University of Natural Ressources and Life Sciences
Department of Water, Atmosphere and Environment
Waste Management Institute

Secondary Raw Material Markets & Recycling Technologies in Low- and Middle-Income Countries

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submitted by
Felicitas Hammerschmied
Stud Kennz.: 427/ Matr. Nr.: h0740116

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Statutory declaration

I hereby declare that I am the sole author of this work. No assistance other than that which is permitted has been used. Ideas and quotes taken directly or indirectly from other sources are identified as such. This written work has not yet been submitted in any part.

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Abstract

Transboundary movements of wastes between developed and developing countries have highly increased over the past 30 years. The goal of this thesis is to examine the main reasons for transboundary movements of secondary raw materials and their further usage in the industry. Based on a literature research the thesis goes into detail regarding the following markets: steel scrap, aluminium and alloy scrap, e-waste, waste paper and plastic scrap. Each of the five secondary raw material markets include the global primary material production, globally traded secondary raw material volume as well as global secondary raw material use to give a structured overview. The biggest importers and exporters of the selected material streams are described and the economic rationale behind the biggest imports are further analyzed. In addition to the material massflows, the recycling technology of each material is described to better understand the use of the secondary raw material. Country analyses for the material streams go into detail in terms of mass flows, describe trends and give an outlook on future import demand. Economic advantages for developed and developing countries have been identified as main drivers for the transboundary trade. Those advantages are profits being made by selling the material, but also avoided compliance costs for the developed countries on the one hand and the cheap purchase of resources respectively secondary raw material for the industrial production of the developing and emerging countries on the other hand. Another goal is to depict recycling methods in developing and emerging countries by giving several examples of low-tech recycling practices for the selected material streams to examine differences between developing and developed countries. Derived from the combined perspective of the global main recipients of secondary resources and their recycling methods, the role of environmental protection and occupational health and safety in the respective countries has been analyzed up to now. In the course of the research on global secondary raw material markets the Chinese import ban came into effect. Due to its major impact on the global waste industry it is discussed in this work. This thesis gives an overview on the global secondary raw material flows and the dependencies between developed and developing countries.

Keywords

secondary raw material markets, waste imports, waste exports, transboundary waste trade

Kurzfassung

Innerhalb der vergangenen 30 Jahre kam es zu einem starken Anstieg der grenzüberschreitenden Abfallverbringung zwischen Industrie- und Entwicklungsländern. Diese Masterarbeit beschäftigt sich mit den Hintergründen für diese grenzüberschreitenden Bewegungen, sowie mit dem Einsatz des Sekundärmaterials in der Industrie. Basierend auf einer Literaturrecherche behandelt diese These folgende Materialströme: Stahlschrott, Aluminiumschrott, Elektroaltgeräte, Altpapier und Kunststoffabfälle. Um einen strukturierten Überblick zu bieten wird für jeden dieser fünf Materialströme die globale Primärmaterialproduktion, die global gehandelte Menge des Sekundärmaterials sowie die weltweit eingesetzte Menge des Sekundärmaterials dargestellt. Die größten Importeure und Exporteure der gewählten Materialströme werden dargestellt und die Bewegründe hinter den größten Importen analysiert. Zusätzlich zum Überblick der Materialflüsse werden die Verwertungstechnologien beschrieben, um den Einsatz der Sekundärmaterialien verstehen zu können. In Länderanalysen zu den Materialströmen wird detailliert auf Materialflüsse eingegangen und Trends sowie die zukünftige Importnachfrage nach Sekundärmaterial beschrieben. Als Haupttreiber für die grenzüberschreitenden Abfallverbringungen konnten ökonomische Vorteile, sowohl für die Industrie -, als auch für die Entwicklungsländer festgestellt werden. Für die Industrieländer sind dies vermiedene Kosten für die Sortierung und das Recycling der Abfälle. Für die Entwicklungs- und Schwellenländer sind diese Vorteile die günstige Rohstoff- bzw. Sekundärmaterialbeschaffung für deren insustrielle Produktion. Ein weiteres Ziel ist die Beschreibung von Recyclingmethoden in Entwicklungs- und Schwellenländern, um die Unterschiede der Methoden zu Industrieländern aufzuzeigen. Aus der kombinierten Betrachtungsweise der Hauptempfängerländer von Sekundärmaterial und den dort angewendeten Recyclingmethoden wird abgeleitet, welchen Stellenwert Umwelt- und Arbeitnehmerschutz in den Empfängerländern bisher hatten. Aufgrund des Inkrafttretens der chinesischen Importregulierung und ihrer maßgeblichen globalen Auswirkungen während der Erstellung dieser Arbeit wurde sie in der These inkludiert und ihre Auswirkung auf die globale Abfallwirtschaft miteinbezogen. Diese Masterarbeit gibt einen Überblick über den globalen Sekundärmaterialmarkt und stellt die Zusammenhänge und Abhängigkeiten zwischen Industrie- und Entwicklungsländern dar.

