DOPPLE

A comparison between the footprint and economic impact of a current and a conceptual supply chain

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MANAGEMENT SUMMARY

In recent years, sustainability has become more and more relevant for businesses. At the same time, in the electronics industry, miniaturization is an important topic. Products need to be smaller but also need more functions while keeping the performance high. Dopple, a high-tech product development company specialized in miniaturized wireless wearable products such as bluetooth headphones, faces these challenges on the subjects of miniaturization and sustainability. Their production takes place in Malaysia, where limits to miniaturization are reached. Therefore they are looking into the possibilities for opening a factory in the Netherlands, in order to produce their products for a local market. They want to lower the footprint of the production of their products, but need to produce much more efficient in order to still be economically viable. Therefore a study has been done into the comparison of supply chains of the current factory and the future factory, while also looking into ways to improve the sustainability of these supply chains.

Context

Currently Dopple designs their products in the Netherlands and production takes place in a factory in Malaysia. Materials and parts are sourced from suppliers in multiple Asian countries and Germany. After production, products are transported by plane to the United States of America, where they are distributed to stores in all states. When Dopple switches to production in the Netherlands, they will also sell their products local, directly from the factory. Sourcing will take place in Europe in this new situation. Because costs for personnel are about ten times higher in the Netherlands, production should also take place ten times more efficient to make sure the economic situation does not suffer from this move. There is no specific focus on sustainability in the current situation, but Dopple did have an eco-cost model made to see what the impact on the environment should cost.

Method

First an analysis of multiple sustainability reports of competitors in the same market is done for benchmarking. This analysis helps to find options to improve the new factory, and therefore supply chain, in terms of sustainability. For example by researching options for recovery, reuse and recycling of products. This is followed by a literature review in which information is gathered about supply chain design, facility location, supplier selection, aspects of circularity and solution approaches. From this review, Input-Output modelling is chosen as a method to compare the current and conceptual supply chain, both on the economic as well as the environmental impact. Input-Output modelling was first used in 1936 for analysing the interdependence between the different parts of the economic system in the United States, but has proven to be also helpful as a model for measuring sustainability, for example by determining the carbon footprint. The model in this research is based on the flowcharts based on the supply chains in both situations. Multiple inputs and outputs are considered to determine the impacts, such as transport, energy consumption, water usage, plastic residue and CO_2 emission. Data is gathered from the company itself, literature and in some cases assumptions and estimates are made. To see the impact of some factors that are still uncertain, such as the prices of parts and materials in the new situation, sensitivity analysis is performed.

Results

The comparison of both supply chains in the model shows that the environmental impact of the supply chain in the new situation is much lower for the new situation, in which the factory is situated in Emmen, the Netherlands. The levels of CO_2 emission, plastic residue and usage of water and electricity are much lower than they currently are at the factory in Malaysia. There is much less transport in the new situation too. Regarding the economic impact, although the models are based partly on estimates especially for the new situation, it is found that the negative impact is not that big. As sensitivity analysis shows, the prices of parts and materials are having the largest impact on the economic situation for the new supply chain. Based on these models, especially if Dopple wants to do good for the environment, it would certainly be advised to start producing locally. The difference in footprints of both supply chain is large, the new situation is more sustainable in all researched facets.

Recommendations

To better understand the implications of the results of this research and its results, further research is needed to determine the full effects of when production takes place in a Western country. Expanding this type of research with more data, by for example including information from suppliers and suppliers of suppliers can determine what the impact of for example

suppliers will be on especially the environmental situation. Dopple decided to use for their new factory a principle in which everything in the factory is integrated with each other. Because of the need for miniaturization, demand for sustainability and focus on efficiency, future studies into this subject of in-factory integration would be considered very relevant. The review of sustainability reports of other companies in the same market shows that those companies handle sustainability issues in different ways and that for example there are not many options for recovery of products currently. Future research is recommended to address what would be needed to make recovery, reuse and recycling possible for more products, parts and materials. When certain options and information about these possibilities would become available, it could lower the footprint of companies in this sector. Last but not least it would be interesting to research the amount of extra costs a customer would be willing to pay when products are produced local and sustainable. Prices of parts and materials will increase when sourcing local in Western countries, and this is the main subject that rises costs when moving production from a low wage country to a Western country, as long as efficiency of the factory is high enough. It would be helpful to know if and how much customers are willing to pay extra when buying sustainable products.

PREFACE

Hereby I present my master thesis called 'A comparison between the footprint and economic impact of a current and a conceptual supply chain'. With this thesis I am completing my master of Industrial Engineering and Management at the University of Twente, which also means that there will finally come an end to my time as a student. Both my bachelor in Industrial Design and my master in Industrial Engineering and Management, combined with many other experiences during these past years enabled me to develop myself continuously and I am very grateful for that.

First of all I would like to thank my company supervisors, Christian den Herder and Johan Schreuder of Dopple, for giving me the opportunity to graduate at their company and being of help during the process. Although working from home because of the Covid-19 pandemic, the meetings we had in real life were full of interesting and educational moments. I also would like to thank my supervisors from the University of Twente, Devrim Yazan and Patricia Rogetzer for their constructive feedback and support.

Lastly I would like to thank my family and friends who supported and encouraged me, not only during this project but also throughout my entire student life.

I hope you enjoy reading this thesis!

Milou Gankema
Enschede, March 2022

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ABBREVIATIONS

ATO = Assemble to Order
B2B = Business to Business
B2C = Business to Customer
CSR = Corporate Social Responsibility
DfE = Design for Environment
DfS = Design for Sustainability
FIFO = First In, First Out
IO = Input-Output
IS = Industrial Symbiosis
kg = Kilogram
km = Kilometres
kWh = Kilo Watt Hour
l = Litres
LCA = Life Cycle Assessment
LIFE = Layer Integrated Factory Environment
MC = Mass Customization
MTO = Make to Order
NGO = Non-Governmental Organization
OBIA = Overall Business Impact Assessment
PCB = Printed Circuit Board
PCBA = Print Circuit Board Assembly
PSS = Product Service System
RBA = Responsible Business Alliance
REACH = Registration, Evaluation, Authorisation and Restriction of Chemicals
RF = Radio Frequency
RL = Reverse Logistics
RoHS = Restriction of Hazardous Substances
SA = Sensitivity Analysis
SCM = Supply Chain Management
SSCM = Sustainable Supply Chain Management
TIOA = Thermodynamic Input-Output Analysis
USP = Unique Selling Proposition
VA = Value Added
WEEE = Waste Electrical and Electronic Equipment

1. INTRODUCTION

In this thesis the sustainability of the supply chain at Dopple, a company that develops wireless wearables such as Bluetooth headphones, is looked into. Currently, Dopple develops the products in Emmen, the Netherlands, while production takes place in Malaysia. There are plans to start producing locally and the search for a factory in Emmen has started. This will change existing processes a lot. Dopple has decided that there will be more automation and therefore less employees for example. The whole structure of the supply chain will be different. To see if the factory in Emmen and its supply chain will be sustainable, research will be done focusing on the environmental as well as the economic aspects of it. The third aspect of sustainability, social, will not be taken into account in this research. In this chapter first the company is described (Section 1.1) and then a research plan and approach are introduced (Section 1.2 and 1.3).

1.1 Company Description

About the company and its future

Dopple is a high-tech product development company, specialized in miniaturized wireless wearable products. Although it is a relatively young company (established in 2017), the team is very experienced having worked together with customers such as Ericsson, Sony Ericsson, Tonalite and Plantronics already. Dopple is not selling to end customers, but is in business to business (B2B) relationships. People working at Dopple have been at the very origin of Bluetooth and the very first Bluetooth headset in the world was created by this company. Over the last 20 years the team designed many mono Bluetooth headsets and later many stereo Bluetooth headsets, including building the complete eco-system with mobile phones and connected watches.

Miniaturization is a key design goal and competence area for Dopple, in which low-power electronics and radio frequency (RF) design are critical success factors distinguishing the company from competitors on the market. The wireless stereo headset products Dopple designs end up for sale in (e-commerce) shops around the world and eventually in the consumers' hands.

Dopple notices that as a result of the increased product acceptance (more and more people are using Bluetooth headsets), a growing number of use scenarios will need to be covered (e.g. voice and biometric sensoring) while keeping the basic performance (RF, audio) on a good level. In order to make this happen, miniaturization is a key design goal at Dopple. Miniaturization will make it harder to assemble products manually, as is now done in Malaysia. Next to miniaturization there is a continuously growing amount of functions that need to be integrated. This extensive integration combined with miniaturization therefore makes it necessary to find new solutions for producing wireless wearables. Next to the trend that people want more functions integrated in headsets, people are also more focused on the sustainability of the products they are buying and using. According to Veit et al (2018), the perception of the sustainability has impact on the purchasing behaviour. That research also shows that physic distance has an influence on these perceptions. Therefore it is interesting for Dopple to put focus on producing local.

The factory and production

The design and development of wearables takes place in Emmen, the Netherlands, while production is done in Malaysia. Products are sold all over the world after production, distributed by planes and trucks. While Dopple designs the products and produces them, the sales is done by other companies, such as Logitech. In other words, Dopple is not involved in the sales of the headphones to the end-users. The products are sent to for example America, where other companies take care of the final stages, such as, for instance, placing logos on the products and ultimately selling them. This causes that sometimes products that are made in Malaysia are sent to America for sales but end up being bought in Asia by a consumer and therefore are flown back to Asia.

The current factory in Malaysia is organized in a functional manner with separate departments like for example: tooling, molding, SMT (Surface Mount Technology), spray-painting and assembly. Between production stages, parts and semi-finished products are stored causing problems such as not knowing exactly (read: real-time) how much of which part is located where. This has an influence on design too, because when changing something in the design it takes weeks before the product with this change can be produced, since first the half-finalized products need to be finished first before starting on the new design.

In order to remain competitive in the market, a higher level of product- and process integration and therefore symbiosis is needed. Therefore, Dopple has decided to realize a new local product factory concept to support this development. In this 'factory of the future' they propose the so-called 'LIFE' concept. This stands for Layer Integrated

Factory Environment and means that the different vertical layers of the factory are all connected with each other. For example, the warehouse is integrated in the ceiling of the factory and parts can be dropped to the work floor via systems that connect the warehouse with the work floor. A more thorough description of LIFE can be found in Chapter 2. There is lots of integration and automation involved in this new factory, which makes it a completely different factory compared to the current factory in Malaysia, where no automation is in place.

Goals of the company

One of the goals that Dopple wants to achieve is to produce more locally, starting with a factory situated in Emmen (where also their design department is based). However, labour costs are much (about ten times) lower in Malaysia compared to production in a Western country, therefore producing locally would maybe not be beneficial from an economic point of view.

Currently, most of the input to the assembly line are parts, such as plastic parts, tapes, foams, PCBA's (Print Circuit Board Assemblies) and batteries. It is a goal to change from sourcing components to raw materials and produce more parts on their own within the assembly line. This would result in higher integration (which is needed for miniaturization) and a lower carbon footprint. At the moment, Dopple uses virgin plastics and no recycled parts, but reusing or recycling parts might also be an interesting way to reduce the footprint of its products.

1.2 Research Plan

The problem description

In the past has been already investigated what the new factory should look like. It uses a concept called LIFE, as explained above, and a simulation of this factory has already been made, as well as a simulation of the current factory. Next to this, an eco-cost model was set up. The goal is to find out if this new factory would be the better option both from an economic as well as an ecological perspective. To ensure that the company still stays as cost-efficient as it currently is the new factory should be producing much more efficiently than the current factory, because of the higher salary costs in Western countries where the local factories would be situated. In the current factory multiple employees are constantly working on transporting materials, parts and semi-finished products because of inventory management problems. It is not always clear where these semi-finished products are and how many are made. This is something that should be resolved by using the LIFE-concept. When resituating the factory, the supply chain design will change a lot. It might give more options for recycling or reusing parts, but also changes the ways of shipping the raw materials or input products. Dopple would also like to use less parts/modules/components/products (such as batteries and plastic parts) as input and more raw materials and have the processes more integrated. Analysing the entire new factory concept and comparing it with the current factory is not possible in the time that stands for this assignment. Therefore, the research will focus on the whole supply chain, from sourcing to end-customers. This is where lots of important changes will be made when changing to the new location, specifically regarding sustainability. Identifying if the concept of the new factory has a more sustainable supply chain than the current factory will be the main part of this project. For this, the concepts of reusability and recycling are taken into account since they influence the footprint. In the new situation, there are some differences compared to the existing supply chain, not only based on the location, but also regarding the use of raw materials or complete products and more integration of the steps of the whole process, leading to symbiosis.

The research problem and research questions

Dopple faces the problem that their current factory might not be future proof, improvements in the products are difficult to make because of the limitations on miniaturization in the current factory and production does not take place in a sustainable way. For example, the factory produces a lot of waste by not being efficient enough, such as injection moulding which causes lots of residuals in Asia, while this process is far more efficient in Europe. Next to that, products are flown and driven around the world before they reach their final destination, the consumer. Since Dopple wants to become more sustainable, they designed a conceptual, local factory and want to know if this factory has a lower footprint. Since labour costs are much lower in the current factory in Malaysia compared to a factory in a Western country, they also need to find out how a new local factory can be more efficient in order not to worsen their economic situation.

The research question that therefore arises is: "*Does the supply chain of the conceptual factory have a lower footprint than the current factory and what is possible to (even more) reduce this footprint, while keeping in mind the economic situation?*"

The aim of the research is to give Dopple an advice about their supply chain design for the conceptual factory in terms of impact, both economically and environmentally, and how to reduce those impacts. For example by reusing product (parts) and/or recycling and more integration (such as: warehouse and inventory closer to and 'working together' with the production lines, production lines more adjusted to each other to prevent semi-finished products from piling up in between stations).

The research question can be divided into the following sub research questions:

Supply chain design: Comparison of currently existing supply chain with new, conceptual supply chain design

- What is the environmental impact of the new supply chain, compared to the old one?
- What is the economic impact of the new supply chain, compared to the currently existing one?

1.3 Research Approach

The research question discussed in Section 1.2 has two important aspects: the sustainable aspects and the supply chain design. The setup of the research will also be divided into these two aspects. The literature streams will cover input-output modelling, sustainable supply chain design and facility location while an analysis of the market and competitors will cover recovery options such as reusing and recycling.

Regarding the supply chain design it is important to find out what the current supply chain looks like as well as the design of the supply chain for the new factory. The aim of this thesis is to compare the current supply chain with the newly proposed supply chain. For that, it is necessary to model those supply chains. The knowledge for the parts of the existing supply chain can be found within Dopple. For the new factory some assumptions will be needed, since it is all still conceptual. The research that needs to be done includes interviewing the company and looking into the documents the company can provide regarding for example suppliers and supply chain, and looking into the current and conceptual factory as well as the eco-cost model that has already been made.

For the research into the environmental impact of the supply chain, Input-Output modelling will be used. The analysis of the economic impact will be done as an integration to this Input-Output model. The options for modelling and analysing are researched in the literature research. Also there will be looked into research and analysis of the current market and competitors, to determine sustainable aspects and options, such as recovery of products. Currently, Dopple does not work with recycled products but mentioned that in the current market, Samsung is particularly known as the company that is strongly committed to design for recycling / repairability. Research into how they do this is a good step to find out which possibilities might be there for Dopple. Dopple also would like to include more raw materials in the new factory, which is also a scenario that needs to be taken into account. An analysis of multiple sustainability reports will be done for benchmarking, to include ideas for different scenarios, including different sorts of recovering products into the new supply chain and see the impact of it.

The goal is to find out if the supply chain of the new factory has a lower carbon footprint by comparing the old and the new supply chain, and to identify what would eventually be possible to reduce the footprint of the new factory. After modelling both supply chains, an analysis will be done on both the economic as well as the environmental impact of those supply chains.

1.4 Outline of the report

In this chapter an introduction about the company and the goals was given, resulting in the research questions and the approach of the research. In Chapter 2, the factories and current information about the supply chain will be discussed on a more detailed level. An analysis of the market and competitors and the options for recovering products follow in Chapter 3. The literature research that is done will be discussed in Chapter 4. Chapter 5 discusses the case study including all the data used, using amongst others the eco-cost model. In Chapter 6 the results of the model are discussed, followed with the discussion in Chapter 7. The conclusion, including recommendations, can be found in Chapter 8.

2. DESCRIPTION OF THE EXISTING SITUATION

In the previous chapter the company has been described, including the factories. In this chapter some more details about these different factories will be described, to make it easier to understand the different parts of the supply chain model that will be seen in next chapters.

2.1 Current Factory

The current factory of Dopple is based in Malaysia. Almost all suppliers, about 80 to 90 percent, of this factory are located in Asia. The only components that are not sourced from Asia are chipsets which are sourced from America and glue which is sourced in Germany. The factory is situated in a large building and has many employees. There is a lot of manual labour involved in the processes of assembling small parts on other small parts. There is not really a symbiosis visible in this factory, there is not that much integration and working together between different departments of the factory. There are piles of stock of half-finished parts and products distributed at multiple places in the factory and there is no detailed track of which products have already been made and what not. If something needs to be changed, it will take about eight weeks before the changed product will really be produced because first the half-finished products are finished, since a FIFO (first in, first out) system is used. Turnaround times are long and it takes a lot of time to make changes to the design. A simulation of this factory has been made in PlantSim (simulation software by Siemens). In Figure 1 a map of the current factory can be seen. The different processes such as molding, tampon printing, nano coating, assembly of the earbuds, pairing and pack to order are all done in different halls of the factory. Employees bring parts from one hall to another when this is needed, and the halls each have their own storage for stock. The same parts may be on stock in different halls because they will be transported from one storage to another before being further produced.

The salary costs are about ten times lower than in, for example, the Netherlands, 2.5 to 3 dollars in Asia while it is around 30 dollars in Western countries. While production is cheaper in Malaysia, processes in this factory are not that efficient: parts are transported around the halls a lot and the same type of parts are kept in different halls. This means that a lot of time and money goes into logistical activities that do not add any value to the products.
Based on earlier research by project groups of the Saxion University of Applied Sciences that was provided by Dopple, the current first pass yield of the products is at two sigma, while Dopple wants to reach four sigma for this. This of course has an influence on the amount of products that will be returned by the customer because they are not working.
Although the factory in Malaysia is not very sustainable as a whole, the current factory does have solar panels on the roof that ensure the use of sustainable energy.
In the factory the waste mostly contains plastic that is used for injection molding but which is not a part of the end product. The part itself is only 20 percent of the total amount of plastic that is used for the injection molding process. Within the assembly lines, most of the waste consists of packaging materials of the supplied parts.

The headphones that are designed and produced by Dopple in the current factory are sold to Jaybird, a sub brand of Logitech. Until now, regarding sustainability, what Dopple together with the factory in Malaysia have done is looking at the materials used and if they are in line with the requirements of the REACH (Registration, Evaluation, Authorisation and Restriction of Chemicals) and RoHS (Restriction of Hazardous Substances) directives. However, Logitech has recently started a lot of initiatives regarding sustainability (see also Section 3.5). Currently, these initiatives are not implemented in the way of working and designing.

2.2 Conceptual Factory

The goal of Dopple is to start producing more locally and therefore eventually have factories in different Western countries, so based at locations where the market actually is. While the production of headsets is currently done in Malaysia, Dopple itself is located in Emmen, the Netherlands. The (first) ‘factory of the future’ that they want to build will therefore also be located in Emmen. The layout of this factory will be completely different compared to the factory in Malaysia, in the first place because of more integration. In earlier research Dopple found that this factory should be designed using the concept of LIFE. An example of this concept, what the new factory will look like using LIFE, can be seen in Figure 2. The goal of Dopple is that not only the production lines will be more integrated, meaning that products will be finished faster and not be on stock at multiple places in the factory, LIFE also means that the different layers of the factory will work together. Every layer has its own function, for example the lowest layer is for energy and fluid supplies and the middle layer is the work floor where production takes place. In the concept of Dopple, the warehouse will be situated in the ceiling of the factory, being the layer above the work floor.

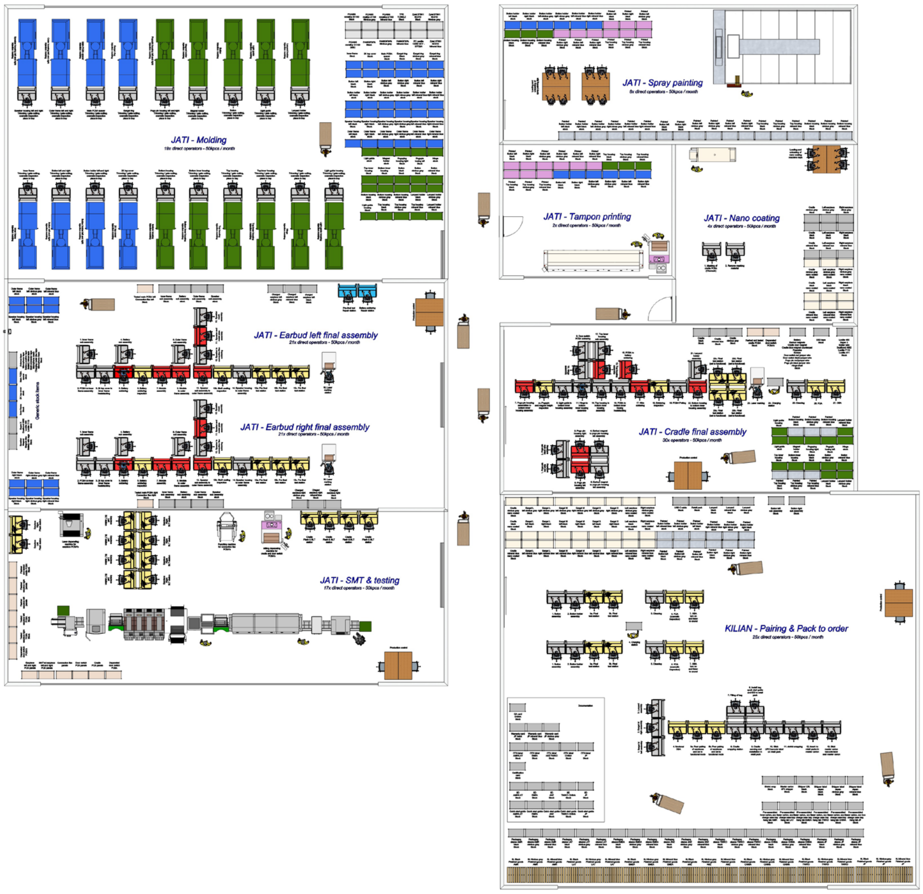

Figure 1: the layout of the current factory in Malaysia, screenshot of a PlantSim simulation that was made for the current factory by Dopple.

