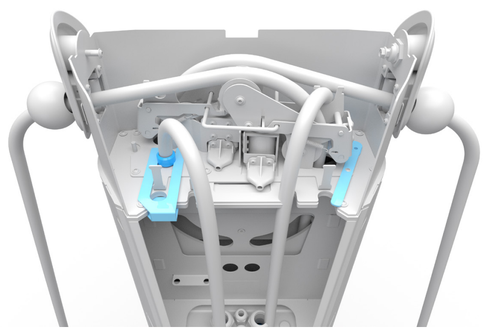


Figure 15. Disassembly Map comparson between the original (left) and redesign (right) of the stopper mechanism. ▼







Towards circular EV chargers: proposal for EVBox's future approach to circular design engineering

Through experiencing and managing this project, advise on future implementation of circular product development is provided. The insights and advise are combined in a separate booklet which can be used by EVBox employees during future circular (re)design activities.

The booklet consists of an explanation of the circular economy and definitions, why it is important for EVBox to go circular and how it can be put into practice to reach overarching circularity goals on both a strategic- and product level by using examples form this thesis.

This project has shown how difficult it can be to optimise a product for circularity when it is already on the market. Therefore, one of the main proposals is to include circular design engineering in the earliest stages of product development. Therefore, it is advised to take the EoL scenarios of all newly developed EVBox product components into account. This can be done based on the component categories 'wear part', 'harvestable part' and 'reconditionable part', which was done in this project. Based on the envisioned categories, suitable EoL scenarios can be developed and then proper disassembly of the components can be ensured. Within this project it has been estimated that plastic parts will not preserve the necessary aesthetic and functional properties after serving 8 years of commercial lifetime and will therefore need to be replaced/recycled. Metal parts will retain functional properties but will have to be reconditioned to bring back the necessary aesthetics. Certain electronics such as the kWh-meters, RCBO's and solenoids are estimated to be harvestable. It is advisable to verify these assumptions and make changes accordingly. Based on the envisioned EoL scenarios of components, design for disassembly can be implemented.

When attempting to optimise a product for circularity that is already on the market, it is advised to focus on one area within the product. This will heighten the likeliness of redesign feasibility, as changes on a smaller scale can often be made than changes on a bigger scale. During this project this was done by focusing on the priority components and their estimated EoL scenario.

When shiftng to a circular business model it is necessary to determine and maintain standard definitions. The field of circular design has been developing rapidly and so has its jargon. In order to communicate with industry professionals and within EVBox it is necessary to define what certain terms mean. For example, during this project it became clear that circularity is often mistakenly interpreted as recycling, which is ironically the strategy in which the least product value and -integrity is retained. Therefore, employees as well as employers will have to be educated on the terminology and principles of the circular economy so there is little risk of miscomunication. The Circular Design Guide, a website created through a collaboration of the Ellen MacArthur Foundation and IDEO provides handy tools and methods to help teams familiarise themselves with the circular economy. A good starting point could be reading the Ellen MacArthur

Foundations 'Towards the circular economy - Economic and business rationale for an accelerated transition'.

The tools used in this project, namely the Disassembly Map and Reverse Logistics Mapping can be used in future circular design activities. They have been proven to be effective for use on EV chargers. The tools can be used on other products within the portfolio in the same way as has been done during this project. Additionally, the already existing Disassembly Maps and Reverse Logistics Maps can be developed further to optimise Iqon and BusinessLine for circularity. A future goal for EVBox could be to make the whole portfolio properly disassemblable to fit the charger's EoL scenario. Then, Disassembly Maps and Reverse Logistics Maps need to be made for other and future AC chargers and the DC charger portfolio.

If EVBox manages to successfully implement a cascading strategy both in- and outside the company, it can become one of the sustainable frontrunners in the EVSE market. This would require the envisioned strategy and redesign proposals to be developed further. EVBox will need to make agreements with all the parties in the reverse logistics chain and investments for the reverse logistics and redesigns will have to be made. However, the actual implementation of circular strategies goes much further than calculations and redesigns; the structure of the company has to be adapted too. The corporate mindset has to shift from linear to circular. Furthermore, as mentioned earlier, definitions have to be clear to promote efficient communication. Especially for big companies, these steps can be difficult and too drastic to make at once. A solution might be to run separate tests to verify and implement the presented models one step at a time. The establishment of a new circularity branch or startup within EVBox could provide the supervision and execution needed to make the incremental circular changes. Whereas implementing a cascading strategy at once might be too big of a step, trying to refurbish or remanufacture a certain amount of products might be feasible. This way, circularity can be implemented in small increments, eventually fully transforming the company into a circular business.

In the long term it might be worthwhile to change to a subscription-based model, also known as charging as a service. A subscription model fits perfectly within a circular business, as product ownership is kept throughout and after a product's commercial lifetime. This facilitates the take back of products at EoL. Then, EVBox's value proposition to users could be described as 'offering accessibility to EV charging' which does not necessarily include the actual sales of the chargers. It would be interesting to investigate whether users would want a charger or a charged EV. Filling in the Business Model Canvas could provide more insights in the key value propositions of EVBox which could facilitate the shift towards a service-model. This proposal could also come to fruition by establishing a separate branch or startup within EVBox developing and executing it.

Modular cable design?
Housing of the plug
Where to split?
5 big cables
2 smaller ones
BOX...
similar connections as DIN components?
How to nicely integrate?
Bigger
Ballpoint principle
Bottle cap
Top & Bottom instead of left & Right
push to open stoppers
Round connector?

EVBOX