Schlüsselwörter

Altstoffmärkte, Abfallimporte, Abfallexporte, grenzüberschreitende Abfallverbringung

Table of Contents

List of Figures

List of Tables

List of Abbreviations

BFRs	Brominated Flame Retardants
BOF	Basic Oxygen Furnace
EAF	Electric Arc Furnace
EEE	Electrical and electronic equipment
ELV	End-of-Life Vehicle
EU	European Union
GFO	Green Fence Operation
Gt	Giga tons
kg	Kilogram
Kt	Kilo tons
Mt	Million tons
NAFTA	North American Free Trade Agreement
PCBs	Printed Circuit Boards
PCR	Post consumer resin
PET	Polyethylenterephthalat
PP	Polypropylene
PRC	People’s Republic of China
UEEE	Used electrical and electronic equipment
UK	United Kingdom
USA	United States of America
WEEE	Waste electrical and electronic equipment
wt.	Weight

1. Introduction

In the last decades it became clear that waste is an important global issue. If not managed properly it leads to the contamination of our environment, human health endangerments and resource scarcity. The more a society produces and consumes, the more waste will be generated. The so-called developing and emerging countries are of special interest concerning the waste management issue, because of their future growth prediction. Notably the solid waste management of urban areas is of high importance. The cost for not dealing with waste now and instead of it in the future, is estimated to be 5 to 10 times higher than dealing with this matter now in an environmentally sound way (United Nations Environment Programme, 2015). Hoornweg and Bhada-Tata (2012) point out that waste generation rates will more than double until around 2030 in lower income countries. Consequently, thereof the costs for solid waste management will increase more than 5-fold in low-income countries and more than 4-fold in lower-middle income countries (Hoornweg and Bhada-Tata, 2012). The knowledge about the impact and costs of rising waste volumes make clear how relevant the careful and sustainable use of resources is in the first place.

For economic reasons, around 1% of the urban population in low- and middle-income countries works in the informal collection and recycling sector (Medina, 2008; Velis et al., 2012). It is estimated that there are about 6-12 million waste pickers in China, India and Brazil (Linzner et al., 2013). The contribution of waste pickers to the system is often unrecognized. Instead, waste pickers are seen as the least worthy individuals in the societal hierarchy. But the opposite is the case. Through their contribution, cities save expenses regarding collection, transport and disposal costs, as well as their work leads to a reduction of the need for landfill spaces. Informal recyclers reprocess waste into secondary raw materials (Agamuthu, 2010; Medina, 2008; Velis et al., 2012). Recycling rates of 20-30% are achieved by the informal recycling sector in low-income countries (Velis et al., 2012). On the contrary the formal recycling sector cannot compete with those rates. Based on the studies of Scheinberg et al. (2010) the informal sector achieves recycling rates without any subsidies from the government as high as recycling rates in developed high-income countries. As well as many more tons of recovered materials come into the value chain via the informal recycling sector in the cities than through the formal recycling sector (Scheinberg et al., 2010). For the informal workers themselves there are a lot of negative aspects going hand in hand with their job. The process of collection and recovery can lead to uncontrolled pollution of human health and the environment. This means that there is an occupational and public health safety risk. Moreover, child labor is very common in this sector (Velis et al., 2012).