Grid Movers will bring the right part to the right production station and 'drop' the necessary parts to the work floor. This means that there are no longer employees needed for doing most of the logistical activities in the factory. The only place where employees are needed, is for putting in and removing the items. So there is a big decrease in the workforce used for this process, especially when comparing this to the current situation. An example of the new situation can be found in figure 3, in which it can be seen clearly that there are multiple different layers, also for electricity and water for example.

Also a lot of the production will be automated. Because of less manual labour, which is error-intense, it is expected that this will decrease the number of mistakes that are made and therefore will cause less faulty end products. Less floor space will be needed because automated stations will work faster than humans, meaning less workstations are needed in total. The whole factory will be more efficient, for example by not having half-finished products or parts in stock for weeks before they are transported to the next station. Using lean manufacturing would improve this even more. This will decrease the total assembly time of the products and makes it possible to have less stock on hand.

The warehouse in the ceiling does not need that much space because the used products, parts, components and materials for producing headsets are very small and therefore it is possible to store a lot in a small space. Not having people involved in picking up the parts, makes it possible to store the parts in the ceiling. At the entry and exit point of the factory there will be storage space in which parts can be stored until they are loaded into the warehouse in the ceiling, and finished products will be stored there for leaving the factory. The proposed factory also includes a room for recovering products that come back.

One of the innovations that Dopple would like to make is

Figure 2: setup of the conceptual factory, including the LIFE- principle

production that is known as assemble-to-order (ATO). All the parts are on hand, but the products are not finished until an order is received. When ordering, the customer can choose all kinds of options to get the product exactly as she/he would like. For instance the colours used can be chosen, or even a customized print. In that case Dopple would work with make-to-order (MTO). Also the fitting of the earbuds into the ear can be chosen, for example by using an app that scans the ears and then determines the best fitting (out of about 20 different shapes). For the customer this will feel as design-to-order, but because of for example the predetermined different shapes, for Dopple this is assemble-to-order. This kind of production takes more time than mass customization and also lots of different parts need to be in stock to make sure that a product can be made and delivered to the customer on time. Production needs to be fast to meet the expectations of the customer, since the products cannot be made before orders are in and therefore there is no stock available. This means that there is lot less waste of space and products that are laying around, as can be seen as lean manufacturing. When an order comes in, Dopple responds immediately and assembles the products ordered, but there are no finished products on stock.
Dopple prefers to have more control over the parts used in their products and would like to make more parts themselves. While currently there is a lot of outsourcing, they are following the trend of back shoring, to get back control themselves. Instead of buying parts they will change to suppliers that have the raw materials needed for the parts and they will be designing and producing themselves. Having more control over the parts is also important for the future, especially because of miniaturization. Dopple has a lot of knowledge inhouse about miniaturization and that is an important USP (Unique Selling Proposition) in this case. Products keep getting smaller but at the same time do need to have more build-in functions. To make it possible to have these functions, it will help Dopple to not be constrained by the specific size of parts used.

2.3 Changes and possibilities in the new factory

Currently Dopple is looking for buildings in the surroundings of Emmen to start this new factory. The possibilities for production are already researched a lot, but next to the sustainability of the products also the sustainability of the factory is important to lower the carbon footprint. The new factory will use less ground because of for example the fact that the storage is in the ceiling. Also the machines will be more productive and therefore can produce more products than when there are multiple stations with employees doing the same job, as is the case in the current situation. In the drawings of the new factory there is space reserved for the recovery operations of products, for example for a machine that can disassemble the products once they are taken back.

Currently Dopple does not specifically work with suppliers that have certificates proving that they are only using

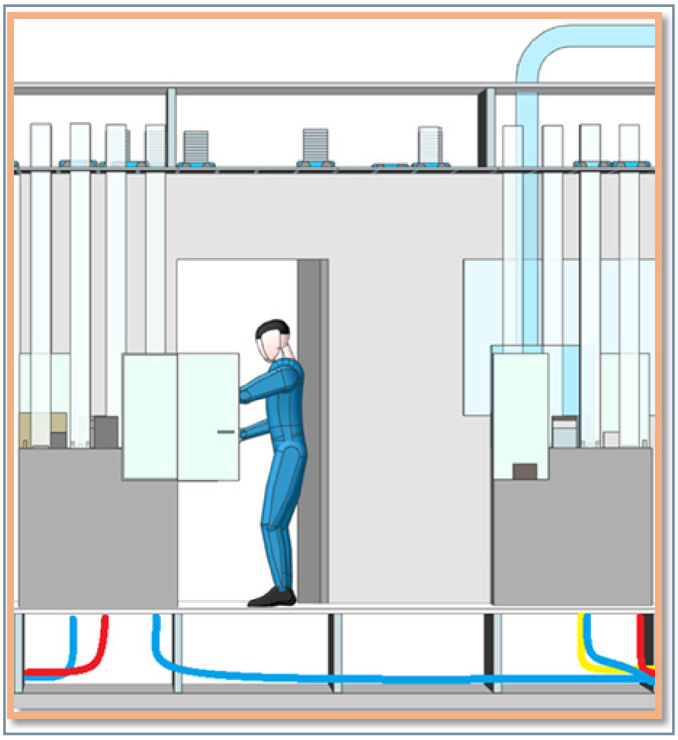

Figure 3: sideview of the factory with the LIFE-principle

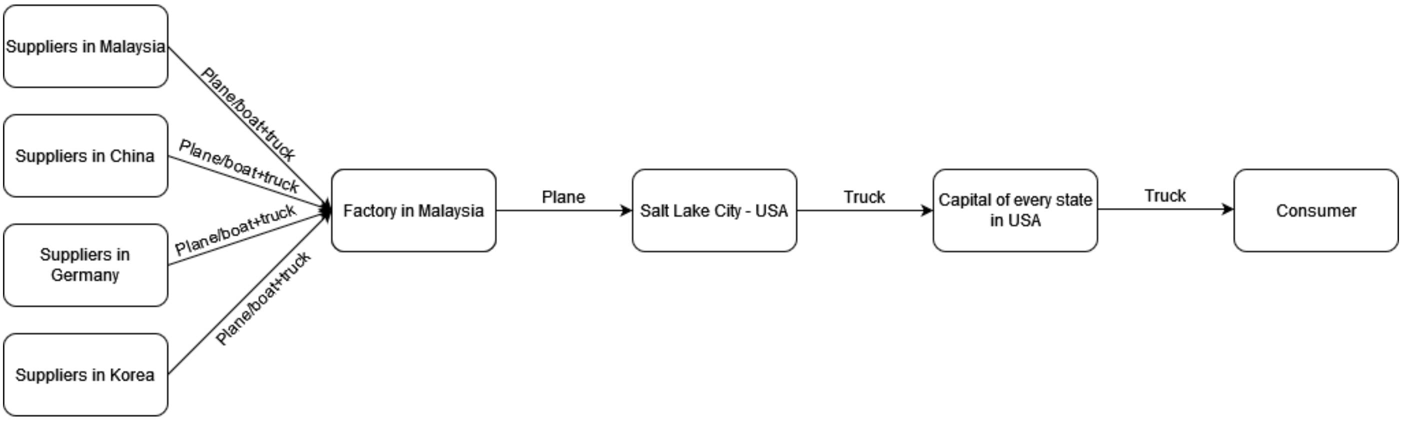

Figure 4: an overview of the current supply chain

renewable energy. It might be hard to establish this soon, but it is possible to design the new factory building of Dopple in such a way that it uses 100% renewable energy and manage the use of energy and water in such a way that the total usage is much lower compared to the current factory. Not only does this new design lower the footprint, it also saves costs. The use of water and electricity and how to minimize that is also interesting to look at before starting to move all production to this new location. Dopple already planned to have solar panels on the roof of the new factory.

The current factory is organized completely functionally, having production halls for a specific part of the process, for example injection moulding. The new factory will have more integration between the processes needed to produce the products, and will work with more 'inline' production. For example injection molding processes will be a part of the production line instead of forming a separate department. This will change the design of the products as well as the processes that are currently used, since new options for production arise. This also causes the change from using raw materials rather than parts that were made elsewhere in the production line. Using less supplied parts will also lower the amount of waste that comes from packaging of these products.

Also the locations of where supplied parts come from will change when the new factory will be used. Instead of focusing on Asia, new suppliers from Europe will be used where possible. In this section some parts and materials that are used in the current design of the headphones will be discussed regarding their changes when the new factory is in use.

As mentioned before, much more parts will be produced inline, for example the inner frames of the headphones. The PCBA's that are used are currently coming from China, since the preference in Malaysia is that it is purchased in Asia. In the future these will be sourced in Europe, for example there are a lot of high tech print companies in Switzerland and therefore it makes sense to buy these parts there when moving the factory. In the further future it might even be that circuit boards become a part of an integrated system in which the PCBA's will be made inhouse. Other parts that are buy-in parts from Asia are tapes and foams. For these it is not possible to buy these in Europe for low, competitive prices, but in the future these parts are no longer needed in production. The adhesives that are used currently that will still be needed are coming from Germany and Japan and in the new situation it is therefore possible to source those from Germany. These suppliers also have their own reactors and can develop them themselves. Another industry that can be found in Germany is the magnet discs. These are currently coming from Malaysia and sometimes China and are complicated parts. They need to be soldered onto the circuit boards, need to look good and have a lot of functions. Lots of knowledge is needed for knowing how to make these parts and the coatings for solder (which is needed to guarantee three years of use). The prices of these parts in Germany are competitive with those in Asia and therefore these will also be sourced within Germany in the new situation. Since lots of sourcing changes, it is important for Dopple to investigate the supplier selection. This is something they have been working on recently, visiting multiple suppliers within Europe.

The silicone molded parts are fabricated in a low-tech way in Malaysia. According to Dopple, a mold costs much less in Asia then in Europe and therefore it is possible to make lots of iterations when trying to design the perfect part. This involves lots of residual waste: only 20 percent of the material goes into the product and 80 percent is considered waste. This goes for plastic as well as silicone injection molding. In Austria silicone molded parts are produced in a high-quality controlled manner, but the costs differ a lot. According to Dopple a machine there costs about 250.000 euros and a mold is about 60.000 euros, which means that the product should be perfect before making the mold while in Malaysia new molds can be made much cheaper. The residual waste from production in Austria however is much less, almost all the material used ends up in the product.

Concluding it can be said that almost all parts and materials can be sourced in Europe, which definitely changes the supply chain a lot and also has a big impact on the transport emissions. This will be discussed in Section 2.4.

2.4 Supply Chain

In this report, research is done into the sustainability of the supply chains. The supply chains of the current and the new situation will be very different. Both supply chains will be discussed in this section, with a focus on the current supply chain. The conceptual supply chain will be discussed in more detail in Chapter 5.

An overview of the current supply chain can be seen in Figure 4. The factory is situated in Malaysia, and most suppliers are from surrounding countries or Malaysia itself. Next to these there are also materials sourced from Germany. The parts and materials are transported by plane or boat and the last part (from the harbour or the airport), they are transported by truck. Transport by plane is used usually, transport by boat is only used if enough parts are in stock and since transport by boat takes much longer. The headphones are produced in the factory in Malaysia and are then transported to Salt Lake City in the United States of America by plane. The products get their final packaging and are then transported by truck to warehouses in all states. From these warehouses, the headphones are

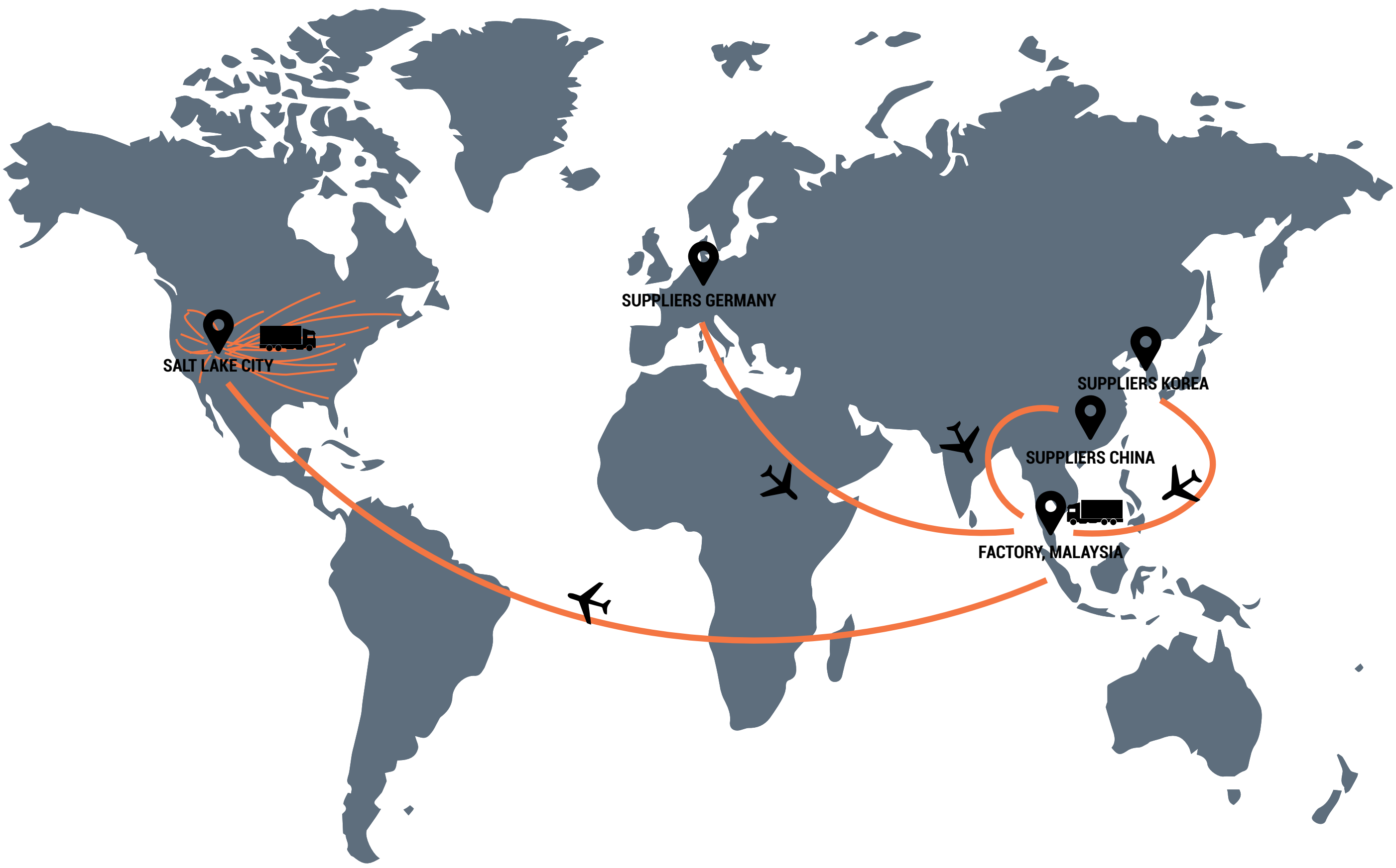

Figure 5: an overview of transport in the current situation

transported by truck to stores across every state, where they will be sold to the consumer. It is clear that in this situation, parts and materials as well as finished products are transported a lot, which causes a lot of emissions. A visualized example of what the current situation looks like in terms of transport can be seen in Figure 5. Although it is a simplified image of reality, it is very clear that there is a lot of transport in this situation.

The whole supply chain will be heavily impacted when the new factory will be used. Not only the location of the factory changes, also the way of working and therefore the input (such as the raw materials and parts) will change too. While currently multiple components are bought as parts, it might be possible to produce these components inhouse in the new factory, therefore only needing to buy the raw materials instead of the complete parts. It is not known and therefore interesting to research whether the shipping of raw materials and then producing the parts is more sustainable than the shipping of parts, this will not be elaborated on in this research but is something for following research. Figure 5 shows almost all Dopple suppliers are based in Asian countries. When changing the location of the factory to Emmen, the materials need to be transported over a much longer distance if they are bought at the same suppliers. Looking into European suppliers to buy the parts or the raw materials is an interesting start for making the supply chain of the new factory at least as sustainable as the current supply chain as well as making sure that the costs of transport will not get too high. This will be a first important change in the new supply chain compared to the current one. An example for which the supplier could be found in the surroundings of the new factory (Europe) is for the SMT (Surface Mount Technology) processes. SMT is a method that is used to attach electronic components to the surface of PCB. Also there are some components, such as glue, already sourced from Europe (in this case Germany).

The current sales market of Dopple is in America, Dopple sells its Bluetooth headphones to companies like Logitech and they sell the headphones across the United States (US). As mentioned before, when the products are finished, they are packaged and sent to the US by plane to a central warehouse. From that warehouse, trucks will bring the products to the sales points across the US. This is the case in the current supply chain but will be different in the new situation, where products are sold local only. In case of a reverse supply chain, this should also be taken into account. Because of the more automatized processes, especially because of further miniaturization, in the production process in the new factory, less mistakes are to be expected when producing the products. When less mistakes are made, less products will be returned because of damage or being faulty. Currently between 5 and 10 percent of the delivered products comes back under warranty and returns, according to Dopple.

Dopple would like to produce customized products for a local market, in the surroundings of this new factory. This differs a lot from the current situation, where products are produced in Asia and sold in the United States. When changing (a part of) the production to MTO or ATO, the customer market and therefore also demand will change. Instead of transporting the products all together to the US, products will be delivered to customers more locally and by local delivery companies. It is not possible to draw hard conclusions about this and therefore lots of assumptions will need to be made for investigating this part of the supply chain.

2.5 Conclusion

In this chapter the current situation of Dopple regarding their supply chain and their current factory in Malaysia are discussed. This is followed with a description of the ideas of Dopple for their new factory in the Netherlands, including an explanation about their innovative LIFT concept. These show the need for a new supply chain and give an insight into what that should look like. The new situation will be discussed in more detail in Chapter 5.
Next to the current situation for Dopple it is interesting to research what other companies in the same market are doing regarding sustainability, to find what can be taken from their situations to improve the new situation. In Chapter 3 the current market and competitors and their ways to sustainability, including options for recovery, reusing and recycling of products will be researched.

3. BENCHMARKING

In Chapter 2 the current situation of the factory and supply chain of Dopple are discussed. Next to the factory and situation of Dopple itself, it is interesting to see what competitors in the small electronics market are doing, especially regarding sustainability. For analysing how competitors work towards (more) sustainable processes and products, some big electronics companies are reviewed. The focus is on Samsung, Apple, Nokia, Sony and also Logitech. This is based on the fact that these companies, especially Apple and Samsung have large market shares in consumer electronics (Statista, 2022) and are in the same market. Also, Nokia, Samsung, Sony and Sony Ericsson are discussed in a relevant article called by Wati & Koo (2010). This article will be discussed in Chapter 4 in the literature research. Last but not least, Logitech is also very relevant because Dopple is currently producing headphones for this company.
The sustainability reports of these companies are analysed and used to find out how these companies work on their sustainability goals. The main focus will be on Apple, since they have a big market share but are also market leaders on technology such as the Apple AirPods. The AirPods are a product that is in the same category as the Dopple headphones.

After discussing the different competitors, the options for recovering, reusing and recycling products by these companies will be reviewed, giving an insight to Dopple about the possibilities for implementing this themselves.

3.1 Market and competitors

3.1.1 Apple

In their environmental progress report of 2020 (Apple, 2020), some highlights Apple mentions are that their new iPhone is built using 100% recycled rare earth elements and that their operations use 100% renewable electricity, not only at their offices but also at the Apple stores and data centres. They reduced their emissions by 35% and want to be carbon neutral in 2030. They include end-of-life recovery into their product life cycle and they aim to design products and packaging such that only recycled or renewable materials are used, as can be seen in their value chain in Figure 6.

Over 70 suppliers of Apple use 100% renewable electricity for producing Apple products. They decreased their carbon footprint by 4.3 million metric tons in 2019 by using recycled and low-carbon aluminium in their products and increasing their efficiency. They clearly indicate that they

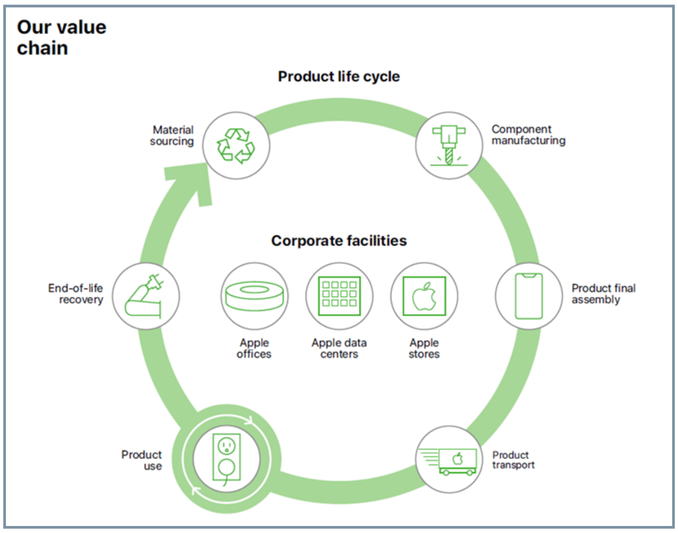

Figure 6: The value chain of Apple (Apple, 2020)

want to take full responsibility and accountability for not only their direct production but for the whole life cycle of the products.

One of the product design changes they mention in the report is sourcing aluminium made with hydroelectricity. They are trying to find ways to not create waste during the production process and by using new techniques reduce the amount of for example steel and aluminium. They also mention that they want to change their material selection; transitioning to materials that are manufactured while not using too much carbon and using recycled content.

Although Apple does not mention its AirPods (wireless headphones) specifically in their environmental report, they are one of the competitors of Dopple in the headphone market. Where Apple designed their own EarPods (in-ear headphones), they took over the brand 'Beats' of Dr Dre in 2014 for the design of over-ear headphones. In the end of 2020 Apple announced their first own over-ear headphones, the AirPods Max. Interesting is that the AirPods Max does not have a switch to turn the headphones off, it goes to low-power or ultra-low-power mode when no sound is played. In the Environmental Report Apple mentions that the customer use of their products is 16% of their overall carbon footprint and that therefore they are prioritizing the energy efficiency of their products. In the report they do not mention the headphones but focus on products like the MacBook and iPhone.

Apple indicates that the energy their supply chain uses is about three quarters of the whole carbon footprint. The emissions mostly come from electricity usage and therefore they try to support suppliers to become more energy efficient and try to get them to use clean and renewable energy sources.