Transboundary movements of wastes from developed to developing countries increased strongly over the past decades (Sawhney and Majumder, 2015). This means more and more waste has been and will be processed in developing and emerging countries under poor conditions regarding environmental and human health impacts, because of the prevalently low-tech recycling methods. Recycling with mainly negative environmental consequences seems purposeless out of an environmental perspective. This leads to the following research questions.

1.1 Research questions & research goal

The two main questions are:

- Is there high demand of low- and middle-income countries for secondary raw materials?
- Why are recycling processes in developing countries different to processes in developed countries?

The goal of this thesis is to give an overview on the global secondary raw material market and to analyze the biggest importers and exporters of the significant globally traded secondary raw material streams to support a better understanding of the coherences and reasons of global secondary raw material flows and the dependencies between developed and developing countries.

The drivers behind the imports and exports of the major players of the secondary raw material market will be analyzed and described. Moreover, this work will explore the usage of the recovered secondary raw materials and will give a short outlook on the future development of the biggest importing countries of each material market.

Examples of recycling processes in low and middle-income countries in Asia, Africa and South America highlight the differences between developing and developed countries.

2. Materials & Methods

2.1 Methodology

The method of this thesis is based on a literature research. Scientific journals, industry reports, political strategy papers as well as global outlooks and online sources served as literature to describe global secondary raw material markets and recycling processes in low and middle-income countries.

In this thesis the author describes five material streams, which were selected based on the fact that increasingly higher volumes of those material streams were traded internationally over the past years.

For each material stream the global production of the primary material, the globally used scrap volume, the globally traded scrap volume as well as the biggest importers and exporters were researched. To support the better understanding of the use of the secondary raw materials the fundamentals of the recycling technologies for each material stream is described thereafter. The author conducts a detailed analysis for each material stream for selected countries based on their production capacities and the import volumes. Each detailed country analysis includes data about the primary production capacity, the domestic secondary raw material use, and the imported- as well as the domestically collected- volumes of the material stream. Resulting from the analyzed market situation of the country an outlook on the future trends regarding the secondary raw material demand is given.

Subsequently a description of recycling processes in low and middle-income countries based on case studies of scientific journals, on-site reports and a video documentation is conducted.

The examples of the recycling processes are chosen based on the described material streams and the analyzed countries.

2.2 Definitions

Demand: Demand in this thesis is understood as the decision and striving of the economic subject to purchase goods or services (Gabler Wirtschaftslexikon, 2018).

E-waste: E-waste denotes waste electrical and electronic equipment (WEEE). There is a vast number of different WEEE. The range reaches from toothbrushes via play stations to freezers. For example, an electric shaver counts as electrical equipment whereas a mobile phone counts as electronic equipment because of its data-processing properties (United Nations Environment Programme, 2015). Electrical equipment is usually divided into six categories: 1) temperature exchange equipment, 2) Screens, monitors, and equipment containing screens having a surface greater than 100 cm, 3) lamps, 4) Large equipment (any external dimension more than 50 cm), 5) Small equipment (no external dimension more than 50 cm) and 6) Small IT and telecommunication equipment (no external dimension more than 50 cm) (EWRN, 2017).

Informal Sector: “A population group undertaking economic activities that are – in law or in practice – not covered or insufficiently covered by formal arrangements. Their activities are not included in the law, which means that they are operating outside the formal reach of the law” (ILO, 2002 cited by Ramusch, 2015, p.1).

Secondary raw materials: „are waste materials collected for recycling and recycled materials that can be used in manufacturing processes instead of or alongside virgin raw materials (Eurostat, 2014).“

3. Demand for secondary raw material in developing and emerging countries

In the last decades the rapid industrialization of emerging countries as well as the continuous high material consumption of developing countries led to an unprecedented growth in demands for raw materials worldwide. International commodity markets expanded, as well as international trade flows. Furthermore, there was an increase concerning mobility and fragmentation of production processes. This was accompanied by a surge in and the volatility of commodity prices. Additionally, there has been a development of growing competition for selected raw materials.