When looking into resources that Apple uses, what stands out immediately is that they have two robots (called Daisy and Dave) who disassemble devices to recover materials from the products. Apple makes hundreds of millions products per year and therefore they can have a positive influence of the way to circular supply chains as well as break down barriers for other companies to follow. Apple leads the market but also the improvements on sustainability. They define the circular supply chain as shown in Figure 7.

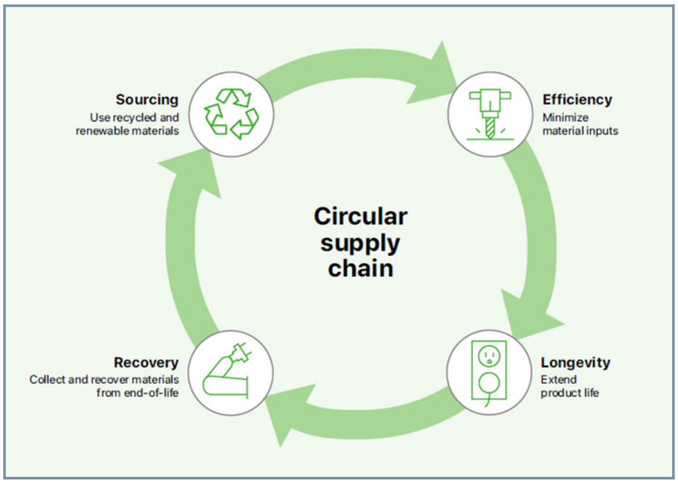

Figure 7: the circular supply chain as defined by Apple (Apple, 2020)

For focusing on which materials have the biggest impact (also based on how much of it is used by Apple every year), they analysed 45 elements and raw materials and made a Material Impact Profile document. The materials they prioritized because of this (14 in total) include aluminium, copper, paper, plastics, rare earth elements and more. Certifications for either recycled as well as renewable materials are important to confirm that the earth's resources are not depleted. They want these certifications to be available for the suppliers themselves so that others can also use the materials with the certifications.

In the iPhone 11 (also the Pro and Max versions) and the AirPods Pro Wireless Charging Case, Apple now uses magnets of 100 % recycled rare earth elements, a high-performing magnet that passed all their performance tests. Virgin products are chosen over recycled materials most of the time because of performance, so this is an important step. At the end-of-life, the new robot called Dave can also recover the rare earth magnets out of the taptic engine in the iPhones now. The other robot, Daisy, is used for disassembly of iPhone devices and for example can recover cobalt and aluminium. They mention that because lithium-ion battery recycling has expanded and there is far more recycled cobalt available on the market now. The following materials are discussed in the Environmental Report of Apple and are also used by Dopple in their headphones:

- Aluminium (batteries)
- Copper (logic boards, circuit boards, wireless charging, power adapters)
- Gold (logic boards, circuit boards)
- Lithium (batteries)
- Paper (packaging)
- Plastics (enclosures, speakers)
- Rare earth elements (magnets, receivers, enclosures)
- Steel (enclosures, cases, screws, structural components, other small parts)
- Tin (logic boards, circuit boards)
- Zinc (power adapters, logic boards)

Mentioned in the report is that the AirPods Pro use 100% recycled rare earth elements in the magnets (of the charging case), that the tin used in the solder of the logic board in the wireless charging case is 100% recycled and that the plastic in four different components of the AirPods Pro are for 35% or more recycled or bio-based.
Repairability is important for the durability of products. Apple has improved a lot in repairability onsite in their newest iPhone, with for example a repairable display, battery, speaker and more. Repairs are done in person or via mail via Apple Stores and Apple Authorized Service Providers. Also, they made it possible for independent providers of repairs to join their program called Independent Provider Repair program (with no costs and free training). This makes it easier for the customer to get access to the needed services. When a product is long-lasting, a customer will probably more likely to choose for the same brand in the future and therefore it is not only important for sustainability but also for keeping market share and happy customers.

Apple tries to effectively reuse and recycle products once they have reached their end-of-life. Their first choice is to recover and reuse parts that still work. After testing they can be placed into another device. They look into creative options, such as reusing recovered Apple cables and power adapters for manufacturing sites and thus decreasing the need for new cables and extending the life of the existing cables. Also end-of-life products are used for testing at their R&D sites before being recycled for raw materials. When creating a new Apple product, they already include the recycling program for that product too. In 99% of the countries where Apple products are sold, there are product take-back programs as well as recycling collection.

Apple tries to improve disassembly and has a Material Recovery Lab (MRL) in Austin, Texas, where they try to develop tools and methods for recyclers to improve the way they process the Apple devices. They invented a semiautomated jig for a more efficient disassembly of AirPods. They focus on using and designing automation to improve ways to take the devices apart. The disassembly robot Daisy works at the MRL in Austin as well as in the Netherlands and can separate components of 15 different models of iPhones. This results in higher quality recovery possibilities for recyclers. Next to robot Daisy, who can disassemble iPhones into components, they designed robot Dave, who can take apart individual components. Dave works at one of their key recycling partners and disassembles taptic engines. The taptic engine represents 24-28% of the total or rare earth elements used in these devices (such as iPhones).
Although using recovered and recycled products is much better for the world because of the lower environmental impacts, Apple indicates that it is harder to move recycled materials around the world in global supply chains than it is for newly mined materials. It can take years to get approval to ship and use components that were recovered. This is because of policies, that treat these recovered materials the same as hazardous waste that will be used as landfill. Therefore to make it possible to have circular supply chains working all around the world, policy innovation is needed.

3.1.2 Samsung

In the Sustainability Report of 2019 by Samsung (Samsung, 2019), they state that already in 1998 they established e-waste take back and recycling centres in Korea and now have taken action to collect e-waste globally. Samsung too designs products while already taking sustainability into account, they look into the energy efficiency, resource efficiency and environmental hazardousness by eco-design process. In 2017 a pilot project was started called the 'Galaxy Upcycling program', in which old Galaxy smart phones are used as IoT solutions. They also have all their Korean worksites Energy Management System (ISO 50001) certified since 2013. In 2020 they want to use renewable energy for 100 percent of the energy used at all the factories and operational facilities as well as the office buildings in the US, Europe and China. On their Korean worksites solar panels are installed already.

Since 2018, all the suppliers that Samsung does business with will be RMAP (Responsible Minerals Assurance Process) – certified for the four most conflicting minerals (gold, tin, tungsten and tantalum). In the product design stage they consider environmentally conscious materials and want the products to be energy efficient. The Galaxy S10, launched in 2019, includes some key eco-conscious features, such as the use of recycled (or bio-based) plastics and a high efficiency for charging. The charger of the Galaxy S10 is made of 20% of recycled plastics and the ear jack housing of the same phone contains 29% bio-based plastics. Bio-based plastics are plastics that are derived from biomass sources that are renewable, for example corn starch and vegetable oils. Samsung focuses on the use of these bio-based plastics to improve the environmental consciousness of their products currently.
Samsung has service centres worldwide to make repair and reuse possible, next to recycling e-waste and separating and reusing waste per material type. For example, in Europe there are take-back and recycling systems in 37 countries and in the US in all 50 states. To find what the environmental impacts of their products are during the life cycle, they perform Life Cycle Assessment (LCA) for some products. The outcomes are used to design products that have less impact.

In their issue identification and risk/opportunity analysis, Samsung also mentions 'changing consumer behaviour' and their approach to it is to use surveys for consumers as well as producing more environmentally conscious products. With climate change being a big subject all around the world right now, consumers will ask for more environmentally conscious products but their behaviour in for example returning used products still needs to change and they must become more aware of the importance of it. Just like Apple, Samsung also tries to reduce its water usage and wants to improve their water management. In the sustainability report they mention that they reuse lots of water, minimize the usage of water by using highly efficient technologies and optimize it through process improvement (from replacing systems such as piping and ducts to using recycled water where possible). Also Samsung does share its knowledge around smart factories with small and medium-sized enterprises (SMEs), helping them increase their profits but also promoting the sustainable business management on the long-term. Samsung only works with internally certified suppliers (Eco-Partner) so that they can manage and assess the environmental impact of the materials and components they use. New suppliers are selected based on five criteria, namely procurement and quality, labour and human rights, their financial status, Eco-Partner and EHS (Environment, Health and Safety). They use checklists and only those that score more than 80 out of 100 points for all the criteria are qualified to become a Samsung supplier.

3.1.3 Nokia

Nokia mentions in their People and Planet report of 2019 (Nokia, 2019) that regarding climate change, they used 46% less energy by the networks that they modernized (compared to the ones that were not modernized), that 56.300 product units were reused and that they undertook a study into the plastics inventory across their operations to see where they can start removing single-use plastics or reduce the use of plastics. By using life cycle thinking while developing new products they create technologies that are taking into account sustainable aspects. They too do offer takeback, refurbish, repair and recycle services for their customers. Of the products that are taken back, 91.6% is recycled, 7.7% is energy recovery and only 0.7% ends up as landfill. According to their report, of all the plastics that are produced and used worldwide, half of it is designed to be used only once. Nokia says that of the plastics they use, 91% is in their products. They do not consider this to be single-use plastic because the products are used over many years. Most of the plastic in these products is recoverable and 92% of the materials in these products were recycled (in 2019) when the product reaches the end-of-life. When working with suppliers, Nokia mentions that sustainability is one of the six pillars in the Supplier Performance Evaluation they use. The supplier requirements around this are part of the supplier contracts and they expect their suppliers to commit to them as part of their contractual obligations. Nokia is working with the RMAP too and found that they achieved an 82% validation level for the smelters and refineries in their supply chain, to be conflict free.

3.1.4 Sony

Just like the other companies, Sony publishes a yearly sustainability report and recognizes the importance of it. As is mentioned in the report, “for people to be connected through emotion, it is necessary for people, society and the planet to be healthy” (Sony, 2021). As mentioned in the chapter Environment of the sustainability report, Sony has the goal to have zero environmental footprint by the year 2050, both for the life cycle of its products as well as for the their business activities. They mention that in fiscal 2020 they achieved multiple goas, such as the decrease of their annual energy consumption of products by 54%, the $CO2$ emissions were reduced with 456 thousand tons by using renewable energy and a decrease of 15% of the waste generated at Sony sites. They also did promotion for the One Blue Ocean Project worldwide together with plastic waste clean-up activities and raised awareness through events and their social media. As also described by other companies, Sony too requested their manufacturing outsourcing contractors amongst others to reduce emissions and take biodiversity into consideration. Next to this, they also urged their component and raw material suppliers to reduce their impact on the environment, reduced shipping weights by making products smaller and lighter and has focused on recycling and take back. They focus on recycling-oriented design of their products and promote take-back for used products. Also if they cannot recycle times themselves, they try to find and collaborate with recyclers to make this possible either way.

In the report one chapter is dedicated to ‘Responsible Supply Chain’. Sony production sites follow the Responsible Business Alliance (RBA), which Sony joined in 2004. Based on the RBA Code of Conduct, Sony established the Sony Supplier Code of Conduct which makes sure that suppliers, subcontractors and other partner firms involved all meet Sony’s standards. For responsible sourcing of minerals that are used in Sony’s products, there is the Sony Group Code of Conduct, which includes basic policies regarding environment but also regarding ethical business. For example, it prohibits forced labour, and especially child labour, which is a known problem when sourcing certain minerals.

3.1.5 Logitech

One other sustainability report that is interesting to look at at this point, is the one of Logitech. Currently, the headphones that are produced by Dopple are sold to Jaybird, which is a sub brand of Logitech. As can be read in the Sustainable Report of 2020 (Logitech, 2020), they have made sustainable reports for 12 years but only recently decided to speak out about it and want to move faster and do more. For example they are now supporting the Paris Agreement and became the first consumer electronics company to provide labels with the carbon footprint on product packaging across their product portfolio. They use Design for Sustainability (DfS) and included environmental performance as a main goal while designing. Logitech has a recycled plastics program and want to avoid virgin materials as much as possible, using renewable materials instead. They also focus on end-of-life recycling, their goal being empowering consumers to recycle the products in their local environment. According to the report, 20 percent of e-waste is currently recycled.

3.2 Recycling and reusing

As mentioned before, recovering products with the intention to reuse or recycle parts is a sustainable option and a step towards a circular economy. In Section 3.1 competitors of Dopple are discussed regarding their steps towards sustainability. In this section the options for recycling for specific materials are discussed. Also reusing is shortly touched upon, since this is another option for more sustainability.

3.2.1 Recycling

In chapter 3 the market and competitors are analysed. This gave an insight in how the big tech companies work on their sustainability goals and what steps they take to becoming more sustainable. In the environmental report of Apple (Apple, 2020) also the progresses per material are discussed. Some of the materials used by Apple are the same as what Dopple uses, since Apple also produces Bluetooth headphones amongst others.
These materials and the options that Apple found will be discussed here as these might also be options for Dopple.

- Aluminium

Apple mentioned that they have created a new alloy of completely recycled aluminium that has a high enough quality for their intended use. They source the recycled aluminium themselves from for example manufacturing scrap and out of recovered products.

- Copper

At first Apple reduces the amount of copper needed for their products and made new foils with less copper. They indicate that they the copper thickness of foils that they need to create printed circuit boards (PCB's) was reduced by a third. Also they started using fully recycled copper in the foils of one of their PCB's as well as sourcing copper from recovered items that were disassembled by their robots.

- Plastics

A known problem with recycling plastics is that they do not have the same performance as virgin plastics. But Apple continued to work with recycled plastics and have together with suppliers now developed a plastic that has over 35 percent recycled plastic in it and still offers the advanced acoustic properties that are needed for speakers. The same goes for plastics for protective cases that need to have strength and resilience, they made them with a recycled content of about 40 percent. So it is possible to at least use partly recycled plastics. Another option to use more sustainable options for plastics is to use plastic made from bio-based content instead of fossil fuels, although of course it is better to switch to fully renewable materials.

- Rare earth elements

As indicated earlier, Apple managed to produce the wireless charging case of the AirPods Pro with fully recycled rare earth elements in the magnets in it. Also they have their new disassembly robot, Dave, that can extract rare earth materials so that recycling partners can recover these. When Dopple wants to recover products investing in such a robot would be an efficient way to renew materials.

- Steel

Steel is already often recycled and therefore it is easier to use recycled stainless steel where possible. Apple next to this focuses on reducing the amount of steel used by enhancing material efficiency and collects their own high-quality steel scrap to make sure it can be used in new products.

- Tin

Tin is often lost in traditional electronic waste recycling according to Apple, however they started shipping recovered components to specialty recyclers so that it can be recovered. Also they already use recycled tin in the solder of main logic boards in multiple of their products and what to extend that to amongst others the AirPods Pro wireless charging case.

3.2.2 Reusing

Although design and production are optimized to have a certain lifespan that is the same for the different parts of the headphones, it might be that some parts have a longer lifespan than other parts. Also, if products are returned because they are not working, that does not mean all parts are not working parts. They could be reused and therefore reduce waste and save materials and parts for new produced headphones. To do this, it is necessary to investigate for which parts this would be possible, especially regarding the fact that these headphones are worn in-ear and therefore hygiene is very important. Of course when Dopple would be able to reuse parts, this would lower the footprint because it lowers the amount of parts that need to be sourced and transported. To be able to reuse parts and materials, Dopple needs to research which parts have a longer lifespan, or could be designed to have longer lifespan, and how to make it possible to recover those from the products that are sent back. Of course enough products need to be recovered in that case, so that the products do not go to waste and cause even more pollution then in the regular situation.

3.3 Recovery of products

In order to reuse parts or materials or recycle them, products need to be recovered. Although in theory it sounds simple to recover products it is not that easy in real life situations. For example regular batteries, that contain valuable raw materials such as iron, copper, nickel and cobalt and are therefore highly recyclable, are ending up in residual waste (Milieucentraal, 2021). In the Netherlands, customers can return the batteries where they bought them, at for example supermarkets that they visit regularly. It even is possible to return small electric products there too but about 20 percent ends up as regular waste in the end. Not only is this a waste of recyclable valued materials, it is also dangerous. Still for example 160 thousand kilos of batteries used in companies end up in regular waste (Wastenet, 2021). In this section the situation at competitors is discussed, followed by options that Dopple could consider for the recovery of their products.

It is important to think of a system in which Dopple could recover the products that they made after they reach their end-of-life at the customer. As mentioned in Section 3.1, Apple has robots to recover parts and materials out of returned products but still have problems with receiving these products. They have their own stores across the world and if a customer buys a new product at these stores they get an offer to get a discount on this new product if they return their old one (Apple, 2021). This sounds like a good system, but as can be learned from Apple's sustainability report (Apple, 2020) still a lot of people do not choose to return their old products. Because of the marketing strategy of Apple, and only launching one new product every year, Apple users who like to have for example the newest iPhone will buy a new phone very often. 51 percent of the iPhone users buys a new iPhone every two years, according to Gallup (Gallup.com, 2021). While previously this was necessary because older products would not receive security updates anymore after a while, that has now changed and it should be possible to use an iPhone for about five years (Statista, 2022). While this is of course a plus for sustainability, since old iPhones could be fully working still but not be used because of the lack of software upgrades, this also means that people sell their old iPhone as they buy a new one. While Apple gives a discount on a new product, this might be less than what the customer gets when selling it to family, friends or via internet. In the end the old products might also end up as for example 'back-up' for when a newer model stops working. Also in that case, old products are not returned to Apple. While this mainly is the case for mobile phones and headphones will not be sold to others because of hygiene, because of the lower price (and therefore lower trade-in price at Apple), they still probably end up as regular waste or laying around in a drawer in the customers house until they really throw it away.

While the climate is becoming more and more a hot topic and people are more aware of sustainability, the necessity of recycling will probably also become more clear in the future. Dopple already has a 'recovery room' in the simulation of the new factory and although at this point in time it is hard to recover products, it is important to be ready for it when it is possible, for example because of regulation changes from governments or when the regulation for certificates change and recycled materials can get certified and used more.

In the current situation the headphones that Dopple produces are sold to another company, who sells them in stores across the United States. In the new situation Dopple would like to sell the headphones themselves, directly from the factory in Emmen. By doing that, it is possible to produce in a MTO of ATO way, giving the customer the option to design the headphones as they want them (based on fitting and colours for example). Since the headphones will not be sold via regular stores, the possibility to collect old products at the stores (such as the option that you can return batteries at a store) is not an option. What would be an option is to 'buy the products back', just like Apple does with their trade in option. To make customers consider sending used products back to the company in return for a discount on a new product, or a reimbursement, this value has to be that high that the consumer sees value in it. Especially since they have the hassle of sending a package back to the factory too. To investigate when a customer would be open to this, a survey could be set up to find out what would be the tipping point for the customer is and then find out if it would be worth it price-wise since also the economic pillar needs to be taken into account.

Another option that Dopple has been thinking about is to set up a subscription system. The option for a service-based product will also be discussed in Chapter 4. When only providing the service and not the ownership of the product, it is easier to stay in contact with customers. This could for example be done by regularly updating them about interesting or important facts or discounts. In such a service it would be possible to ensure that a customer gets new headphones every year or two years when they return the old one. All services would then be included in one subscription price, and it could include a condition that the customer needs to send back the headphones before getting new ones. Subscriptions for all kinds of services are used more and more and it would therefore be a futureproof option, although it also needs to be investigated if customers would like another subscription or do not see the value of it.

3.4 Conclusion

The big tech companies that are in the same market as Dopple, focus the most on energy savings at both their own facilities as well as at their suppliers. Water savings are also looked into a lot. The recovery of products is something multiple competitors work on, it is possible to return used products and for example Apple has a robot that is able to separate iPhones back into parts. However, policies for reusing the recovered parts and materials are not in place yet and therefore it is not possible to recycle products on a large scale. All companies try to use recycled materials, from melted aluminium to recycled plastics, multiple materials that are also used by Dopple are discussed in Section 3.2.

This information can be used by Dopple when designing the new headphones, since the design of the headphones as well as the way of manufacturing will be different in the new situation. For example something to take into account is how to make sure that the product can be taken apart easily to recover certain materials, or look into the options to use recycled materials instead of virgin materials when producing the headphones.

To discover what would be the best options for recovery of products, Dopple should do research into what options are perceived as positive and workable for the customer. Dopple can already take out of the research done in this chapter that a reimbursement or discount price needs to be high enough and that smart marketing may be needed to make sure the customer takes the option of such a service into account. A subscription service may somewhat force the customer into making sure that products are returned at the end of use or end of life, but it needs to be researched if the customer would want yet another subscription service.

This Chapter already includes the part of the research question that is as follows: *what is possible to (even more) reduce the footprint for the new situation?*. Options for reusing and recycling parts and materials are discussed in Section 3.2, while the possibilities for recovery of end-of-use and end-of-life products have been researched in Section 3.3. Dopple should take the options and recommendations into account when designing the product that will be produced in the new factory. Creating a circular supply chain, recovering products and then recycling or reusing parts and materials will lower the footprint of Dopple in the new situation.

4. LITERATURE REVIEW

In this chapter literature will be studied in-depth on supply chain design, facility location, circularity aspects and solution approaches. This will result in a choice of the solution approaches for this research and ends with a conclusion about the literature review.

4.1 Supply Chain Design

As mentioned in Chapter 2, one of the goals of this research is to compare the current supply chain with the new supply chain, both from an environmental as well as an economic aspect. Therefore the literature research starts with looking into (sustainable) supply chains and how they are managed and optimized. Facility location is taken into account as well.

Sustainable supply chains

Sustainability has become very important for organizations worldwide. The supply chain is the place where an impact can be made, positively as well as negatively (Carter & Easton, 2011). Particularly they can influence the environmental and social aspects of sustainability. For example by vehicle routing, decisions regarding locations, select specific suppliers or influence them to develop in a sustainable way and the selection of transport options. The definition of the supply chain can be defined as follows: "the supply chain encompasses all activities associated with the flow and transformation of goods from raw materials stage (extraction), through to the end user, as well as the associated information flows. Material and information flow both up and down the supply chain" (Handfield & Nichols, 1999, p. 8).

Organizations these days are establishing different environmental strategies into their strategies, both to improve their environmental operations as well as business operations. One of the fields in which environmental strategies are found is in Supply Chain Management (SCM), mentioned as Sustainable Supply Chain Management (SSCM) (Al-Odeh & Smallwood, 2012). According to Al-Odeh and Smallwood (2012), the most accepted definition of SSCM is "the process of managing the SCM activities with consideration for environmental, economic and social issues for enhancing the long-term economic goals of individual organization and its supply chains" (p. 85). Integrating environmental and social aspects together with economic considerations, which is also referred to as the triple-bottom-line (TBL) for sustainability in organizations, is more and more relevant for managerial decision making in general but also for operations management and SCM (Brandenburg, Govindan, Sarkis, & Seuring, 2014). The TBL is also known as the three P's: People, Planet and Profit (3Ps). TBL differs from traditional frameworks because it takes into account ecological and social measures next to finances (Slaper & Hall, 2011). It is harder to measure ecological and societal activities and therefore calculate the TBL. Multiple measures will be needed. This will be discussed in more detail in the next section.

There are five activities considered in SSCM, following the life cycle of a product, namely design, purchasing, production, marketing and transportation (Al-Odeh & Smallwood, 2012). The first activity, design, includes the design of the product as well as the packaging. Considered are designing products in a way that they can be recycled or remanufactured (design for recyclability), but also design in such a way that the impact of product waste is decreased. Not only does sustainable design lead to successful recycling of products, it also changes how customer see the brand and will save money. This may also include developing new business models in which the product ownership will be replaced by services (Guide et al. 2003).

Another activity mentioned by Al-Odeh & Smallwood (2012) that is also relevant to Dopple is the sustainable production. Using a clean production method and new technology as well as reducing the use of raw materials and resources are helpful to decrease pollution (Al-Odeh & Smallwood, 2012). Options that are mentioned as the first production strategies that helped to achieve environmental production are lean manufacturing and Just-in-time (JIT) techniques. These could help to reduce waste and minimize hazardous waste, as well as reducing the marginal costs of pollution. Reverse logistics, in which products are going back through the supply chain to be remanufactured or recycled is another activity that could work in sustainable production.

The third activity that is mentioned by Al-Odeh & Smallwood (2012) is sustainable marketing. Within sustainable marketing, the managing of waste could lead to enhanced competitiveness and cost savings. It also has an impact on how customers see the brand. Currently, Dopple is a business to business (B2B) organization and does not sell directly to customers that use the end product. This will change when the new factory will be opened. Sustainable marketing may be important to research further in the future.

The following activity discussed by Al-Odeh & Smallwood (2012) is sustainable transportation. This is an important element of the supply chains that will be reviewed in this report. Types of transport, such as planes, boats and trucks, but also the fuel sources for these types of transportation and the whole infrastructure have an impact on the sustainability. The last activity is sustainable purchasing, which is already mentioned above to be important. Purchasing sustainable (such as recycled) materials leads to reductions in waste and the reduction of using e.g., virgin rare earth materials.

The importance of SSCM is not only seen in the lower footprint but it also leads to cost reduction. This economic benefit might also be an encouragement for organizations to adopt SSCM practices. It is important to involve the stakeholders into the process of developing SSCM since they play an important role. The integration of economic risks prevails over the consideration of environmental and social risks (Rebs, Brandenburg, Seuring, & Stohler, 2018). Stakeholders are individuals and/or groups that can influence the achievement of a corporation's goals or that are affected by the company's performance (Freeman, 2010). When looking into SCM a stakeholder is mainly a part of the supply chain (such as customers or suppliers). Stakeholders are also possible outside the supply chain, for example competitors, the government and non-governmental organizations (NGOs) or the media (Meixell & Luoma, 2015). These can be seen as secondary stakeholders.

For reaching SSCM, industrial symbiosis can be an important factor. This is defined as follows: "Industrial symbiosis (IS) engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and by-products. The keys to IS are collaboration and the synergistic possibilities offered by geographic proximity" (Chertow, 2008, p. 12). Further research about industrial symbiosis will be done when talking about input-output modelling (Section 4.5).

Indicators

To measure the performance of the supply chain both on an environmental as well as an economic level, indicators are needed. Indicators are used as parameters that show the aspects of performance that need improvement and indicate directions of change (Clift, 2004). Seuring (2013) looks at quantitative models to model sustainable supply chains. The four categories that are mentioned in this paper are equilibrium models, life-cycle assessment models, analytical hierarchy processes and multi-criteria decision making. They all focus on the minimization of costs. The previously suggested method for this research is input-output modelling. This is part of the equilibrium models mentioned in the paper of Seuring (2013).

In supply chain management the indicators that are most often chosen to measure the economic aspect of sustainability in a supply chain are total cost and net revenue (Seuring, 2013). This paper also mentions that for the environmental aspect the most used indicators are energy demand and CO_2 emissions. In some cases also other impact criteria are included, for example energy, water and waste. The approach that is used a lot for determining the environmental aspect is life-cycle assessment (LCA), which together with its management in the supply chain leads to supplier selection and points out to hotspots that can be improved, such as the transport to the customer (Seuring, 2013). The social aspect of sustainability, also referred to as corporate social responsibility (CSR) has not gotten a lot of attention in papers regarding sustainable supply chain management or was rather standalone and not connected to other topics within sustainability (Carter & Easton, 2011). Since the focus in this research is on the economic and environmental aspects, the social aspect will also not be taken into account here.

An indicator mentioned by Clift (2004) for economic dimensions is Value Added (VA), which is defined as the value of sales minus the costs of raw materials, goods and services that are purchased. For measuring the overall impact, so both environmental and economic, Clift (2004) suggests an indicator set that was developed by Unilever which is known as the Overall Business Impact Assessment (OBIA). In this formula that is used for the OBIA, the value that needs to be filled in is taken as the total sales (of the business) and the impact is based on the whole life cycle. Working with this indicator set, it is be helpful to identify which activities are unsustainable but it can also be used to find the differences between scenarios.

Economic situation

While most of the negative environmental impacts can be traced back to market failure, the pollution caused by companies both on the production process as well as the use of their products is not taken into account in the market (Ding, Liu, & Zheng, 2016). The costs for removing damages and/or the repair of environmental issues are not taken into account by the companies and therefore they do not subtract these costs from their revenue. For Dopple this was already investigated by using an eco-cost model for their current headphones and indeed found that they should be working with a higher cost price when including environmental costs.

4.2 Facility location

Although the location for the new factory is already chosen, it is still interesting to look into facility location. The new factory is a concept version and if it will be feasible, more local factories like this might be interesting. Also, it is helpful to have a look into how the three pillars of sustainability impact the facility location decision making and see what might be important. Taking into account the three pillars of sustainability when solving the facility location problem is still rare (Dombrowski, Riechel, & Döring, 2014). This paper gives an overview of the approaches and the methods and indicator sets that were used in previous researches. An interesting fact is that it mentions that none of the researched indicator sets used all three pillars of sustainability, most of the time it only focused on one or two and the social dimension was left out. Regarding methodologies to use, mathematical models that are sustainability-oriented have an advantage because of the use of multi-criteria analysis. This way also the development of the factory as well as the environment can be taken into account, something that is lacking in most facility location problems. It is recommended that Dopple includes this when more local factories will be set up, looking into the right locations for those based on all three pillars.

Dopple indicated that, especially now during the COVID-19 pandemic, the communication between the developers (based in Emmen) and the production (based in Malaysia) is much harder. Before the pandemic the factory in Malaysia was visited every six weeks, but also not by all employees of Dopple. They noticed that it would work much better to have the developing close to the production. This will be the case when the new factory is started in Emmen, but it is also important to take this into consideration when the new factory will be duplicated to other locations around the world. This will not be taken into account in this research but is very relevant when Dopple will expand to other locations in the future.

Next to the location of the factory, the design of the new factory itself is also very important for Dopple. To make sure the factory is working as efficient as possible and produce high quality products, but also for fluctuating demand, lean manufacturing is advised. The goal of lean manufacturing is to minimize waste while having maximum resource utilization (Venkat Jayanth et al, 2020). According to this author implementation of lean specifically in electronics industries shows that there is continuous improvement possible in both quality and productivity. This is important to take into account since the production process in the new situation will be completely different from what it is in the current situation, amonst others because of miniaturization. The reason behind miniaturization is that more functionalities are needed over time, while the package size of electronics needs to be reduced further (Feldmann et al, 2010).

4.3 Supplier selection

To ensure that the complete new supply chain is as sustainable as possible, Dopple should not only focus on their own production but also on the suppliers they are working with. Dopple can state selection criteria such as that the supplier only uses green energy when producing their raw materials or parts, or that the supplier uses recycled materials when and where that is possible. Also the social pillar of sustainability could be taken into account when only selecting suppliers that prove to be good for their employees. The strategic decisions for supplier selection may show many facets and it can be hard to determine the right supplier when trying to take into account sustainability but also risk criteria (Alikhani et al, 2018). An approach or framework as suggested by the authors can be helpful for Dopple when deciding on which suppliers they want to work with. Another example of a framework that can be used for sustainable supplier selection, monitoring and development is proposed by Zimmer et al (2015). Another framework for sustainable supplier selection is proposed by Luthra et al (2016). The authors work with the three dimensions of criteria based on the pillars of sustainability (environmental, economic and social) and identified 22 selection criteria. Some important criteria according to their findings are the price of the product, the environmental costs and the quality of the product. Luthra et al (2016) mentions that sustainable supplier selection is not only important because of ecological pressures of multiple stakeholders, but also because of increased customer knowledge. With the help of one of the proposed frameworks, Dopple can find the right suppliers for their new factory.

4.4 Circularity aspects

One way to make a supply chain more sustainable is to make it circular or to at least include a reverse supply chain. This means that (parts of) the products are recovered, reused or recycled. It is interesting to see if there are competitors already doing this. Dopple does not recover its products currently, but indicated that for example Samsung has made steps into this direction. Dopple also mentioned that Apple is doing research into this and even has a robot that can take products apart after being discarded. Therefore an extensive research into the sustainable approaches of large electronics companies such as Apple, Samsung and Nokia is done. That research can be found in the previous chapter, chapter 3.

Wati & Koo (2010) studied the environmental reports of four big electronics companies, namely Nokia, Samsung, Sony and Sony Ericsson. They indicates that sustainability is becoming more and more a hot topic, this paper shows that companies were already working on “going green” in 2010, mentioning that concerns over environmental protection had recently become mainstream. The authors mention that the focus of the companies was on green disposal practices and on energy efficiency efforts. As found in the research of the sustainability reports of last years, also a big focus lies on efficient water usage and the reuse of raw materials and parts.

The European Environment Agency mentions that energy usage from human activities represents the largest source of greenhouse gas emissions around the world (European Environment Agency, 2021). This is the same for Europe, where this makes up 78 percent of the total European emissions (numbers from 2015). This includes energy that is used for electricity but also for heating, industry and transport, which are scope 1, 2 and 3 emissions according to the Greenhouse Gas Protocol. Therefore the use of energy has a large impact on climate change.

Within the total international waste stream the electronic waste, also called e-waste, is one of the fastest growing areas, and compared to other individual waste streams it is increasing about three times faster (Herat, 2007). The lifespan of electronics also becomes shorter and shorter because of new inventions and a demand for more speed, more power, more memory. For a new model of a computer the lifespan decreased from 4.5 years in 1992 to about 2 years in 2005, while mobile telephones already had a lifespan of less than a year in 2007 (Herat, 2007). This author also mentions miniaturization very specifically as a cause for increased resource consumption. The number of devices being produced keeps growing because sales keep growing.

Changing from a linear method to a borrow-use-return approach should be the most important challenge to lower impacts, since it is not possible to have influence on what happens to the products as soon as they are sold to the consumer (Herat, 2007). To ensure this, the Design for Environment (DfE) approach should be priority. DfE focusses on the reduction of the environmental impact of the products already during the design stage. Goals are to lower or exclude the use of toxic and critical raw materials next to already thinking of the end-of-life stage of the product. When the product reaches this stage, it should be easy to disassemble the product so that parts can easily be sorted and reused or recycled. Also focusing on a lower weight will lower the footprint, as well as working with materials that have a the lowest environmental impact possible. LCA can help determine what the environmental impact is on a product level and material level (Bocken et al, 2016). While DfE is the responsibility of the company that designs and produces the product, the consumer also is very important in the process. Only when the consumer brings the products back when the lifespan of the product is over, it is possible to use the reverse supply chain. While the recovery of products is discussed in the next section, it is important to notice that business models of a company need to change when a circular supply chain is established. A sustainable product-service system could be used, which is a system that is designed to provide the customer with a specific function or result instead of the ownership of a product (Roy, 2000).

Although it might take some time to reach a large group of customers for their customized products, it is one of the goals that Dopple wants to reach to maximize their profits. Hankammer & Steiner (2015) research the potential of sustainability in the case of mass customization (MC). Mass customization can be determined as a kind of strategy that is mentioned regarding products with personalization and therefore high variety, next to flexible production. Hankammer & Steiner (2015) combine MC with a product service system (PSS) in a business model, which is very relevant for Dopple. The reason of this combination is sustainability, the goal behind PSS is to have less materials in the economy by only offering what customers need exactly, therefore lowering the burden on the environment. An aspect that is mentioned is that with

PSS it is easier for companies to have an influence on the relationships with their stakeholders, which also gives the opportunity to inform the customers about environmental impact (Hankammer & Steiner, 2015). The benefit of these relationships can be large and has great potential because if Dopple would exactly fulfil the needs of these customers by mass customization.

The shifting from focussing on 'end of pipe' towards a 'cleaner' manufacturing process started around the late 1980's, and this is when designers and engineers started to think about the development of 'greener' products (Roy, 2000). Green IT can be approached by four holistic approaches, namely Green disposal, Green manufacturing, Green design and Green use (Wati & Koo, 2010). Some key concepts for Green IT that are mentioned in this paper are DfE, energy-efficient computing, responsible disposal and recycling and eco-labelling of IT products. In the paper the environmental reports of four big electronics companies are analysed, leading to some limitations and implications. However, this research was done in 2010 and climate change has since then gotten lots of attention. Some conclusions may be outdated, but most practices will still be in place. One of the things the authors mention is that implementing life-cycle thinking, and then detecting hotspots and working on these, is the optimal solution to reduce the consumption of energy. The other important conclusion is that for the reduction of electronic waste, the consumer needs to be aware that they should return their old devices.

When products are recovered, they cannot just be used again. It is interesting to look into the different parts of the product and see which parts could be reused and which parts need to be recycled. To make sure that the quality of raw materials and parts stays high, combined with the certificates the materials need, not everything will be possible to recycle in-house. The current situation at the market regarding these options are discussed in Chapter 3, while the information from literature about the recovery of products is discussed in the next section.

Recovering products

The recovery of products is an important step to be able to recycle parts of the products. For the Bluetooth headphones that Dopple produces, refurbishing is not really an option since these are products that will not be hygienical for a next customer (because of wearing it in-ear). Also there is a difference between refurbishing an iPhone worth 1000 dollars and headphones worth 170 dollars, both on the number of critical materials used as well as the price a refurbished item can be sold for. The reuse and recycling of parts will be discussed in the next section. To be able to recover the products, service points are needed across the countries where the product is sold. At a service point it is possible to do repairs and take back old products for recycling and reuse. Apple for example uses these (see Section 3.2), and when buying a new iPhone a customer will get the question if they want to give back their old iPhone and get a discount on their new one because of it. However, even while Apple has a robot to separate the parts of the iPhones, the take-back is not used as much as it could. Apple themselves mention that, to be able to get this reverse supply chain working, policies need to be changed to make it possible. This is also the conclusion in the paper of Wati & Koo (2010). At this point in time recovery of the products is not something that will make a big impact, simply because it is not possible yet on a big scale to reuse parts of the products easily. On the other hand, the world is focusing more and more on climate change and the sustainable goals and big companies are a big part of the carbon footprint. Although it is maybe not directly possible for Dopple to make a difference on this part at this point in time, chances are that big companies like Apple and Samsung will continue with their work on this and that may give possibilities in the long term for smaller companies too.

Since Dopple is currently a business to business company and not in direct contact with the customers, it is important to work with the companies that sell the products they made to set up service points and create a reverse supply chain. Haddock-Fraser & Fraser (2008) analyses the difference between 'close-to-market' and 'business-to-business' companies regarding the assessment of corporate environmental reporting motivations. They mention that there is a positive correlation between the closeness to the market of a company and its proactive communication regarding environmental activities. This might be based on the fact that customers know the brand. However, as can be read in the previous Section, business to consumer (B2C) companies like Apple are asking of their suppliers to held the same standards regarding the environment, for example by using only renewable energy. Next to this, Dopple is planning on designing and selling their own custom-made headphones directly to customers. In that case, it is possible to include their warranty and return but also the disposal of products by customers in the new factory. When opening new factories at other local countries, they should have this as well to keep the short distances and good services.

Recovering products is done by using reverse logistics (RL): instead of going from factory to consumer, the products go from consumer back to the factory. When including reverse logistics by recovery of products into the supply chain, a closed-loop supply chain can be established. A closed-loop supply chain has significant differences from the standard, forward supply chain in multiple aspects (Guide et al, 2003). While in a forward supply chain the consumer is the end of the process, in a closed-loop supply chain the consumer sends the product back after use and it goes back into the supply chain, the consumer is in the middle of the process. Not only the process itself changes, but as mentioned before the consumer should also be made aware of these processes so that the product will not become waste after the end of life. Of course also new processes are needed to sort out the received products and determine which can be reused or recycled. Details about reusing and recycling will be discussed in the next Section. For reverse logistics to work out it is therefore important to design this process very carefully, taking into account all different scenarios that may occur. For example, since the high tech industries keep developing very fast, there might be a big difference in when the end of use is and when the end of life of a product occurs. This should be taken into account when planning how a closed-loop system can work out for a company so that the value of the recovered products is optimized. It is important that all steps and situations are integrated in the process instead of being seen as separate activities. Not only in the supply chain, but also in for example marketing and sales. According to Guide et al (2003), these departments will be afraid that remanufactured sales will cause less new sales and also might damage the image of the brand. Of course it is also necessary to include the options to disassemble products when designing the product.

There are lots of different reasons, and therefore moments in time, for products to be returned. As mentioned before the end-of-life and the end-of-use stages of the product may differ a lot in time, but of course there are also repairs, commercial returns and returns based on warranty. All these need to be taken into account in the business model, they all have their place in the reverse supply chain. Because of these different moments, companies may go a step further and decide to develop a business model in which the product ownership is no longer at the customer but stays at the company itself (Guide et al, 2003). The customer then pays for a service instead of the ownership of the product. Nowadays customers are more used to these service-based products, therefore it might be a good option to make profit while taking into account the environment. Legislation to make sure producers take care of their products when those reach their end-of-life was set up around the year 2000, for example in 2003 the Waste Electrical and Electronic Equipment (WEEE) directive became officially European law (Govindan et al, 2015). Other countries followed later with laws alike.
According to De Brito & Dekker (2004), companies get involved with RL because of three different drivers. These are economics (make profit), legislation or because they feel they need to do this on a social basis, named corporate citizenship. The latter has a big impact nowadays because of citizens being involved in social and environmental issues, which causes small as well as big firms to start acting responsibly. The three different drivers are of course not mutually exclusive (De Brito & Dekker, 2004), it might be rather difficult to see what reason caused a company to decide to act more responsible.

De Brito & Dekker (2004) mention that recovery of products is actually only one part of the list of activities that is included in the process of reverse logistics. The first step is collection, which can be done via stores as Apple does for example. When the returned products arrive at the factory, the products need to be investigated and sorted accordingly. Then the recovery process can start, which may include forms of reprocessing, but could also be direct. This is followed by redistributing the recovered parts and materials, either inside the factory or back to manufacturers and suppliers. All these steps need to be thought off when designing the reverse supply chain.

Reuse and recycle

As mentioned before, DfE plays an important role in being able to reuse and recycle (parts of) products, as well as the consumer taking the responsibility to discard the product in the right way when it reaches end-of-life. While sometimes products or materials are ‘recycled’, a lot can be seen as ‘down-cycling’ (Herat, 2007). This means that the product is not going into the waste stream yet, but is used in another product, but that new product will not be recycled and therefore it will in the end still end up as waste. An example of downcycling is the recycling of plastic that is used for the hectometre markers along the roads. While plastic could be recycled again and again normally, that is not possible for those markers and therefore in the end it will end up as waste instead of a material that can be reused. In 2007, it was reported by the Basel Action Network together with the Silicon Valley Toxics Coalition that of all the e-waste collected in the United States about 50 to 80 percent went to developing countries for recycling (Herat, 2007). Especially China is mentioned, where in the region of Guangdong the e-waste is dismantled with bare hands by men, women but also children. Because of the ways they do this, toxic fumes are released and drinking water gets contaminated. In the three pillars of sustainability, the social element is the one that does not get that much attention, while it in this case also influences the environmental pillar again. Therefore not only recycling itself is important but also the way that it is done and even the location.

Next to recycling, reusing is also a possibility. As said before, not the whole headphones can be reused (which would be refurbishing), but certain parts may be eligible for this. While one part may already have reached its end-of-life, another part could possibly be used for two more years. Remanufacturing can have a significant impact on the environmental impact of a product, it can reduce the energy consumption from a factor three to even a factor ten (Herat, 2007). Not only does remanufacturing have an impact on the environment, it also saves costs and therefore is economically interesting. To implement this in a good way, it is necessary to design the products in such a way that remanufacturing is possible, the so called 'design for disassembly'.

Integration of reuse and recycle in the supply chain will be done via reverse logistics (RL). RL is a process in which products at the end-of-life are taken back for remanufacturing, recycling or for disposal (Dowlatshahi, 2010). RL can be cost effective because of the reuse of resources. Because of this, the life cycle of the product is also extended.

It is important to notice that when a product is redesigned, for example by using DfE, also the supply chain may change because of that. This is also the case for Dopple in the new situation, in their new factory the products will be made in a different way and will use different materials. By changing to the new factory not only is there a new location which changes the supply chain, also the way the product is produced will have an important impact. Therefore it is important to keep in mind the fact that this redesign has an influence on the supply chain. Specific materials in the headphones Dopple produces are analysed, regarding the possibilities to recycle them and if they can be made of recycled materials, in Chapter 3.

4.5 Solution approaches

As mentioned in the previous chapters, two approaches for comparing the supply chains are mentioned. For the environmental aspect input-output modelling seems to be the best option, while for the economic aspect both input-output modelling and a cost-benefit analysis might be possibilities. In this Section will be looked into these options and how to use them as well as determining the indicators that can be used for these solution approaches.

Input-Output modelling

Input-Output (IO) modelling was first introduced by Leontief in 1936 (Leontief, 1936). It was used for analysing the interdependence between the different parts of the economic system in the United States (Leontief, 1936). Only years later it was used as a model for sustainability, namely for determining the environmental impact of systems, for example by using the carbon footprint. The book of Miller and Blair regarding input-output analysis develops the framework that was first made by Leontief further, including the extensions that have been made during the years since, for example energy and environmental Input-Output analysis (Miller & Blair, 2009). Since the IO analysis was first designed for analysing economic systems, it is possible to use this method for both the economic as well as the environmental parts of the supply chain in this research.