The OECD (2012) reports that an estimated fifth of the raw materials extracted or more specifically 12 billion tons (Gt) worldwide end up as waste per year. If valuable materials are disposed of as waste, and not recovered, their value is lost for the economy.

On the one hand recycling rates are increasing for materials such as glass, aluminum, steel, paper and plastics. But on the other hand, recycling rates remain low for many other high value materials such as precious or specialty metals.

Secondary raw material markets have expanded but are contending with volatile prices.

Tighter environmental laws combined with still rising waste volumes in industrialized countries have led to the replacement of the traditional method of waste disposal in its area of origin. Instead, the shipping of wastes from developed to developing countries became the solution for developed countries to save costs and even gain profits. Consequently, transboundary movements between developed and developing countries have increased strongly over the past years. 586Mt of waste were imported by developing countries in 2012. This makes a five-fold increase of waste imports by developing countries between 1996 and 2012. Some of the major recipients of the generated wastes are China, India, Pakistan, Indonesia, Malaysia, Nigeria and Ghana. The main purpose for the export of waste from developed to developing countries is recycling. Reprocessing and recycling processes are labor-intensive, therefore developing countries have an economic or rather comparative advantage, because of low labour cost (Sawhney and Majumder, 2015).

3.1 Global secondary raw material flows and markets

Secondary commodities are closely connected to primary commodity markets and to manufactured goods (Chalmin, 2010). Primary materials can be displaced through the use of recycled materials. That reduces the need for the extraction of virgin material resources and with that negative environmental impacts like greenhouse gas emissions by prevention of resource extraction and processing.

The United Nations Environment Program reports that the globally traded secondary raw materials are foremost ferrous and non-ferrous metals, paper and board, plastics and textiles. Whereas glass or wood waste is traded nationally and regionally. Materials like compost as a soil conditioner or aggregates from construction and demolition wastes are traded relatively local. An economic and environmental benefit through separation and collection of recyclables can only be made if these recyclables are used as secondary raw materials in the industry. So therefore, the usage of secondary raw materials industry as marketplace for recyclables is the basis for the waste industry.

Asia represents the most important global recycling market (United Nations Environment Programme, 2015).

3.2 The steel scrap market

3.2.1 Mass flows

Global crude steel production (non-alloyed and alloyed steel) in 2016 accounted for 1630Mt. Since the year 2000 the annually produced amount of steel has doubled. In the 1960's mostly Europe, North America and the former U.S.S.R. shared the crude steel market with market shares between 20 to 30% each. This picture changed completely during the last decades. Today China alone accounts for 49.6% of the global crude steel production (World Steel Association, 2017).

Worldwide steel scrap use for steelmaking in 2016 yielded 560Mt, which totaled 34.36%. Global trade in steel scrap was around 89Mt (Lee and Sohn, 2015). Table 1 gives an overview on the global crude steel production, global steel scrap use and global steel scrap trade in 2016.

Table 1: Global steel production, global steel scrap use and global steel scrap trade in 2016

MASS FLOWS	Mt	year	source
Global production	**1630**	2016	World Steel Association, 2017
Steel scrap use (global)	**560**	2016	Lee and Sohn, 2015
Steel scrap trade (global)	**89**	2016	Lee and Sohn, 2015

Steel scrap can be subdivided by the following different sources:

- '**Post-consumer scrap**', which is collected after the end of life of a product which contains steel.
- '**Prompt scrap**, **industrial scrap** or **new scrap**', which is purchased by mills from industrial users (e.g. production off-cuts).
- '**Home scrap'**, own arisings, which are directly recycled within a steel mill.

Steel scrap use peaked in 2014 with 585Mt. In 2015 it decreased down to 555Mt (Bureau of International Recycling, 2017).