Wang et al (2020) shows that an IO modelling approach works for measuring the sustainable performance of a global supply chain. Another example of a research regarding sustainable supply chains in which IO modelling is used can be found in the paper of Ukidwe & Baskhi (2005). It includes natural sources, such as ecological goods, human resources and ecosystem services by using the developed 'thermodynamic input-output analysis' (TIOA). It is used to determine the natural and economic throughputs.

Other examples of authors that investigate Input-Output analysis for supply chains are Albino et al (2002) and Yazan et al (2016). Yazan et al (2016) describes reaching Industrial Symbiosis (IS) through IO modelling, Albino et al (2002) shows a model developed for improving the design and management of the supply chains for both a global supply chain as well as a part of it. The model helps for a greater understanding of the relationships that can be found amongst the processes in the supply chain and the environment. That is one of the main goals of an IO model: showing and being able to analyse the flows between sectors, firms and processes. It can also be used within a company, where the production processes within the factory are modelled as the input.

As mentioned before, for reducing waste along the supply chain, IS is an interesting concept. Within IS, companies reduce their waste but mainly reuse waste as a primary resource. What is the waste of one factory, can be the input for another factory, therefore leaving no waste that will go to landfill but reusing everything. In the optimal IS network no primary resources are needed from the outside and at the same time there is no waste discharged outside of the network (Yazan et al, 2016). As can be read in that research paper, an input-output approach is used for that too. This will help determining where waste is left so that solutions, being other companies who can use it as input, can be found and by that making a positive impact on the environment.

The advantage of IO modelling is that it traces all primary inputs, by-products, wastes and the flows of a production unit (Yazan et al, 2016). While this is perfect for trying to reach IS, it is also a good way to analyse these flows, inputs and outputs and the balance between them. Although in IO modelling fixed values are used, in real life these might fluctuate or be influenced by technological improvements (Yazan et al, 2016). Therefore sensitivity analysis can be used for primary inputs and waste coefficients to see what the influences of different values are.

Cost-benefit analysis

Cost-benefit analysis can be used to find the optimal economic situation, one of the pillars of sustainability and important in this research to see if the costs of the new supply chain are lower so that the increase in for example salary costs are balanced. When sharing costs and benefits within the supply chain, it is possible to reduce costs, improve performances and manage risks (Niemsakul et al, 2018). To reach successful collaboration within the supply chain it is important that the costs and benefits are shared by all. Cost-benefit analysis is a helpful tool in determining the value of returned products in RL systems, as well as the costs that come with remanufacturing and recycling the products (Dowlatshahi, 2010). The results can indicate whether it would be the right choice for the company to accept the returned items, or to rejected them. When the recovery of materials has a lower cost than the original cost for manufacturing, it is profitable to remanufacture, as the prices of virgin products are higher than of remanufactured goods while the quality is on the same level (Dowlatshahi, 2010). Improving RL also causes a better working process for returns which could enhance customer satisfaction when repairs are needed and these are done fast because of the smooth logistics around it.

Choices of solution approaches

For the environmental part of this research input-output modelling will be used to determine the impacts. Since the new factory is still conceptual and so will be the supply chain, assumptions will need to be made to compare both supply chains. Also, for the conceptual supply chain different scenarios will be implemented. The book about Input-Output Analysis will be used to determine the exact values (Miller & Blair, 2009) as well as other literature about input-output modelling. For the economic impact, there is looked into cost-benefit analysis and input-output modelling. Both are possibilities, and cost-benefit analysis is referred to as a helpful tool in determining the value of returned products in reverse logistics systems. However, input-output modelling was introduced to measure the economic impacts of a country and therefore is the preferred approach when starting to determine the economic impacts in this research.

4.6 Conclusion

In this chapter is investigated what a sustainable supply chain is and what is important regarding SSCM. Facility location is mentioned too, although not used in this research it can be an important factor for Dopple when new factories at different locations will be opened after the one in Emmen is a success. The same is valid for the factory design in Section 4.3, it is not used for building the model and doing the analysis but it is helpful for Dopple as they are starting the new factory. Also in the previous chapter, the market and competitors of Dopple are thoroughly looked into to find which options there are for recovering products in order to reuse or recycle them. Of course when having all the information, a method is needed to be able to compare the supply chains and its scenarios in this research. In Section 4.4 two different methods are investigated, leading to the choice of using input-output modelling for both the environmental and the economic impacts.

5. SCENARIO ANALYSIS

In this chapter the data that is needed will be gathered and analysed. The gathered data will be used to model the current and conceptual supply chains regarding two sustainability pillars, namely the economic and environmental ones. The conceptual supply chain will already differ a lot from the current supply chain because of the location and the difference in (locations of) suppliers. Some options regarding sustainability are also discussed, these scenarios include recycling and reusing parts. Some research into which parts would be eligible for recycling or reusing, as well as the options to create a reverse supply chain (for example by setting up service points), was done in Chapter 3 and will be touched upon in this chapter.

5.1 Current Supply Chain

The current supply chain is mainly Asia-based. The headphones are produced in Malaysia and suppliers are based in Asian countries such as China and South-Korea. The products are sold in the United States, first being flown to a central warehouse and from there they are transported by trucks to the different states where they eventually end up in stores. The eco-cost model that was provided by Dopple is used to find out where the different parts and materials are sourced from. An overview of the current supply chain is shown in in Figure 4, as introduced in Chapter 2. First the raw materials and parts are sourced from different suppliers in Malaysia, China, Germany and South-Korea. These materials and parts are transported by plane or boat and truck to the factory in Malaysia. There the headphones are produced and packaged, whereafter they are transported by plane to the USA. Planes are used for fast transport, if it is possible to deliver later, a boat may also be used. When the products arrive in Salt Lake City, USA, they are transported by truck to the capitals of every state in the USA first, and then from there on to the stores where they will be sold. Consumers buy the headphones at stores and will discard them at the end-of-use time (which may be the end-of-life stage but not necessarily). In other words: there is no reverse supply chain.

5.2 Conceptual Supply Chain

The supply chain for the new factory in Emmen, the Netherlands, will be very different from the current supply chain. Not only the location of the factory and because of that the suppliers, but also the sales market will change. When looking into the differences between the current and the new situation on the level of the factory, these will some of the changes:

1. Technical parts that are currently delivered separately, will be made inline (instead of offline). This mainly concerns structural parts and not the visual parts on the outside since they are close to the customer.

- Instead of separate injection molded parts that are produced somewhere else, the parts will be made inline by means of 3D printing or injection molding. Some examples are the inner frame, main PCBA spacer and most tapes and foams.
- The resin and liquids required for this will be sourced locally, mainly from Germany, in the new situation. In the current situation these types of materials are sourced locally in Malaysia or Japan in case of specialty items.

2. At this point all metal stamping parts are made in Malaysia but in the new situation these will probably also

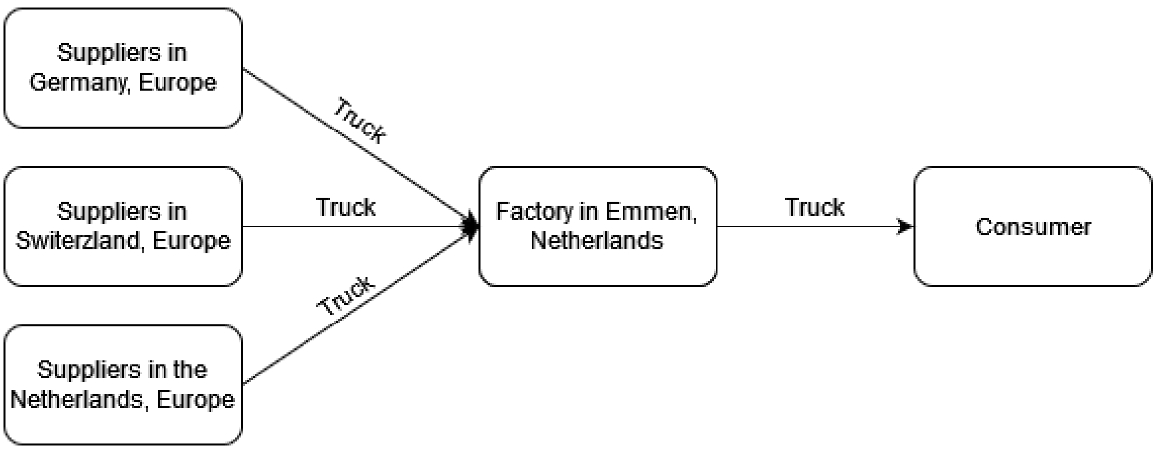

Figure 8: an overview of the conceptual supply chain

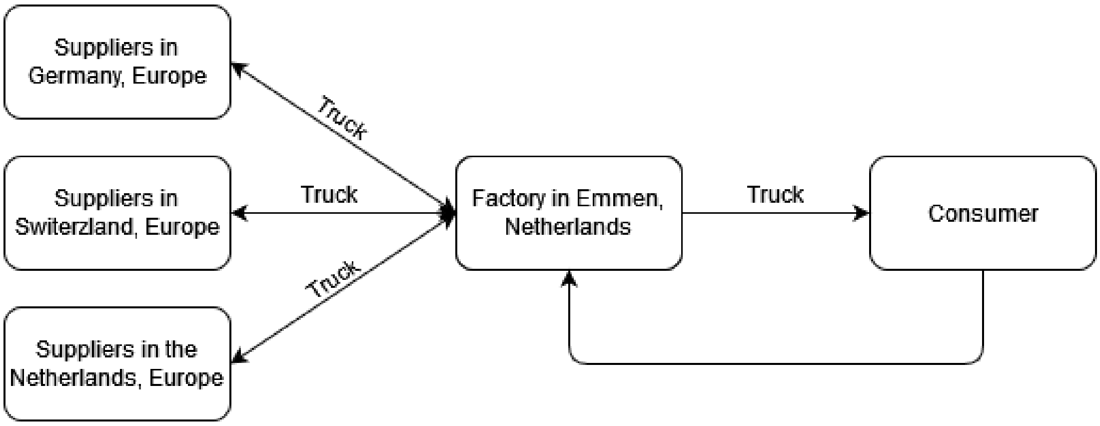

Figure 9: an overview of the conceptual supply chain including reverse logistics

be sourced from Germany. Examples of the metal stamping parts are magnet discs, battery contacts and magnets.

- Currently the PCB's are mainly made in Korea (high-end) and China (lower-end PCB's) and then shipped to Malaysia. In the new situation, PCB's will be made in Switzerland or Austria. This only concerns high-end PCB's.

At first, because of the change in location, the locations of sourcing will change. These will be Europe-based instead of Asia-based. Because of that, planes and boats are no longer needed to transport raw materials, parts or products. Especially since the focus for sales shifts from the USA to the Netherlands, the goal is to produce and sell local. Another difference is that the products will not be send to stores to be sold. After production and packaging is done in the factory in Emmen, products will be send directly to the customer. This too will be done by trucks, via parcel delivery services. An overview of the new supply chain can be seen in Figure 8.

5.3 Scenarios

Next to looking into the current and conceptual supply chain and comparing them, different scenarios could be taken into account. The scenario that is important in this case and that also will show some differences from the current and conceptual situation of the models now (see Figure 4 and Figure 8), is a scenario fo a reverse supply chain (Figure 9). In that case, products are taken back to the factory and materials and components will be sent back for recovery or recycling, also to suppliers. Since Dopple plans to move their factory to the Netherlands either way, and recovery options in the new factory will be an option, the conceptual supply chain is used as the basis of this reverse supply chain. There are multiple options for recovering products, such as reusing and recycling. Since the model that will be used in this research does not include such specific processes and being very broad to take into account here, the focus on what happens with this scenario will not be in the calculations but on the conclusions that can be drawn from the situation.

5.4 Input-output modelling

The method that will be used for the calculations is Input -Output (IO) modelling. This works with first physical values and after that, to compute the economic situation, monetary values. Physical values means that the exact amounts of parts and materials are determined to produce exactly one product. For instance for headphones, that means that a part that is used in the left earbud is also used in the right earbud and therefore of that part the physical value for producing one product is two. When using monetary values, everything is translated to the cost in a certain value, in this case euros. Then the price of the previously mentioned two parts (so the price of two pieces together) is the value that is used in the calculations for producing one part. The calculation of the monetary values is done by the use of the monetary technical coefficient and means that all the equations for the physical flows can now also be used for the monetary flows.

To make clear how the model should be set up, first a flow diagram needs to be made. In this flow diagram it becomes clear what the processes, primary inputs, main outputs but also the waste and by-products are.

The main output of one process is, in this case of a supply chain, the input of the next step. So the inputs for the process of complete production in the factory are the different processes that deliver the parts and materials that are needed for production. Next to this there are primary inputs. Primary inputs are only those inputs that are not provided by one of the production processes that are the other inputs. For example raw materials such as silver or water, but also energy resources such as gas or coal.

Next to the main outputs (such as the parts and the finished products), there are secondary outputs. These are waste and by-products. Waste is what is discarded because it has no economic value, while by-products are having economic value and can be reused or recycled. By the use of matrices and the calculations as determined by Leontief (1936) all the data can be filled in and calculations can be made. The values that come out of these calculations can be compared, to see the differences between the current and the conceptual supply chain. The economic difference will be found by using the monetary values, while the environmental differences will be found based on the physical input-output table by looking at for example CO_2 emissions.

The flowcharts of the current and conceptual supply chains can be found earlier in this report, in figures 4 and 8. These supply chains have been used as the main input to design the flowcharts of the processes within these supply chains, which will be used for the Input-Output model. Parts and raw materials are sourced at various locations, which makes it hard to take into account all these different products into the input-output model, as it would become very large in that case. Therefore, the decision is made to group all the sourced parts and materials. The first suggestion was to divide them into groups based on the location they are sourced, however this would cause a problem when comparing both situations. Products would be in one group in the current situation, and in another in the conceptual situation. Therefore it is chosen that the parts and materials are divided into groups based on the sourcing location in both situations. For example, when a part is sourced in Malaysia in the current situation and will be sourced from Germany in the conceptual situation, it belongs to group A. If it is sourced from China in the current situation and from Germany in the conceptual situation, it belongs to group C. But if a part is sourced from China in the current situation but in the new situation will be delivered from Switzerland, the part belongs to group E. A full overview of the parts and materials that are

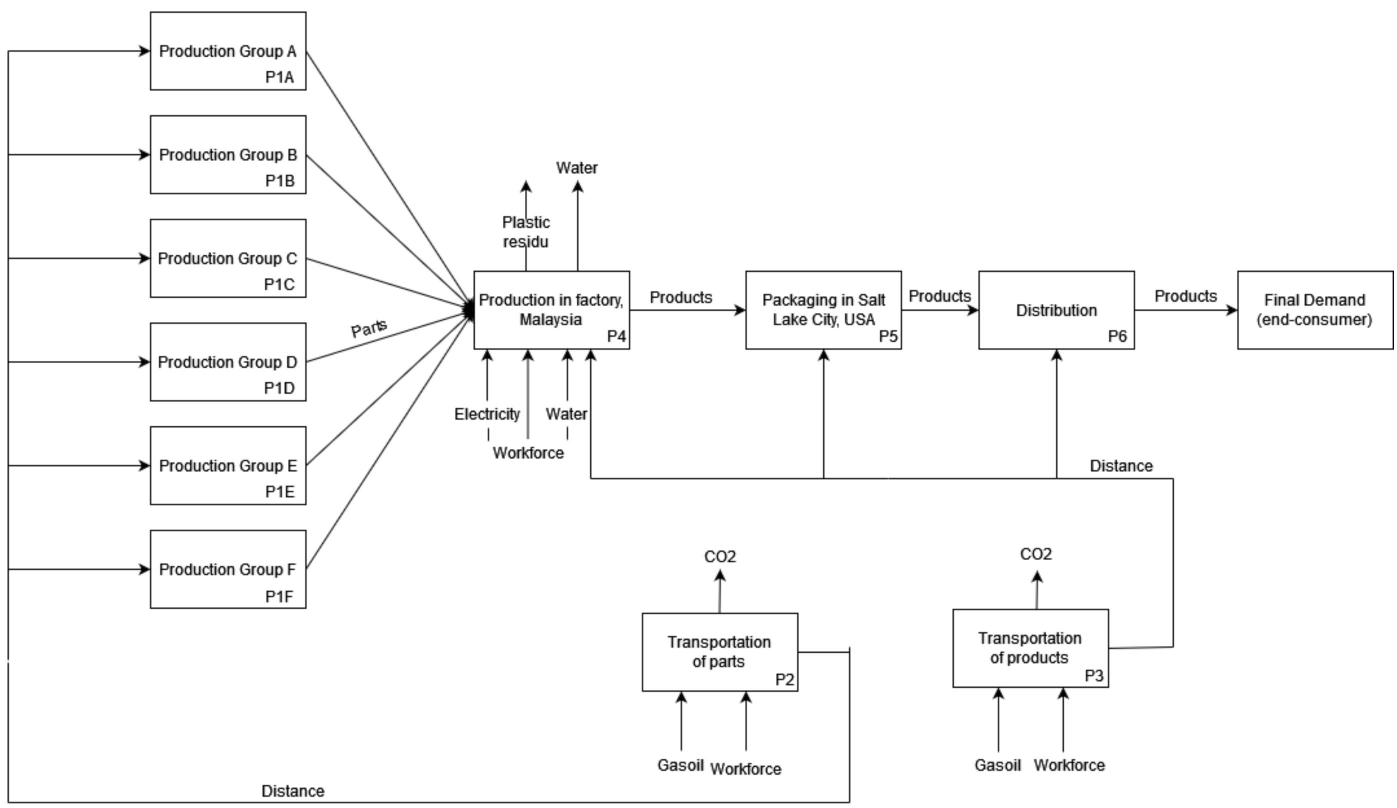

Figure 10: the flowchart of the processes in the current situation

considered for this model and which groups they belong to can be found in the appendix and the Excel-model.
To use the supply chains as shown in figures 4 and 8 for Input-Output modelling, they are redesigned to 'processes'. In this case, because there is no data available from the suppliers for example, it is chosen to use transport and production as the processes that will be investigated. These two processes will change a lot when comparing the current and the new situations, and therefore are the most important to measure environmental and economic impacts.

The overview of the flowchart for the IO model that is set up for the current situation can be found in Figure 10. In the IO model there are seven groups of parts, materials or products considered, which are noted as processes P1A to P1F. Since no information is known about these processes, no primary inputs or waste are considered. After the parts are produced, they need to be transported to the factory in Malaysia. Transportation of parts is therefore considered as an input for processes P1A to P1F and is noted as process P2. For this process, it is known that for example the trucks used for transportation will need gasoil and will emit CO_2. This can be seen in Figure 10 too. The same goes for process P4, which is the production in the factory in Malaysia. Electricity, water and workforce are considered primary inputs, while plastic residue and water are waste products. An input for this process is the transportation of the products that are made (process 3), from the factory to their next destination, Salt Lake City in the USA where definitive packaging is applied. From there the products are transported again until they reach their final destination, being the consumer. The process of transportation (P3) is therefore considered an input for multiple processes. In the input-output model, the distance of transportation for each different process is taken into account, since the processes are put in a matrix table.

Figure 11 shows an overview of the flowchart for the conceptual situation, with the factory based in Emmen, the Netherlands. The processes for the different production and sourcing of parts and raw materials are divided the

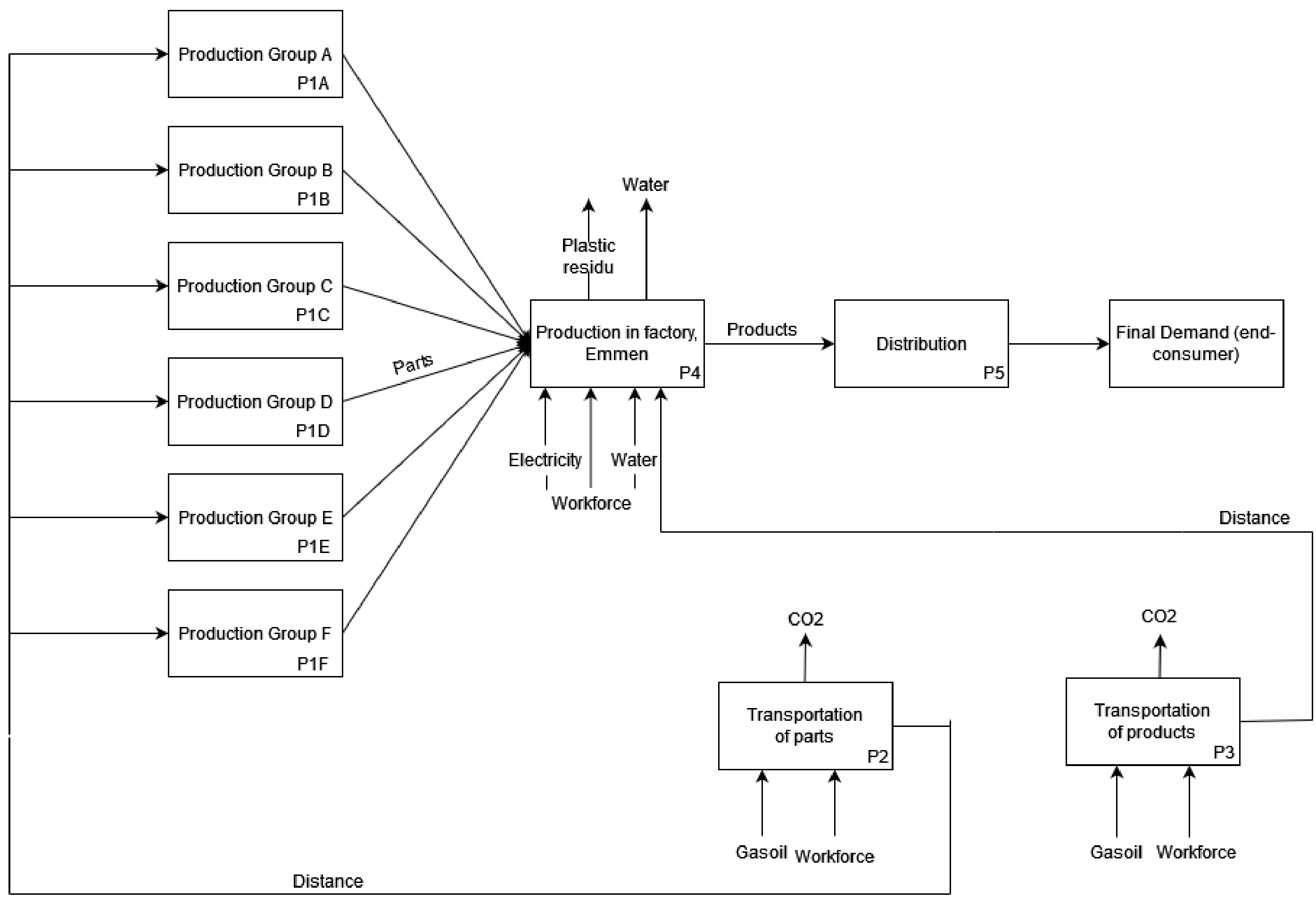

Figure 11: the flowchart of the processes in the new situation

same way as in the current situation, to make comparison of the two situations possible. Process 4 is in this situation the production in the factory in Emmen instead of Malaysia, and finished products are distributed immediately to the consumer instead of going to multiple locations such as distribution centres and stores. Just like in the current situation, there is a process for transportation of parts and a process for the transportation of finished products. The same primary inputs such as electricity and workforce can be found here too, as well as waste products such as plastic residue and CO_2.