Since 2000 steel production increased by 4.3% per year, however scrap utilization growth averaged around 3.1%. The reason for the slower growth of the steel scrap utilization rate lies to a large extent in the fact that China occupied the leading position in the steelmaking sector and has a low steel scrap utilization, which will be explained further in the following (Vercammen et al., 2017).

Table 2 shows world's major producers of crude steel by country in 2016. China's share of nearly 50% amounts to 808.4Mt of crude steel. Right behind China follows Japan with a share of 104.8Mt. India was world's third biggest crude steel producer with 95.6Mt in 2016.

Table 2: World's major producers of crude steel by country in 2016 in Mt (World Steel Association, 2017)

World's major producers of crude steel by country in 2016	**Mt**
China	808.4
Japan	104.8
India	95.6
USA	78.5
Russia	70.8
South Korea	68.6
Germany	42.1
Turkey	33.2
Brazil	31.3
Ukraine	24.2
Italy	23.4
Taiwan	21.8
Mexico	18.8
Iran	17.9
France	14.4
Others (countries with a production <14.4Mt per country)	175.8
Sum	**1629.6**

Asia dominates the steel market by far with a 69.1% share of crude steel production, which equals 1126.33Mt in 2016. If Asia and the rest of the world is contrasted in regard of steel production, Asia produces more than twice as much crude steel as the rest of the world altogether (World Steel Association, 2017).

World’s major importers by country and region are represented in Table 3. The major importing country was Turkey with 17.7Mt. India was not only third biggest steel producing country, but it was also second biggest importer of steel scrap. China and the EU imported nearly the same amount of steel scrap, whereas China produced nearly five-times as much crude steel than the EU. As can be seen in Table 3 the United States of America (USA) imports steel scrap although there is an abundance of domestic scrap. Low freight costs are the explanation for this strategy. The USA imported mostly scrap from Canada and Mexico. The scrap imported from Canada supplies steel mills in the Northeast and Midwest of the USA and the Mexican steel scrap supplies EAF mills in the South of the USA (Lee and Sohn, 2015).

Table 3: World's major importers of steel scrap in 2016 (Bureau of International Recycling, 2017; World Steel Association, 2017)

World's major importers of steel scrap in 2016	**Mt**
Turkey	17.7
India	6.4
Korea Republic	5.8
USA	3.9
Taiwan	3.2
EU	2.8
China	2.2
Mexico	1.9
Canada	1.8
Others (countries with imports <1.8Mt per country)	40.6
Sum	**86.3**

Table 4 displays world’s major exporters of steel scrap in 2016. The EU countries together are forming the biggest steel scrap exporter globally.

This is because the EU produces 60% of its steel by using basic oxygen furnaces, where only a small share of steel scrap is used in the process contrary to steel production with electric arc furnaces, where a major share of steel scrap is used for steel production (Hodecek, 2019; EUROFER, 2018). In the following the technology, as well as the steel scrap usage ratios will be described further. Another essential reason for the EU’s export surplus is its historically well-developed collection schemes in terms of metal scraps, which lead to a high occurrence of steel scrap in the EU. Additionally, new markets have evolved in the EU through the dismantling of industrial plants, stadiums, bridges etc. (Hodecek, 2019). Parallel to the increase of the steel scrap market volume in the EU the steel production capacities decreased over the past 10 years (EUROFER, 2018).

If one considers only individual countries, the biggest exporter is the USA. It has continuous excess scrap supply produced from infrastructure rebuilding and availability of obsolete scrap from consumer goods. Japan also exports high amounts of steel scrap, but it localizes its exporting radius to Asian close-by countries, because of favorable logistics (Lee and Sohn, 2015).

Table 4: World's major exporters of steel scrap in 2016 (World Steel Association, 2017)

World's major exporters of steel scrap in 2016	**Mt**
EU	17.8
USA	13.2
Japan	8.7
Russia	5.6
Canada	3.6
Australia	1.6
China	1.3
Singapore	1.0
South Africa	0.6
Others (countries with exports <0.6Mt per country)	32.5
Sum	**85.9**

As shown in Figure 1, Turkey imported 10.4Mt of the 17.8Mt steel scrap exports from the EU.

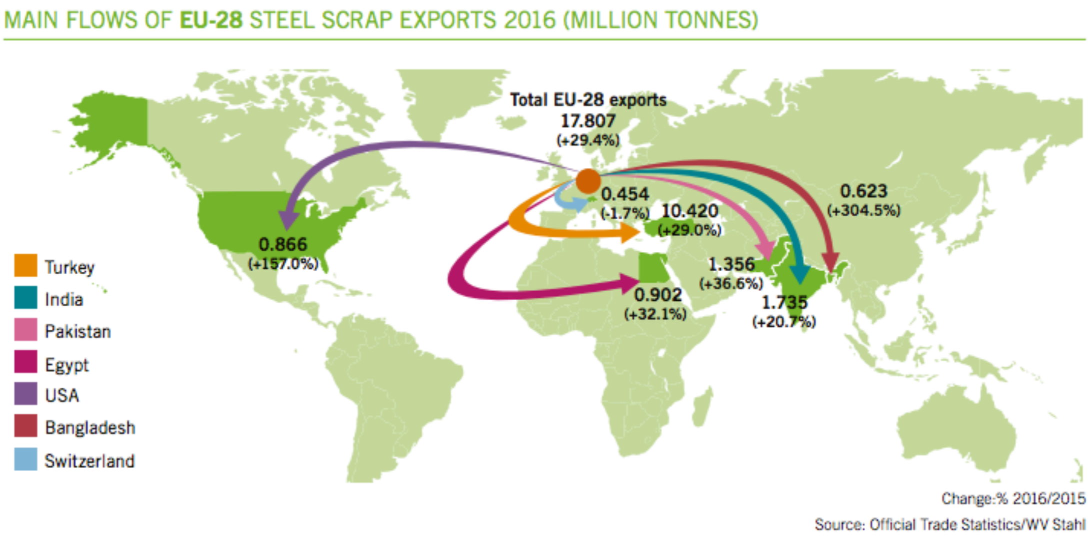

Figure 1: Main flows of EU steel scrap exports 2016 (Mt) (Bureau of International Recycling, 2017)

Scrap usage rates depend on the production process used in each country and the domestic scrap availability. There are huge regional differences in scrap usage rates.

Vercammen et al. (2017) state three main factors, which affect the amount of scrap used in steelmaking:

- The choice between Electric Arc Furnace (EAF) and Basic Oxygen Furnace (BOF) is determined by domestic scrap availability and the total volume of metallics needed to support steel production
- The quality and volume of the steel products
- Capital cost and cash availability co-determine the choice between EAF and

BOF (Vercammen et al., 2017)

The ratio of steel scrap and crude steel in the steelmaking process is very diverse as mentioned above. Table 5 shows a number of ratios to get an idea about the wide variations.

Table 5: Ratios of steel scrap and crude steel use in steelmaking in 2016 in percent (Bureau of International Recycling, 2017)

Ratios of steel scrap and crude steel use in steelmaking in 2016	**%**
Turkey	78.0
USA	72.1
EU	54.4
Korea	39.9
Japan	32.0
Russia	24.3
China (based on 90.1Mt scrap use in 2016)	11.1

EAF's use steel scrap as main raw material, whereas traditional blast furnaces can only be fed with a small percentage of 20-25% steel scrap. Traditional blast furnaces use mainly iron ore and coke (United Nations Environment Programme, 2015; Vercammen et al., 2017).

3.2.2 Technology

Around 70% of global steel production is based on the Basic Oxygen Furnace (BOF) technology. The remaining 30% are represented by the Electric Arc Furnace (EAF) technology (Primetals Technologies, 2018).

3.2.2.1 Basic Oxygen Furnace (BOF)

The BOF can also be called oxygen converter or Linz-Donawitz (LD) converter, because the first and second production scale BOF was erected 1953 in Linz, Austria and in Donawitz, Austria (Umweltbundesamt, 2012; Voestalpine AG, 2018).