Both flowcharts are used to construct the IO model in excel, using three matrices for both situations. The first matrix is used to define the processes, examples of the numbers in this matrix are the distances for transportation and the numbers of parts. There is a major focus on transportation in this research, since that is the factor that causes the biggest differences. This makes sense when looking into the different supply chains in figures 4 and 8 already, when placing the different locations on a map it is immediately clear that the distances have a large impact. The second matrix is used to include the primary inputs, which are gasoil, workforce, electricity and water. The third matrix includes the waste products, in this case plastic residue, water and CO_2 are considered to be important and measurable. In the excel model all the processes are defined and calculated. In the following Section the formulas used will be explained, the Section after that discusses the assumptions and estimates used.

5.5 The IO-Model

The modeling starts with designing the Physical Input-Output Table (PIOT), which has measures in kilometers, number of parts, number of products, hours, kWh, liters et cetera. The matrix for the intermediate flows, which contains the processes, is called Z_0. There are n processes, and therefore the Z matrix is n x n. The total physical flow from process i to process j is denoted by z_{ij}. The final demand vector, which is n x 1, is called f_0 and the elements of the f_0 vector denoting the final demand of process i is f_i. Matrix A is the technical coefficients matrix (also n x n), containing element a_{ij} which denotes the required main output quantity of sector i to produce one unit of main output of sector j. The total outputs can be found in x_0, which is the total output vector (n x 1), in which x_i denotes the total output produced in process i (which is a quantity). While processes can have inputs from all other processes, it cannot have input from itself. Therefore the diagonal of the matrix Z_0, and therefore of matrix A, is zero. The matrix A can be defined as follows:

$$A = Z_0 x_0^{-1}$$

Then x_0 is:

$$x_0 = Ax_0 + f_0 = (I-A)^{-1} f_0$$

There are more inputs than only the processes. These are the primary inputs, s ($k = 1,2,\ldots$), and the by-products and wastes, m ($l = 1,2,\ldots$). Primary inputs matrix R is a s x n matrix which contains elements r_{kj}, in which k is the primary input of process j. By-products and wastes are found in the m x n matrix W, containing element w_{lj}, with l being the by-product of waste type of process j. Considering primary input vector r_0 and by-product and waste vector w_0, with sizes s x 1 and m x 1, results in:

$$r_0 = Rx_0$$
$$w_0 = Wx_0$$

It is assumed that $z_{ii}=0$.

The values that will be in matrixes A, R and W are coming from data obtained via the company, literature research or assumptions.

After including all the data and calculations into the model, called the Physical Input Output Model (PIOT), the data in the matrices are ready to be converted to monetary values for the monetary model. For modeling the monetary input-output table (MIOT), which is based on the PIOT, the values from the matrices are multiplied with their price or costs:

$$x'_j = p_j * x_j$$
$$z'_{ij} = p_i * z_{ij}$$
$$f'_j = p_j * f_j$$
$$a'_{ij} = z'_{ij} / x'_j = (p_i/p_j) * a_{ij}$$

Now the physical flows are valid for the monetary flows too. For the monetary part data about costs are used. Not only costs of the parts and raw materials, but also costs of workforce, gasoil and water for example are included. The result of that is the Monetary Input Output Model, also referred to as MIOT, which will show what the difference in costs is when looking at both situations.

5.6 Assumptions and estimates

The method that will be used for the calculations is Input-Output modelling. This works with first physical values and after that, to compute the economic situation, monetary values. Physical values means that the exact amounts of parts and materials are determined to produce exactly one product. For instance for headphones, that means that a part that is used in the left earbud is also used in the right earbud and therefore of that part the physical value for producing one product is two. When using monetary values, everything is translated to the cost in a certain value, in this case euros. Then the price of the previously mentioned two parts (so the price of two pieces together) is the value that is used in the calculations for producing one part. The calculation of the monetary values is done by the use of the monetary technical coefficient and means that all the equations for the physical flows can now also be used for the monetary flows, as explained in the previous Sections.

5.6.1 Processes and transport

Looking into the current and the conceptual supply chain, it can be seen that the biggest difference will be in the transport processes. Both the total distances that will be travelled as well as the ways of transport will change a lot when looking into the new situation. This can be seen in the overviews of the supply chains in figures 4 and 8.

In the eco-cost model that has been made of the current situation transport is part of the calculations. This means that there is detailed information for transport in the current situation, however this is not the case for the conceptual supply chain. As mentioned in Section 5.2 and what can be seen in figure 8, the suppliers that will be used in the future are based in Europe. Exact locations, and therefore distances are not known yet. It is needed to work with assumptions instead and this means that it will not be as detailed as in the eco-cost model. Since the changes will be large though, it is still possible to to draw conclusions from the differences when seen in the model.

In the physical input-output table (PIOT) of the current situation, the distances for transport are taken from the eco-cost model that was made earlier. The distances differ per sourcing location, but the parts are divided into different groups which can have the same sourcing location in the current situation. For example, the parts in group C are sourced from China in the current situation, but the parts from group E are sourced in China too. The difference for these groups is where they are sourced in the conceptual situation. The distance for multiple groups may therefore be the same. Next to transport by truck, also transport by plane is taken into account in the current situation. In the conceptual situation this is not necessary, since there are no parts or products transported by plane or boat, the distances are much smaller in that case. Especially for the conceptual situation, it is now known where the suppliers will exactly be located. This is why lots of assumptions will be made.

In the eco-cost model that was made for Dopple, the eco-costs are based on the production and sales of 80.000 sets (earbuds and cradle). This means that for example transport is also based on this (a truck does not transport one piece but multiple fit in the truck), however the eco-costs are in the end determined per product (set of two earbuds). For the setup of the IO model of the current situation the ways of transport, distances and how much fits into the truck or plane will be used and will also be the basis for the new situation. Meaning that there will be assumed that the parts and materials do not change much regarding size and that trucks have standard sizes as used in that model.

The distances from supplier to factory, factory to store or end consumer et cetera cannot be determined exactly and will therefore be averaged. The distances used for the current situation will be as determined in the eco-cost model, while for the new situation some assumptions will be made. For example, the goal of Dopple is to sell the products (in the new situation) directly to the customer, which means that after production in the factory they will be send to the customer directly via for example PostNL (a delivery company in the Netherlands). It is impossible to already know where the customers live, therefore a central city in the Netherlands is chosen as average location. For this case it is chosen to be Utrecht. The distance from the centre of Emmen (the location of the factory) to the centre of Utrecht is 165 kilometres by road. Other distances that need to be assumed are the amounts of kilometres from the suppliers to the factory in Emmen. In the case of Switzerland the centre of the country will be chosen. For Switzerland this is Brienz, which is about 900 kilometres to Emmen by road. Other suppliers are from Germany. Germany is a big country that is also next to the Netherlands and therefore just taking the centre of the country might not be a very correct assumption. Multiple companies, for example those that produce adhesive tapes, are located around Keulen and therefore that location will be used as an assumption in this case. The distance between Emmen and Keulen by road is around 250 kilometres.

The number of finished products per year is 80.000, at least in these calculations. The numbers of parts that are needed are based on this number, as can be found in the appendix and the tab 'overview productgroups' in the excel file too. These are the numbers used in the PIOTs. It is important to notice that not all parts are included and also that the same parts and materials are used for the product in both Malaysia as well as Emmen. Because of innovation and using new production techniques that are available in the Netherlands, the design of the earbuds will probably differ from the current design. This is not taken into account here.

5.6.2 Primary inputs

The primary inputs that are considered in this IO model are electricity, gasoil and workforce. The goal was to use water (which is used for cooling) as a primary input too, but because of missing data that is not possible. However, water is used as a by-product, which is explained in Section 5.6.3. For the current situation, the data that was given by Dopple and Salutica (where the production takes part) is used. For example, the electricity usage is based on an average of the usage over three years (2018-2020) of the factory and taking 40% of that (which is what Dopple approximately uses). For the new situation, 10% of that amount is used, based on the assumption that production in Europe needs to be ten times as efficient to be viable. The workforce for 80.000 products is 40.000 hours, which means that to produce one product it takes 0.5 hour. This is based on the fact that 105 operators produce 40.000 products per month. The last primary input, gasoil, is only taken into account for transportation (processes P2 and P3). Although it is very hard to determine an average for the amount of gasoil used by a truck because of circumstances such as driving style, surroundings and weight of the freight. In research done by Huo et al (2012) it is determined that a heavy-duty truck has an average fuel consumption of 24,9 litre per 100 kilometres in China, mentioning that this should reflect the fuel consumption in real-world. This means that a truck uses on average 0.25 litres of gasoil per kilometre, which is multiplied with the distance for each process. Next to transport by truck, there is also transport by plane to be found in the current supply chain. In the new situation transport is only done by truck, so this only considered for the current situation. To determine the environmental impact of transport by air, kerosene is used as a primary input. This is the fuel that is used by planes. A plane is of course not flying with only the products of Dopple, so it is hard to find data that can be used. There was found that on average 4.18 litres of kerosene are used to transport one passenger over a distance of 100 kilometres, so 0,0148 litres of kerosene per kilometre (Lufthansa, 2021). The CO2 emissions that are calculated are based on CO2 emissions in kilograms per 100 passengers, which is 10,52 (kg/100 pkm), therefore 0,1052 kg CO_2 per kilometre is used as the emission value. Transport by air is used for transporting the products from Malaysia to the USA, but also for the parts of group B that go from Germany to Malaysia.

5.6.3 By-products and waste

The third matrix in the model includes the by-products and waste that are produced in the processes. Of course not all information is present, but the three sorts of waste, CO_2, plastic residue and water, will be discussed in this section.

Two types of waste are considered at the current factory, namely schedule waste (chemical, oil, glue, solder paste and e-waste such as PCBA's, electronic parts, wires and batteries) and recycle waste (plastic materials/parts and metal parts). These two bodies are registered under the Government called "Department Of Environment Malaysia (DOE)". When there are faulty products, they will be dismantled and separated into single parts such as plastic, electronic, metal and silicon. The respective license scrap collector (schedule waste) will be appointed to collect the parts and dispose them in the appropriate method. Plastic parts, molding gates and plastic material (resin) will be crushed prior to being handed over. The assembly line disposables such as carton will be collected by the recycle scrap collector (recycle waste) about two to three times a month and will be recycled. Other assembly line disposables such as empty glue cartridges and solder waste will be collected by the licensed scrap collector (schedule waste) and will be disposed in an appropriate manner. In the new factory there will still be waste such as packaging of parts and materials, next to faulty products. Everything that can be recycled will be recycled. However, since not all data is available here and the focus is on major environmental impact, the waste that is taken into account in the model is only the plastic residue. This is waste that shows a really big difference in amount when looking at both situations. The data for plastic residue are based on the weight of the plastic used in the products. In the current situation, 80% of the total weight of plastics used is residue, only 20% will be part of the product. The data of weights comes from the eco-cost model: per product this is 31,365 gram. In the conceptual situation, it is exactly the other way around: 20% of the weight is residue and 80% of all plastic used ends up in the product.

For the calculation of electricity consumption the data from Salutica and Dopple was used, the same is done for the water consumption. Water consumption is not used as a primary input in this case, but it is considered it is a waste product, since it is used for production and then discarded. In the current situation, water is used at multiple places in the process of manufacturing the headphones. New water is used for the spray paint line to wash away the excess paint, although the same water is reused till the end of the lot run. The same is done for molding, the Mold Temperature Controller (MTC) uses water to control the mold temperature during the injection process, this water is reused until the end of the lot run. New water is also used at assembly, after soldering the operators are supposed to wipe the solder tip onto a wet sponge to ensure the soldering tip is clean and no excess solder left on the tip. This water is not reused, only new water is used. The number that is used in the model is based on the data from Salutica and Dopple, again 40% of the total consumption of the factory is assigned to Dopple. The amount is an average over three years (2018-2020). For the conceptual situation, it may be assumed that much less water is used. Therefore, the consumption of the current situation is multiplied with a factor 0.1 to determine the usage for the conceptual situation, just as in the electricity case.

The last indicator that is seen as waste is also what is used a lot to measure environmental impact, namely the emission of carbondioxide (CO_2). To determine this, the distance that is travelled is used to determine the total emission by using standard emission factors. For this research the values that are determined by TNO are used (TNO, 2016). It is assumed that the products are transported by heavy duty trucks over motorways mostly, which have a maximum speed of 80 kph in Europe. For comparison reasons, the same will be assumed for trucks in Asia and the USA.

5.6.4 Monetary model

When all the data for the PIOTs is determined, it is possible to calculate the data for the MIOT too. To convert the PIOT to the MIOT, data about the costs of the processes, primary inputs and by-products and waste are needed. In some cases this is easier than in others. For example, the costs of workforce are straightforward, it is already something that is based on the hours of production. In case of the emission of CO_2 it is harder to determine what exactly are the associated costs. This means that here too some assumptions are made.

Important to notice is that there are some conversions needed because different currencies are used. In the end, because this research is done for the Dutch market and a Dutch company, everything is conversed to Euro's. The currency rate that is used can be found in the excel model, however this is sensitive and may have changed by now.

The costs of energy consumption for example are based on data from the website www.globalpetrolprices.com, which makes it possible to see the different prices per country. The costs of transportation by air are based on data that Dopple has provided, while the price of plastics is an estimate based on available plastics for sale online. The costs of emission of CO_2 are based on research by Wygonik and Goodchild (2011). Prices of gasoil for both Western Europe as Malaysia are researched while calculating, these are prone to changes too. An overview of all data and its costs can be found in the excel model on the tab 'data'. The explanation of all data and its sources can also be found in the appendix of this report.

5.6.5 Conclusion

While the model is complete, some numbers are based on rough assumptions while others are prone to change. However, it is possible to update the model with different costs or numbers easily when changing it in the excel file.

One of the goals is to measure environmental impact, though it is hard to do this precisely when not too much data is available. The focus for environmental impact is on transport, which makes sense because this is a major difference between both situations. But while most of the processes used in the model are transportation processes, there is one other important process which is the production of the product itself. In the model the production process will be seen as a 'black box' with as input the parts and materials needed and as output the finished products. To determine the environmental impact of the factory will be hard to determine, especially for the new factory since this is still a concept and not a real factory. Therefore, this is not taken into account in the model for now.

5.7 Conclusion

While in Chapter 2 the current situation has been reviewed extensively, together with all the ideas for the new situation, the new situation has been explained broader in this chapter. The flow diagrams of both the current as the conceptual supply chain are drawn and used for the Input-Output model. Also the Input-Output model has been discussed in detail, followed by the inputs that are needed. In some cases, primary inputs and by-products and wastes as well as some data for the processes cannot be determined exactly, in those cases assumptions and estimates are made as discussed in Section 5.6. The result of this chapter is the Input-Output model filled with data. The results and comparisons of the models will be discussed in Chapter 6.

6. RESULTS

In this chapter the model and its outcomes will be discussed and interpreted. Some limitations on the results will also be discussed. In the excel-file of the model there is a sheet named 'comparison', which includes a comparison of the values for both the current and the new situation. The values in this chapter are coming from that data-sheet. Also there is a sensitivity analysis (SA) performed, which will be discussed at the end of this chapter, followed by a short conclusion.

6.1 Findings

6.1.1 Environmental performance

The model, calculations and therefore the results can all be found in the excel model. As became already clear in chapter 5, the processes in the current situation PIOT and the new situation PIOT look much alike. This is because the processes themselves do not change that much, parts are still produced and transported to the factory, the factory still produces final products and the final products are delivered to the customer. Although the specific parts and materials used will change probably in the new situation, this is not taken into account because these changes are not known yet. What does change a lot from the current to the new situation, is transport. The processes for transport are measured in kilometres. The transport of parts has a difference of 20.771 kilometres for instance, while the distance for finished products is even larger. The current situation needs much more transport than the new situation. This can also be seen in Figure 12, which is an overview of the compared data. Although both factories source their parts and products from surrounding countries mostly, the distances still differ a lot. Also, some of the materials that are used in the current factory in Malaysia are sourced from Europe, like the glue from Germany. Not all parts and materials are taken into account, but in the current situation there too will probably sourcing from countries in Asia but since this is also the case for the current situation (parts sourced from Malaysia are not all produced or coming from Malaysia, but come in via for example the harbour), these impacts will probably cancel each other out for this model. As can be seen in Figure 12, there is a difference, but the impact for transport of parts and raw materials is not that big in both cases. What does have a big impact, is the transport differences for the final products. In the current situation these are transported by plane from Malaysia to the United States, and transported by trucks around the country and end up at the customer

			PIOT values		
	Processes		**Total value Current Situa**	**l value New Situa**	**Difference**
Process 1A	Production parts of type A	parts	1120000	1120000	0
Process 1B	Production parts of type B	parts	240000	240000	0
Process 1C	Production parts of type C	parts	240000	240000	0
Process 1D	Production parts of type D	parts	160000	160000	0
Process 1E	Production parts of type E	parts	480000	480000	0
Process 1F	Production parts of type F	parts	80000	80000	0
Process 2	Transportation of parts	km	22751	1980	20771
Process 3	Transportation of products	km	40126192	13200000	26926192
Process 4	duction of products in factory, Mala	products	80000	80000	0
Process 5	Packaging in Salt Lake City, USA	products	80000	0	80000
Process 6	Distribution of products	products	80000	80000	0
	Primary Inputs				
r1	electricity		2192800	219280	1973520
r2	gasoil		14000490	3287293	10713197
r3	workforce		40000	4000	36000
r4	kerosene		2184	0	2184
	By-products and wastes				
w1	CO2		36014833	3038785	32976048
w2	plastic residu		20074	5018	15055
w3	water		23659	2366	21293

Figure 12: Overview of the comparison of all the PIOT values

via shops. In the new situation, products will be directly transported to the customer, by truck, and the Netherlands (where Dopple will start with selling the product) is much smaller than the US. The difference in kilometres between both situations is 26.926.192 kilometres, which is of course heavily impacted by the transport from Malaysia to the US. Using a plane for transport is not only expensive, it also has a big impact on the environment. A cheaper alternative that also has less environmental impact is transport by ship, which is used by Dopple when it is possible but since this takes much more time it is only an option if lots of products are in stock in the US beforehand. When comparing the processes in both situations, the new situation clearly has much less environmental impact and is therefore recommended.

The primary inputs in the model consist of electricity, gasoil, workforce and, in the current situation, kerosene. Kerosene is not used in the new situation because materials and final products are not transported by planes in that case, and kerosene is the fuel used by planes. It is hard to determine the right numbers for these inputs, especially for the new situation. Dopple can change the numbers into other values that are more close to the real numbers as soon as they have more plans executed for the new factory. For instance, the use of electricity that is used in the model is for the current situation based on the numbers for the factory in Malaysia (40% of the total, which is an estimate of what Dopple uses), for the new situation 10% of that value is used. The new factory will of course use more machines, which will use more electricity than the current ones, but the factory will be much smaller and more efficient. Also, green energy, for example by using solar panels or wind mills will have an impact.

Gasoil is used for the trucks that transport parts and products. As stated above, there is much more transport going on in the current situation. Therefore the use of gasoil is also much higher in the current situation. The difference in litres gasoil between the current and new situation is 10.713.197 litres, which is what the current situation uses more than the new situation. When looking into workforce, this is also much higher in the current situation. Workforce is only calculated for the production at the factory itself, but of course there is more workforce involved in the whole supply chain, from the production of parts to the transport employees. Those amounts are hard to determine and also not necessary for Dopple (the prices of workforce are included in the prices for parts, materials or transport), so the focus for this primary input is on the workforce for the factory. In the current situation, 105 operators produce 40.000 products in a month. This means that every product takes 0.5 hours. The new situation is more efficient, less operators are needed because more is automated for example. It takes 3 minutes to produce a product. This is of course costing more, which will be discussed in the next Section, regarding the MIOTs. The difference in workforce hours for both situations is 36.000 hours as the current situation needs 40.000 hours and the new situation only needs 4000 hours for producing 80.000 products.

The last of the primary inputs is kerosene. This is only used in the current situation, the total amount of kerosene used is estimated to be 2184 litres in case one plane is used to transport all final products from Malaysia to the US. This is used to determine the impact of the supply chain in waste in the third part of the model, namely the by-products and wastes. These consist, in this model, of CO_2, plastic residue and water. CO_2 emission is based on transport in this model, and because there is more transport and even transport by plane, this is much higher for the current situation. It would be possible to include the CO_2 emissions of the factories too if more data is available in the future. The factory in Malaysia has solar panels, but it is not known how much of the energy used is coming from the solar panels. Also, the data for the new situation depend on estimates. According to Wise Nederland, the emission factor of grey energy is 0,649 kg CO_2 per kWh, based on the electricity used in the current situation this would be 1.423.127 kilos of CO_2 for the factory in Malaysia alone. It has a big impact on the environment and should certainly be taken into account when making decisions about how and where to produce. The difference in kilos CO_2 emitted between the situations is 32.976.048 kilos, in which the current situation is therefore clearly much worse for the environment. It would be possible to lower the impact the electricity has on CO_2 emissions by using only green energy in Malaysia.

The second by-product is plastic residue. Although there is also packaging that consists of plastic and ends up in waste, the plastic residue considered in this case is the plastic that becomes waste because of injection molding. The machines used in Malaysia are older and cause much more residue. 80 percent of the total weight of plastic used ends up as waste, only 20 percent is used in the product. In the new situation this is the other way around. This causes that there is 15.055 kilos more residual plastic waste in the current situation than there will be in the new situation. For water the numbers can be adjusted in the new situation if there is more data available, currently because of expected efficiency it is considered that only ten percent of the amount of water will be used in the new situation compared to the current situation. Water is considered a waste product here because it is used as cooling water during production.

The current situation has a much higher environmental impact, there is much more CO_2 emission, more plastic residue and more water used than there will be in the new situation, even if values were updated with better estimates for the new situation. In the next Section the impact of both supply chain situations on the economic situation will be discussed using the MIOTs.

6.1.2 Economic performance

For the Monetary Input Output Table (MIOT), the data of the PIOT and the price values available are used. It is not everywhere exactly possible to convert the values from the PIOT to a monetary value. Therefore some values are calculated different than others, based on the available data. For example, it is known how much gasoil costs in the Netherlands so the price for transport by truck is based on this value. On the other hand, it is not known how much kerosene costs and it is also a question how relevant this would be for the model. Prices for transporting pallets with products by plane however are known, so that data is used to determine the costs of transporting by plane. Also it is not known how much the different parts and materials cost at new suppliers (except for the parts of group B, which keep the same supplier), which is why it is chosen to use a factor of 1.5 to determine prices for the Netherlands. When more information is known while Dopple is continuing to build their factory in the Netherlands, Dopple can adjust the values accordingly. An overview of the compared results from both MIOTs can be found in Figure 13.

When looking into the MIOT processes in both situations, it is immediately clear that the production is more expensive, which makes sense because production and therefore products are more expensive in western countries. Also transport is much less expensive in the new situation because there simply is less transport and over lower distances. Gasoil may be much cheaper in Asia, but the total amounts of costs are still much higher. The values for the primary input electricity are mostly based on estimates, but the prices are based on the current energy prices in

			MIOT values		
	Processes		**Total value Current Situation**	**Total value New Situation**	**Difference**
Process 1A	Production parts of type A	parts	€ 1.343.990	€ 2.015.986	-€ 671.995
Process 1B	Production parts of type B	parts	€ 1.302.273	€ 4.842.605	-€ 3.540.332
Process 1C	Production parts of type C	parts	€ 1.231.803	€ 1.083.987	€ 147.816
Process 1D	Production parts of type D	parts	€ 253.440	€ 570.240	-€ 316.800
Process 1E	Production parts of type E	parts	€ 16.169.430	€ 12.127.072	€ 4.042.357
Process 1F	Production parts of type F	parts	€ 278.080	€ 834.240	-€ 556.160
Process 2	Transportation of parts	km	€ 5.921	€ 2.673	€ 3.248
Process 3	Transportation of products	km	€ 29.566.518	€ 17.820.000	€ 11.746.518
Process 4	duction of products in factory, Mala	products	€ 3.762.316	€ 6.769.087	-€ 3.006.771
Process 5	Packaging in Salt Lake City, USA	products	€ 278.080	€ 6.769.087	-€ 6.491.007
Process 6	Distribution of products	products	€ 0	€ 0	€ 0
	Primary Inputs				
r1	electricity		€ 177.529	€ 22.367	€ 155.163
r2	gasoil		€ 7.353.837	€ 4.437.846	€ 2.915.992
r3	workforce		€ 123.200	€ 80.000	€ 43.200
r4	kerosene		€ 1.710	€ 0	€ 1.710
	By-products and wastes				
w1	CO2		€ 110.925.687	€ 9.359.458	€ 101.566.228
w2	plastic residu		€ 14.132	€ 3.714	€ 10.418
w3	water		€ 6.896	€ 2.058	€ 4.837

Figure 13: Overview of the comparison of all the MIOT values

both countries and show that, if the factory is indeed 10 times as efficient, not only in production itself but also in electricity usage, the total costs of electricity would be much lower in the new situation. Prices of electricity do not differ too much from each other in Malaysia and the Netherlands, however, prices in the Netherlands are rising currently. The costs of gasoil however, are almost the same in both situations while there is much more transport in the current situation. This is because gasoil is much more expensive in the Netherlands than it is in Asia and the USA. Although this is based on only the prices of gasoil, it can be expected that transport by truck is indeed much cheaper in Asia than it is in Europe because of this. The costs of workforce are interesting. While in Malaysia there are 40.000 hours needed to produce 80.000 products, in the Netherlands this would only be 4.000 hours. Since one workhour costs $3,50 (~€3,08) in Malaysia and one workhour costs €20,- in the Netherlands, the total costs of workforce are higher in Malaysia. While producing 80.000 products in 40.000 hours, costing €3,08 per hour is €123.200, producing the same amount of products in the Netherlands in 4.000 hours, costing €20,- per hour is €80.000.

The costs of emission of CO_2 are estimated to be $3,50 per kg, which is used to determine the total costs of CO_2 emissions. Because there is much more emission in the current situation, which is based on transport but would also be the case when taking into account the factory, it is no surprise that the costs of emissions are much higher in the current situation. The difference is a very large; more than 101 million euros. When researching the prices of plastics needed for injection molding, the prices seemed to be pretty equal in both situations. However, it can be expected that such raw materials are more expensive in Europe. But because the amount of plastic residue needed for the current situation is that much higher, the costs of the not-used plastic is about €10.000 higher for 80.000 products, so even with higher prices the impact on the economic situation will be even or less in the new situation. The same goes for the cooling water used, the prices of water are much higher in the Netherlands, but by being more efficient (in the model 10 times more) the costs are lower in the end.

6.2 Interpretation

The models build for this research are needed to determine the differences between the situation of the current supply chain, for the factory in Malaysia, and the situation for a new supply chain where the factory is in Emmen. For comparison reasons, for example the same parts are used in both situations and estimates for the new situation are based on values of the current situation. The model will be more valuable when more accurate numbers are used, which means that the model should be updated as more data becomes available for Dopple. Out of the PIOT and MIOT, it can be concluded that the environmental impact for the new situation is much lower, while the economic impact will, even when numbers change, not be to big to become a problem. The data in the models cannot be compared exactly one on one, because there are differences in the processes part (for example, packaging is a separate step in the current situation, but not in the new situation). Therefore two tables are made which include the most important values and differences for the environmental impact (Figure 14) and the economic impact (Figure 15). It can immediately be seen that the new situation has a smaller footprint, the differences beteen the two supply chains are large. For example, there is much less transport (26.946.963 kilometres) and because of that there is also much less CO_2 emission in the new situation. But also the consumption of electricity and water is much lower, as well as the usage of plastic. Figure 14 clearly shows that the environmental impact of the new situation is much smaller.

Type	*Current situation*	*New situation*	*Difference*
Transport (km)	40.148.942	13.201.980	26.946.963
Electricity (kWh)	2.192.800	219.280	1.973.520
CO2 (kg)	36.014.833	3.038.785	32.976.048
Plastic (kg)	20.074	5.018	15.055
Water (l)	23.659	2.366	21.293

Figure 14: Overview of the PIOT values for the environmental comparison in both current and new situation

Type	*Current situation (€)*	*New situation (€)*	*Difference (€)*
Products	€ 4.040.396	€ 6.769.087	€ - 2.728.691
Electricity	€ 177.529	€ 22.367	€ 155.163
Gasoil (transport)	€ 7.353.837	€ 4.437.846	€ 2.915.992
Workforce	€ 123.200	€ 80.000	€ 43.200
CO_2	€ 110.925.687	€ 9.359.458	€ 101.566.228
Plastic	€ 14.132	€ 3.714	€ 10.418
Water	€ 6.896	€ 2.058	€ 4.837

Figure 15: Overview of the MIOT values for the economic comparison in both current and new situation

When looking into the economic impact, as shown in Figure 15, it is clear that the production of headphones is more expensive in the Netherlands. Although the exact prices are not known (a factor of 1.5 is used) and also there will be a new design and different materials and parts used in the new situation, it is known that parts and mateirals are more expensive in western countries. However, all the other factors that are taken into account show that these are much less expensive. Since not all costs that Dopple will face are considered and not all data is exact it is not possible to draw a hard conclusion, but the difference in transport costs for example already makes up for the biggest part of the extra costs for the product itselves. The costs of CO_2 are mentioned in Figure 15 and the difference is large, but CO_2 emission is not something that is paid for directly. Therefore it cannot be taken into account in defining the difference in total costs, but when policies change and it will become necessary to pay for emissions, this shows that local production has a big advantage.

6.3 Sensitivity Analysis

Since some of the data used in the models is hard to estimate, sensitivity analysis (SA) is performed to find out what the influences of different values would be on the results. The consumption of electricity and water in the new situation as well as the price of parts and materials when sourcing from Europe are rough estimates and therefore will be discussed here. Currently for electricity and water consumption in the new situation, a percentage of ten percent of the current situation is used. For the prices in the new situation, a factor of 1.5 is multiplied with the prices of the current situation. For both water and electricity consumption and the prices of parts and materials two different values are researched by SA.

6.3.1 Higher costs for parts and materials

In this sensitivity analysis the factor that the prices of the current situation are multiplied with will be 2 instead of 1.5 in the first SA, and 1.1 in the second SA. This means that both a situation in which prices are higher as well as prices are lower is analyzed. The results of these changes can be found in Figure 16 (SA 1) and Figure 17 (SA 2). As seen in Section 6.2 and Figure 15, the cost savings for electricity, gasoil, workforce, plastic and water add up to €3.129.610. Figure 16 shows that the difference in costs when parts and materials are twice as expensive is €4.326.543, which is more than the savings. Not all costs that are made in the whole process of production are taken into account of course, but in the case that parts and materials are

Type	*Current situation (€)*	*New situation (€)*	*Difference (€)*
Products	€ 4.040.396	€ 8.366.939	€ - 4.326.543

Figure 16: Sensitivity Analysis 1: prices of parts and materials multiplied with factor 2 instead of 1.5

Type	*Current situation (€)*	*New situation (€)*	*Difference (€)*
Products	€ 4.040.396	€ 5.490.805	€ - 1.450.408

Figure 17: Sensitivity Analysis 2: prices of parts and materials multiplied with factor 1.1 instead of 1.5

Type	Current situation (€)	New situation (€)	Difference (€)
Electricity	€ 177.529	€ 44.733	€ 132.796
Water	€ 6.896	€ 4.117	€ 2.779

Figure 18: Sensitivity Analysis 3: energy and water consumption are 20 percent instead of 10 percent in the new situation

Type	Current situation (€)	New situation (€)	Difference (€)
Electricity	€ 177.529	€ 111.833	€ 65.696
Water	€ 6.896	€ 10.292	€ - 3.396

Figure 19: Sensitivity Analysis 4: energy and water consumption are 50 percent instead of 10 percent in the new situation

twice as expensive, it may cause Dopple to use a higher sales price for their products to cover the expenses. While parts and materials are only ten percent more expensive in Europe however, the difference is only €1.450.408 which will be compensated by the savings on for example transport costs.

6.3.2 Higher costs for electricity and water

The factor that the costs for electricity and water is multiplied with in the model is 0.1, since it is the goal that the new situation is ten times more efficient. Although this is a goal, it is interesting to see what the results are if this goal is not reached. In the third sensitivity analysis that is done, the factor used is 0.2, while in the last analysis (SA 4) it is 0.5, indicating that the consumption in the new situation is half the consumption in the current situation. The results of these sensitivity analyses can be seen in Figure 18 (SA 3) and Figure 19 (SA 4). When the costs of electricity and water are higher, there are less savings to compensate for the more expensive parts and materials. In the model the most important savings (as shown in Figure 15) add up to €3.129.610, in the case of 20 percent more usage (SA 3) these will be €3.105.185, and in case of 50 percent more (SA 4) it is €3.031.910. These can still cover the expenses for the higher prices of parts and materials.

6.4 Conclusion

In this chapter the results of the Input-Output Model that was build have been discussed. Also sensitivity analysis was performed to see what influence changes to some factors cause. Different scenarios are not implemented in the model since there are currently no possibilities to recycle the product or its parts at Dopple, mainly because of policies, however these will be discussed in Chapter 7, the discussion. The model shows that the environmental impact of the supply chain in the new situation is much lower than it is in the current situation, while the MIOTs show that the economic impact will not be too big considering all options. However, the model is not perfect, estimates are used and it does not take into account the complete supply chain since no data is known or used for, for example, the production of parts that Dopple uses in their products. More about the limitations of this model and the research can be found in Chapter 7, the discussion.

While it would be expected that the new situation would be more expensive because Europe in a whole has higher prices, the new situation only costs more in the case of more expensive raw materials and parts. Transportation is much less expensive, other values depend on efficiency of the new factory but will also be equal or less expensive than in the current situation. Dopple is investigating the possibilities to produce more inhouse, which would cause a change from sourcing raw materials instead of already made parts, which would be cheaper. Next to this, the general opinion of consumers in the Netherlands is shifting to buying local and no longer buying products that are made in Asia. When placing the headphones in the market the right way, with emphasis on local production, consumers are probably willing to pay more so sales prices can be higher, which would make up for the more expensive parts materials used when producing in the Netherlands.

7. DISCUSSION

To improve the model and research in the future and to make sure what influence the assumptions of this research have on the outcome, it is important to discuss the implications and limitations of this research. This chapter will start with some general discussion points, followed by sections about the implications and limitations. Recommendations are given in Section 7.3 and the chapter will end with a conclusion in the last section.

The goal of this research is to find out the impact on both the footprint as well as the economic situation for two supply chains, and to find out what can be done to lower the footprint of the conceptual supply chain. The results indicate that the conceptual supply chain has a much lower footprint than the current supply chain, the amount of transport is much smaller. The reason that the economic impact is important is that although the production is more efficient in a Western country than it is in Malaysia, labour costs are also much higher in Western countries. While it was expected that the overall costs would be much higher in the new situation, the results show that that is not the case. Costs are higher indeed, but not that much. While the environmental impact of the new supply chain is already much smaller, this research shows that there are options to decrease the footprint even more by for example using a reverse supply chain and recycled materials.

Because of globalization, many companies relocated their production to low income countries (CBS, 2013). One of the main reasons for this is the low labour costs. This is also the problem Dopple is dealing with, as mentioned above. This research shows however, that even if costs are higher, it is possible to move production back to Western countries when the production process is efficient enough. Would more companies follow, then this would decrease the footprint immensely and therefore be much better for the environment. It is important to note that when starting a factory in Europe, to have this decrease in environmental impact, sourcing should also take place within Europe. To be able to produce in Europe, the costs of raw materials and parts can be higher than in for example Asia, but not too high (higher than a factor of 1.5 as in this research for instance) to make sure the economic situation is still viable.

The three pillars of sustainability are environmental, economic and social. Environmental and economic impact are discussed in this report, but the social aspect is not taken into account. The circumstances that employees work in, and the salary they receive, are some of the factors that will fall in that category. There are large differences between these situations when comparing Europe to Asia, with the circumstances often being much better in European countries. However, when production will stop in Malaysia, the employees will lose work and therefore income. Also, because of more automation and more efficient production, less employees are needed in the factory in the Netherlands. This aspect is important to take into account in the future.

7.1 Implications

The Input-Output model has been used since 1936, though only in recent years it is also used to measure environmental impact, next to the economic situation. While in most cases one model is set up and different values within the model are changed, in this case two separate models are compared with each other. Although it is needed that the models are similar to each other, such as that they use the same primary inputs and have the same waste and by-products, this research has shown that it is possible to find out which supply chain is more sustainable using IO modelling. In practice, other companies could use the same kind of comparison to find out the implications on both the environmental as the economic situation.

Part of the literature research in this report has been done to find solution approaches for the comparison, another part was dedicated to finding solutions for situations that Dopple faces when relocating and building a new factory in another country. The chapter about benchmarking gives an overview of the sustainability measures electronics companies take within their supply chain and material use. This analysis gives an updated insight, something that currently cannot be found in other literature for this specific market.

Although literature shows that a reverse supply chain in which materials are recycled and reused would decrease the footprint of companies, the possibilities to make this work in practice are limited. Only when policies will change, another step into decreasing environmental damage can be taken. Sustainability is booming, because of the big impact that global warming will have on the planet, the people and our life in general. Governments begin to see the importance of focusing on the environment and therefore new research, new rules and new policies are set up. This means that new research, with new insights, will probably become available all the time. Not only in literature, but also the sustainability reports of competitors of Dopple show this, while sustainability was only a sub item of the yearly reports some years ago, companies now have specific reports about sustainability. It is important to keep up with literature and competitors to be aware of new possibilities in time.

7.2 Limitations

The Input-Output Model used for this thesis is based on the model that was set up in 1936 by Leontief for measuring economic impacts, but has shown to be applicable for environmental evaluations too. However, to use the model to its full extent, much more data would make it more accurate. At first, for the new situation, it is impossible to find exact data, for example because there is no overview of how much electricity the factory will use since the factory has not been built yet. Also, production of parts at suppliers is in this case seen as a black box, not taking into account environmental impacts of those. Other companies in electronics show that they are only working with suppliers that have a certificate of being sustainable enough. This is currently not the case for Dopple, it might be possible that they are working with suppliers whose factories have a large impact on the environment. When doing further research, it would be desirable to take more data into account. Nevertheless, the results of this research are still valid for answering the research questions. The focus of this research was on the differences in the supply chains, which occurred at the factory and at the distances and means of transport. These are thoroughly taken into account.

The calculations of data are based on assumptions or estimates in multiple cases, being it the price of plastics or the amount of green energy used by the factory. Also the values in the MIOT for, for example, transportation are based on the prices of gasoil. This does gave an insight in the costs since they differ a lot per country, but are not the complete costs of transportation of course. Distances are not all exact, partly because not all suppliers are at the same place while being in the same country but also because it is not fully known where parts and materials will be sourced in the new situation exactly. Also, during this research Dopple decided to move from Emmen to Assen and also started researching the possibilities to open the new factory in Assen instead of Emmen. The distances that are calculated for this model are based on Emmen, so especially on short distances there will be a deviation that will have some impact. For example, the average distance of the transport from the factory to the consumer is based on the distance between Emmen and Utrecht, and Assen is more up the north of the Netherlands. Also, for some parts the sourcing location is Malaysia, just as in the eco-cost model that Dopple already had made, but these parts might come from other countries and are only sourced from a warehouse or the harbour of Malaysia. This means that the actual distances and therefore the environmental impact would be even larger than it is already in this model. The same however could be the case for parts sourced from suppliers in Europe, it is possible that those suppliers do source the materials they use from another country, such as China. It is important to consider the suppliers of suppliers too, when choosing for a certain supplier, to keep the environmental impact as low as possible. When Dopple takes this into account at their supplier selection, the differences in environmental impact for both supply chains might even be larger than calculated in the model.

In the current model it is assumed that the materials and parts needed for the product are the same in both situations, implicating that the exact same product will be produced in the new situation. This will not be the case, but the new designs are of course not known yet. To make as much use of local production, the design should also be changed to be for example be easier to repair to extend the life time of the product, or be designed for disassembly so that all parts and materials can be reused. This will take a lot of research, but when the final design differs a lot from the current, the IO model might not be that accurate anymore on all parts. But when policies change, recycling becomes possible inhouse and Dopple produces their headphones mostly from raw materials and are able to recover products on a regular basis and reuse these, the impact of sourcing materials and parts will probably be much lower. Not only would it save costs and therefore have a positive economic impact, cutting out the transport and sourcing from other factories would also be a positive impact on the environment.

The plastic residue that is caused by injection molding will be much less in the Netherlands, which is good for the environment. The plastic itself is taken into account in the model, however the mold that is needed for injection molding is not. These molds are less expensive in Asia, which makes it easier to change something to the design and ‘try again’. In Europe, a mold is much more expensive and therefore once it is made, it costs a lot if something in the design is tweaked. These costs are not taken into account in the monetary part of the IO-model, which would also not be possible because it is unknown how often a new mold would be needed. But it is something that Dopple should consider when starting production in the Netherlands.

While it was discussed whether it would be an option to include the options for a reverse supply chain into the model, this does not seem useful at this point since for example recycling is not yet possible for Dopple. It would be very interesting to see what the environmental impact would be if parts and materials could be recycled and reused immediately for new products. However, at this point in time this would mean that products need to be taken apart at the factory and each raw material or part needs to be send back to their manufacturers, where additional processes would be needed to make sure it can be used again. This is necessary because of policies and the fact that the materials used in products need to have the right certificates, which can only be given by the suppliers or manufacturers and not by Dopple itself. Also, most electronical products are not sent back to its producer but end up in residual waste or even in some forgotten drawer in the home of the consumer. Some electronic products end up at the collection points that can be found in some stores and supermarkets. As long as not enough products are sent back to their producer, it is not efficient to include recycling and reusing in the company's processes. Also it will not be cost-efficient to invest in a machine to take the products apart for recovery. Ways of recovery and suggestions for it are discussed in Chapter 3.

7.3 Recommendations

Future research on this topic should take the options for a reverse supply chain into account as soon as it becomes possible for companies to recycle products and materials inhouse or close to their factories. Including a reverse supply chain is something that Dopple should keep in mind when designing their new supply chain when production in the Netherlands will start. When policies change, they will then be able to jump right in and take the possibilities given. They already have plans to manufacture much more inhouse in the new factory, which would mean that after taking a recovered product apart, it would be possible to reuse parts or materials immediately if policies allow it. Therefore t is important that the design of the headphones is engineered in a way that makes it possible to take the product apart once it comes back. The focus should be on making it possible to easily separate different materials, to ensure they can be sent back to the supplier, or be recycled or reused inhouse. To enable this, it can be interesting to look at the possibilities for an automated process to disassemble (parts of) the products, for example by a similar robot as Apple uses for taking apart parts of returned iPhones.

While currently some parts may be designed to only last two years because of guarantees or because other parts will break down after two years, it may be possible to design and build parts with a much longer lifespan in this new situation. In that case, the longer lasting parts could be taken out of the recovered products and, after testing, just be reused. That would immediately lower waste impact, especially in the case of parts that are harder to recycle. Next to that it is recommended that Dopple looks into the possibilities for using recycled instead of virgin materials in their products in the meantime. It is important that Dopple stays on top of the news about regulations, is already thinking about how the design could be changed in case of recovery, reuse and recycle of their own products. If there are materials or parts that they will not be able to reuse or recycle themselves, it would be good to consider how these materials and parts can be used as input for other factories, ensuring industrial symbiosis within the supply chain too.

Next to being able to reuse and recover parts and materials, another subject that Dopple needs to look into is the recovery itself. Multiple options have been discussed in this report, but more research is needed to determine which method will work best for Dopple and is the most sustainable option. It is possible to let consumers sent the products back to the factory, but another possibility is to recover them from stores where the consumer can take it. For example via the already existing system of the collection of electronic waste. Another option is to collect the old product when a new product is bought, which would work with the subscription service that Dopple is thinking of. Working with a subscription service in which for example every customer gets new headphones delivered every two years is advised. According to Hankammer and Steiner (2015), mass customization with PSS causes large benefits to create relationships with the customer this way. When customers are loyal and use this service, this ensures that at least most of the sold products are returned. However, it those products are not recycled, returning the headphones only creates more transport and therefore more emissions. Also, it might be possible that the headphones are working perfectly fine after two years, but are still replaced because of the subscription agreements, causing more waste then when the customer would have used them until the headphones reached their end-of-life. These points need to be taken into account when Dopple decides on how to include a reverse supply chain.

8. CONCLUSION

In this chapter the conclusion of this research will be discussed. It will start with the research questions and will be followed with implications and recommendations.

8.1 Conclusion

The research done in this thesis is based on the following research question: "*Does the supply chain of the conceptual factory have a lower footprint than the current factory and what is possible to (even more) reduce this footprint, while keeping in mind the economic situation?*". This question is divided into the following research questions regarding supply chain design - the comparison of currently existing supply chain with the new, conceptual supply chain design

- What is the environmental impact of the new supply chain, compared to the old one?
- What is the economic impact of the new supply chain, compared to the currently existing one?

To find an answer on these questions, an Input-Output model has been built for both the current as well as the new supply chain. To determine the impacts on the supply chain, first both supply chains have been researched and drawn. These drawings are used to design the flowcharts of the processes in the supply chain that are needed to set up the Input-Output Models. The models are filled with data coming from the company, literature and estimates and assumptions. The outcomes of these models are compared with each other to find the differences. First the environmental impact has been researched, by building the Physical Input-Output Table (PIOT), containing all the physical processes, inputs and outputs such as transport, electricity and plastic residue. The economic impact is then measured by using the Monetary Input-Output Table (MIOT), in which the values in euro's are considered.

The results of the analysis of the environmental impact of both the current and new supply chain show very clear that the impact on the environment is much less for the new situation, in which the factory is situated in Emmen, the Netherlands. The levels of CO_2 emission, plastic residue and usage of water and electricity are much lower than they currently are for the factory in Malaysia. There is much less transport in the new situation too. The economic impact is determined by using the MIOT, which takes into account price values. Although the models are based partly on estimates, especially for the new situation, it can be seen that the negative impact on the economic situation is not that big. For example, while workforce is much cheaper in Malaysia, with the efficiency that Dopple wants to reach in the Netherlands producing 80.000 products is less expensive. The prices of parts and materials are having the most impact on the economic situation for the new supply chain. By doing more research into designing and producing the products more inhouse, by starting with raw materials instead of already built parts, Dopple could reach lower costs and therefore the impact of moving from Malaysia to the Netherlands will certainly be a good option. Based on these models, especially if Dopple wants to do good for the environment, it would certainly be advised to start producing locally. The difference in footprints of both supply chain is large, the new situation is more sustainable in all facets.

Although the focus in this research is on the differences in economic and environmental impact between the supply chains, sustainability as a whole is one of the goals of Dopple. Also mentioned in the research question, what is possible to (even more) reduce the footprint? Therefore this is included in multiple ways in this research too. One of the goals of Dopple is to produce their headphones from scratch as much as possible, starting with raw materials. Chapter 3 focused on what other companies within the electronics market do regarding sustainability and recovery of their products. All competitors started focusing on sustainability, but also all show that it is hard to recover products and reuse parts and materials. Mostly this is caused by the fact that materials need certificates before they can be used, which only can be given by the suppliers of the raw materials. Dopple already takes into account that a part of the new factory is needed for recovery of their products and will need to include the possibility of recovery in their (reverse) supply chain and processes as soon as that is possible. When possibilities arise for recycling materials because of new policies, they can then immediately jump in. Because of less sourcing of (critical) raw materials, the footprint of the factory and supply chain in the Netherlands would become smaller in that case.

8.2 Theoretical contribution

Although literature shows that Input-Output modelling can be used to measure the environmental impact of a (global) supply chain, in this research it became clear that this works too for comparing two different supply chains. Next to that, the model is used not only for comparing environmental impact, but economic impact too. This approach is different from current findings in literature, and demonstrates not only the sustainability of a supply chain, but specifically the difference between supply chains in different locations in the world. While lots of companies moved their production to low wage countries in the past because of cost reduction, this research shows that local production does not need to be that expensive as long as the production is much more efficient.

Next to the implications for using the Input-Output model, this report provides an insight into the approaches of multiple large electronics companies towards sustainability. While there is more and more focus on sustainability, research on how companies in the electronics industry are working on this subject is not that recent. This research closes the gap between the reviews of electronics companies from years ago and the current status of it. This report shows the similarities and differences between multiple large electronics companies and distilled the most relevant parts. For example the focus on energy savings at both their own facilities as well as their suppliers, taking apart products by a robot and the conclusion that more recycling is only possible when policies change. It shows how these competitors handle the recovery of products and discusses multiple methods that would be possible. Next to this, the literature research of this thesis combines the multiple relevant subjects that have an influence when deciding to open a(nother) production facility by a company and how these should be taken into account regarding sustainability.

8.3 Managerial implications

Dopple started with doing research into opening a factory in the Netherlands already some time ago, and is currently at the point where they will start with some tests. This research shows Dopple what they can expect the impact to be on both the environmental as well as the economic situation and proves to them that the footprint will be much lower when producing and selling their products in the Netherlands. This will be an encouragement for their current research and tests. Next to this, this report provides insight in how to lower the footprint even more, by investigating options for recovering products to make recycling and reusing possible. It advises on options for a reverse supply chain so that Dopple is able to implement all the relevant processes from the beginning of production in the Netherlands right away.

8.4 Recommendations

In Chapter 7, recommendations have already been introduced. A short elaboration will follow in this section. To better understand the implications of these conclusions, further research is needed to determine the full effects of the situation when production takes place in a Western country. Expanding this type of research with more data, for example including information from suppliers and suppliers of suppliers can determine what the impact of for example suppliers will be on especially the environmental situation.

Dopple decided that for their new factory they want to use the so-called LIFE principle, in which everything in the factory is integrated with each other. Because of the need for miniaturization, demand for sustainability and focus on efficiency, future studies into this subject of in-factory integration would be considered very interesting.

Companies handle sustainability issues in different ways and there are not many options for recovery of products currently. It is recommended that future research determines what would be needed to make recovery, reuse and recycling possible for more products, parts and materials. When certain options and information about these possibilities would become available, it could lower the footprint of companies in this sector.

Last but not least it would be interesting to research the amount of extra costs a customer would be willing to pay when products are produced local and sustainable. When a certain price increase is known, it is easier for a company to determine if they are able to move their production from low wage countries to production at the location of selling the products.

8.5 Summary

Summarizing, the comparison of the supply chains show that the environmental impact is much lower for the new factory and that the economic situation will not change too much when producing in the Netherlands. It is currently not really possible to set up a reverse supply chain, it is hard to recover most of the products, taking apart the products into recyclable or reusable parts would take a lot of time and it is, due to policies and certificates, not possible to recycle materials at Dopple itself. However, Dopple should include disassembly options in the design of its products to make sure that as soon as it is possible to recycle themselves, they will be able to do reuse parts and materials. Also recovery of their products should be part of their business plan for the products in the Netherlands, to make sure that once they can start recycling and reusing, the products are there. This would make the supply chain and factory in the Netherlands even better in terms of low environmental impact.

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APPENDIX

A.1 Overview of parts and materials

A part of the parts and materials that are needed to produce the earbuds are listed below. Next to the material the location of the supplier in the current situation and the location of the suppliers in the new situation are indicated.

In the last column the parts group can be found, which is based on the locations of the current and new suppliers. An overview of these groups can also be seen in the table below.

Description	Current location supplier	New location supplier	Parts Group
Plastic parts	Malaysia	Germany	A
Silicone parts	Malaysia	Germany	A
Nylon parts	Malaysia	Germany	A
TPE parts	Germany	Germany	B
PC parts	Malaysia	Germany	A
Glue type 1	Germany	Germany	B
Glue type 2	Malaysia	Germany	A
Glue type 3	Malaysia	Germany	A
Glue type 4	Malaysia	Germany	A
Earpiece battery	China	Germany	C
Cradle battery	China	Germany	C
Speaker	Korea	Germany	D
Earpiece main PCBA	China	Switzerland	E
Earpiece connection flex PCBA	China	Switzerland	E
Cradle PCBA	China	Switzerland	E
Cradle door switch PCBA	China	Switzerland	E
Packaging paper/carton	China	the Netherlands	F

Table A.1: Overview of the parts and the locations of their suppliers

Group	Location of current supplier	Location of new supplier
Group A	Malaysia	Germany
Group B	Germany	Germany
Group C	China	Germany
Group D	Korea	Germany
Group E	China	Switzerland
Group F	Cina	Netherlands

Table A.2: Overview of the groups that the parts are placed in

A.2 Description of (the data in) the model

In this part of the appendix, the data that is used in the IO-model will be discussed, per excel sheet.

Current situation PIOT

Processes

The data for the number of parts is based on the information of the eco-cost model that was provided by Dopple, which can be found in the excel sheet 'overview productgroups'. The number of parts can also be seen in table A.1 on the previous page. The quantity of each part is multiplied with 80.000, which is the number of products made. This number is chosen because it is the same as the number that the eco-cost model is based on, making it easier for Dopple to use the documents next to eachother later on. As can be seen in table A.2, the parts and materials are divided into groups based on the location they are sourced from. The total numbers of parts that can be found in the processes part of the PIOT comes from the number of parts for each group added together. For the other processes that involve products, the number 80.000 is used since that is the number of products produced in this setup.

The other important metric in the processes part of the table is transport, which is measured in kilometers. Transportation takes part by truck or plane, and there is transport for parts and transport for products. Since the parts are divided into groups based on their location, the transport is also based on this. The numbers used to calculate the total amount of kilometers can be found below the table in the excel file. These numbers come from the eco-cost model, parts are transported from for example China, Korea or Germany to Malaysia by plane, and then the last 200 kilometers by truck to the factory in Malaysia. The same goes for the transport of products, these data come from the eco-cost model too. Transport from the factory to the airport by truck is 200 kilometers, and from there the products go by plane to Salt Lake City, USA which is 14054 kilometers. Just as in the eco-cost model, the distance used from Salt Lake City to all 50 states is done by multiplying 50 (all the states) by the average distance to the capital of every state, which is 2239 kilometers. From there on the products will be sold to customers and will be transported on average 500 kilometers within the state, multiplied with 80.000 products. The number of products as seen in the processes-table at the latest processes is 80.000 because of the 80.000 products. In the last column of the table the total production can be seen, for instance the amount of kilometers for parts is 22.751 kilometers, and that there are 80.000 finished products.

Primary inputs

The primary inputs that are considered in this table are electricity, gasoil, workforce and in this case also kerosene for plane transportation. Electricity is only considered for the production in the factory, since there is no data available for the production of parts and materials at suppliers. The amount of electricity used at the factory is based on documents that Dopple supplied, with the total usage of electricity of the factory. 40 percent of the total usage is used for the production of the headphones by Dopple. The number that can be found in the data-sheet of the excel-file is based on the total consumption of the years 2018, 2019 and 2020. The average is calculated and 40 percent of that is the number that can be found in the model.

The amount of liters gasoil used is based on the transport distances and the assumption that 0.35 liter gasoil is used per kilometer. Below the table in the excel file, the calculations for the different productgroups are made (process 2), the total number of gasoil used is the sum of the liters used per productgroup (and therefore distance). The same goes for the liters gasoil used for transportation of the products (process 3), here too the total distances and the assumption of 0.25 liter per kilometer are used to determine the total usage.

The total number of hours used for workforce are based on data provided by Dopple, every product takes 0.5 hour to produce. Therefore to produce 80.000 products, 40.000 hours are needed. The usage of kerosene is based on transport distances, just as the calculations for gasoil. A plane is of course not flying with only the products of Dopple, so it is hard to find a good assumption. There was found that on average 4.18 liters of kerosene are used to transport one passenger over a distance of 100 kilometres, so 0,0148 liters of kerosene per kilometre. This is what is used for determining the total numbers, which can also be found below the table at process 2 and process 3. Although this might not be completely accurate, it will give an insight in the CO_2 emissions, which is what it is used for in the end.

By-products and wastes

The by-products and wastes considered in this table are CO_2, plastic residu and water. Because of data limitations, CO_2 emissions are only calculated for transport, while plastic residu and water are used as indicators for the factories. The emission of CO_2 by a truck is assumed to be 900 grams per kilometer, the CO_2 emissions that are calculated for plane transport are based on CO_2 emissions in kilograms per 100 passengers, which is 10,52 (kg/100 pkm), therefore 0,1052 kg CO_2 per kilometre is used as the emission value. Multiplications of these values with the total number of kilometers and liters result in the values that can be found in the table.

For determining the plastic residue, Dopple provided the data that 80 percent of the total weight of plastic used is residu. It is known that there are 80.000 products produced and the weight of the plastic used per product can be found in the eco-cost model, which is 0,31365 kg. Therefore the residue is 0,8 * (80.000 * 0,41365), as can be seen in the excel model sheet named 'data'.

The usage of water is determined the same way as electricity was determined at the primary inputs, since Dopple provided data for the total water usage of the factory in Malaysia over multiple years. The average over these years (2018, 2019 and 2020) is calculated and 40 percent of that is taken as the total consumption (as indicated by Dopple).

New situation PIOT

Processes

The setup of this table is the same as in the current situation, however there is are five processes instead of six, because products go to the customer immediately after production in the factory, instead of going to different places and stores. Because the design of the headphones has not changed in this case, the number of parts are the same as in the current situation. However, this is something Dopple could easily change if they are deciding on different parts or a new design. The final number of products is the same as in the current situation, namely 80.000.

What does change a lot in the new situation is transport. There is no transport by plane since all parts and materials are sourced from Europe and can be transported by truck. The distances are again calculated for the different productgroups, as can be seen below the PIOT table at process 2. Most of the parts are coming from Germany, however as discussed in Chapter 5 it is not logical to take just the middle of the country, therefore a city for which it is known that multiple suppliers of for example adhesive tapes are located there is chosen, in this case Keulen. The distance between Emmen and Keulen (by road) is about 250 kilometers. In the case of Switzerland the centre of the country will be chosen. For Switzerland this is Brienz, which is about 900 kilometres to Emmen by road. The other distance is from Hoogezand (where packaging is produced) to Emmen, which is about 80 kilometers by road. The other important distance is from the factory in Emmen to the customer. Since it cannot be forecasted where customers will be located, a central city in the Netherlands is chosen as an estimate. Utrecht is about 165 kilometers from the factory in Emmen. Since the 80.000 products are transported one by one to customers, the total distance is 80.000 products multiplied with 165 kilometers.

Primary inputs

The primary inputs that are considered in this table are electricity, gasoil and workforce. Kerosene is not included since there are no transportations by plane in this situation. The consumption of electricity is based on the number of the current situation. Since it is believed that the new factory needs to be at least ten times more efficient, 10 percent of the consumption of the current situation is used. The amount of liters gasoil used is based on transport distances and the assumption that a truck uses 0.35 liters gasoil per kilometer travelled. The workforce is based on data provided by Dopple, in the new situation it takes 3 minutes to produce one product, so for 80.000 products 4.000 hours are needed.

By-products and wastes

The same by-products and wastes are considered in the new situation, just like in the current situation, which are CO_2 emission, plastic residue and water. CO_2 emissions are again calculated based on the assumption of 900 grams CO_2 per kilometer and the total distances. While plastic residue was 80 percent in the current situation, it is now 20 percent. The products are in this case still the same so the weight of plastic is the same, resulting in 5018,4 kg of plastic residue. For the water consumption the same approach is used as for electricity, namely that it would be 10 times more efficient in the new situation and therefore 10 percent of the total water consumption of the current situation is used.

Current situation MIOT

Processes

For the monetary table, prices are needed for all the different inputs of the model. For the costs of the parts and materials, the data sheet 'prices of products' is used. This is based on data provided by Dopple. The prices per productgroup can also be found in this sheet and are used in the MIOT. The monetary values for transportation are based on the costs of gasoil, which are of course different per country. The prices used can be found on the data-sheet in the excel-file, and are converted from dollars to euros. The values are looked up in November-December 2021 and might have changed by now since oil prices are sensitive to changes. If needed, updated prices can be implemented in the MIOT easily by changing the values in the data-sheet. The costs of packaging are determined by using the prices of the packaging out of the 'prices of products'-sheet, multiplied with the total number of products (80.000). The prices of air transport are based on data that was provided by Dopple, as can be seen in the data-sheet.

Primary inputs
The costs of electricity for the current situation are based on the electricity prices in Malaysia, converted to Euros, multiplied with the total electricity consumption. The same goes for gasoil, the total amount of liters gasoil is multiplied with the current prices of gasoil in Malaysia, converted to Euros, as can also be found in the data-sheet. While the prices of gasoil in Malaysia are used for the transport there, prices of gasoil in the USA are of course used for transport there. The prices of workforce are based on data provided by Dopple, one hour of work costs 3.50 dollars. For comparison all prices are again converted to euros. The price of kerosene is based on the average around the world, as can be seen in the data-sheet. Although the costs of kerosene and gasoil are included here, the costs of transport are already included in the processes-part of the table.

By-products and wastes
For the by-products and wastes the prices of CO_2 emission, plastic residue and water are calculated. Based on sources, the costs of CO_2 emission are $3.50 dollar per kilogram CO_2. After converting to euros, this value is multiplied with the kilograms of CO_2 emitted. For the monetary value of plastic residue, the prices of the sort of plastics that are used by Dopple are looked up and found to be around $0.80 per kilogram. The prices of water are found for Malaysia and converted to euros too, to determine the costs of water consumption. All the data can be found in the data-sheet in the excel-file.

New situation MIOT
Processes
For the prices of parts again the table with provided data by Dopple is used, which can be found in the 'prices of products'-sheet. However, there is no data known yet for the prices of the parts and materials when sourced from Europe (except for the materials that are already sourced from Europe in the current situation). Since production in Europe is more expensive, an assumption has been made that parts and materials are 1.5 times more expensive, and based on that the prices of parts and materials are estimated. These can also be found in the 'prices of products'-sheet and can easily be updated in case better estimates are found.
Although data has been found for prices of transport by truck based on the distance in kilometers, the prices of transport will be based on the prices of gasoil in the Netherlands in this table. This is necessary because of the fact that the outcomes of both tables will be compared with eachoter and therefore need to be based on the same type of estimates and assumptions. However, if data is found for (total) prices of transport in Malaysia and the USA, it would be possible to use these and the other data found to update the model. The current monetary values in the new situation MIOT are based on the price of gasoil in the Netherlands.

Primary inputs
The monetary value for electricity is based on the amount of electricity used multiplied with the average current price of electricity for business in the Netherlands, as can be seen in the data-sheet. The prices of gasoil are based on the prices of gasoil in the Netherlands, just as in the processes-part of the table. For workforce costs, data provided by Dopple are used. The cost of one workforce hour is 20 euros, and it takes 4.000 hours to produce 80.000 products. Therefore the total costs of workforce are 20 * 4.000 = €80.000.

By-products and wastes
Just as in the MIOT of the current situation, CO_2 emission is calculated by the value of $3.50 per kilogram as found in a scientific source. This is calculated based on the amount of CO_2 emitted as found in the PIOT, which can also be seen below the MIOT table at processes 2 and 3, since it is calculated for transport only. The price of plastic residue is based on the price of similar plastics as Dopple uses, found at a supplier in Europe. This is multiplied with the amount of plastic residue as determined in the PIOT table. For the costs of water, the price of water per liter in the Netherlands is used as can be found in the data-sheet, which is multiplied with the amount of water consumed.

Comparison
In this sheet of the excel-file, the outcomes of both the PIOTs as the MIOTs are compared for both situations. The processes are not completely the same in both situations, so it is important to not compare the values exactly, but it is used for indications. The differences for both processes, primary inputs and by-products and wastes can be found

in this sheet.

Overview productgroups
In this sheet an overview of the parts and materials can be found, with a description of the part, their quantity and the locations of their suppliers in both the current as well as the new situation. Based on the locations of the suppliers, the parts are divided into product groups (A-F), which can be seen in this sheet. Also the data needed for the PIOTs regarding the total number of parts and materials in a productgroup can be found here.

Prices of products
This sheet contains the different parts per group, with their price at the current supplier. For comparison reasons, these prices are converted to euros (with the conversion number that is on this sheet too). Prices at the new supplier are calculated by multiplying the current prices with 1.5 (except for the parts that will be sourced from the same supplier in the new situation). The total prices that are calculated in this sheet are used in the processes parts of the MIOTs for the total product prices.

Data
The data-sheet contains data that is used in all parts of the model, from energy consumption and the prices of electricity in Malaysia to the workforce hours and prices of gasoil. Sources are included in this sheet in the notes of different cells. At the end of the table there is an overview of costs for transportation by truck, data from the United Kingdom, that could be used as an example for improving the monetary parts of the model.

Sensitivity Analysis
The sheets SA 1, SA 2, SA 3 and SA 4 contain the results of the sensitivity analysis that was performed. The explanation for this can be found in the report, including the used factors for these SA's.

Sources
Most of the data used in the model comes from Dopple. Next to that, there are estimates and assumptions made. In case of the distances for transportation, Google Maps is used to determine the distance between the locations as noted in chapter 5. For the data that comes from other, multiple resources, these will be noted below. These resources were consulted in November 2021.

Costs of electricity in Malaysia:
https://www.globalpetrolprices.com/Malaysia/electricity_prices/

Cost of plastics in Malaysia, example:
https://www.alibaba.com/product-detail/PC-ABS-Plastic-Plastic-Raw-Materials_62495163085.html?spm=a2700.pc_countrysearch.main07.17.514a695duOH0gl

Cost of water in Malaysia:
https://www.nst.com.my/news/nation/2020/02/562532/higher-water-tariff-necessary-upgrade-infrastructure

Costs of electricity in the Netherlands:
https://www.globalpetrolprices.com/Netherlands/for business

Cost of plastics in Europe, example:
https://plasticker.de/preise/pms_en.php?kat=Mahlgut&aog=A&show=ok&make=ok

Cost of water in the Netherlands:
https://www.waternet.nl/service-en-contact/drinkwater/kosten/

Emission of CO_2 by trucks:
https://ecoscore.be/en/info/ecoscore/co2

Price of CO_2 emissions:
https://www.sciencedirect.com/science/article/pii/S0386111211000136

Kerosene consumption and CO_2 emission planes:
https://www.lufthansagroup.com/en/responsibility/climate-environment/fuel-consumption-and-emissions.html

Price of kerosene:
https://www.globalpetrolprices.com/kerosene_prices/

The currency rates used in the model are from December 2021, the following numbers are used:
Conversion USD to EUR: 1 : 0,88
Conversion MYR to USD: 1 : 0,24