In the BOF process liquid high-carbon raw iron, made from iron ore and coking coal, which is produced in the Blast Furnace is converted into low-carbon steel by using oxygen (O2) to oxidize impurities in the hot metal. The oxygen must be of a purity of at least 99.5%, otherwise the steel may absorb nitrogen (N2). Hot metal makes the primary raw material for this process with around 80%. Steel scrap makes up the remaining 20%. Both together is charged into a vessel in which the oxygen is blown at supersonic velocities. The oxygen oxidizes the carbon and silicone, which is contained in the hot metal. This process liberates great quantities of heat, which melts the scrap. The oxidation of iron, manganese and phosphorus liberate heat as well, but not as far to the same extent as carbon and silicone. Calcined lime with a Calcium oxide content of more than 92% is primarily used as flux for the process. During the post combustion of carbon monoxide heat is transmitted back into the bath of hot metal and steel scrap. The final product of the process is liquid steel with a specified chemical characteristic at a temperature of around 1650 degrees Celsius (Sarna, 2015). Secondary metallurgy processes most often follow the BOF process to give the product its final characteristics (The Institute for Industrial Productivity, 2018).

3.2.2.2 Electric Arc Furnace (EAF)

In an Electric Arc Furnace steel can be produced primarily by melting and converting steel scrap and/or manufactured iron units - such as direct reduced iron, pig iron or iron carbide into steel. This is done by using high-power electric arcs formed between a cathode and one anode (for direct current arcs) or three anodes (for alternating current arcs). Scrap accounts for about 80% of the raw material used as metal feedstock in EAFs (The Institute for Industrial Productivity, 2018). Ferroalloys, such as ferromanganese or ferrochrome may be used as additional feedstock in greater or lesser quantities to adjust the desired concentrations of non-ferrous metals in the finished steel (Umweltbundesamt, 2012).

Similar to the process in the BOF, limestone is used for slag formation. Limestone reduces the melting point of the slag and binds impurities (The Institute for Industrial Productivity, 2018).

The following main operations are performed for the production of carbon steel and low alloyed steels:

- raw materials handling, pretreatment (if any) and storage
- furnace charging
- EAF scrap melting
- steel and slag tapping
- ladle furnace treatments for quality adjustment
- slag handling
- casting.

High alloyed and special steels require more complex and tailor-made operation sequences for the end-products (Umweltbundesamt, 2012). The utilization of steel scrap in the steel production requires preprocessing steps. Post-consumer scrap must be shredded, and non-ferrous metals, as well as compounds, contaminants and impurities must be separated. Afterwards it must be sorted. New scrap is sorted and baled and can be utilized after this process. Home scrap is clean, and the composition is known, thus there is no need to sort it, therefore it can be utilized in the production process without any preprocessing. High quality steel production requires the utilization of sorted high quality steel scrap (Gara and Schrimpf, 1998).

3.2.3 China

By producing 808.4Mt of crude steel in 2016, China is the biggest steel producer in the world. The Worldsteel Association estimated a BOF production capacity share of 766.36Mt and an EAF production capacity share of 42.04Mt in 2016 (World Steel Association, 2017). China's steel scrap use increased by 8.2% in 2016. At the same time China reduced its steel scrap imports, what leads to the fact that China utilized more steel scrap of its own domestic collection. The amount of China's domestic steel scrap makes about 87.9Mt based on the data of the Bureau of International Recycling. The imports of steel scrap were at 2.2Mt. China used 90.1Mt of steel scrap in 2016. This is the worldwide highest amount of steel scrap used in one country (Bureau of International Recycling, 2017). Numbers differ regarding the amount of China's steel scrap use. Vercammen et al. (2017) write in ‚Metals and Mining 2017' of about 180Mt of steel scrap, whereby in their calculations scrap from small steel plants, foundries and estimates used in the grey economy were considered. Vercammen et al. (2017)

reported that the China Association of Metal Scrap Utilization (CAMU) excluded those contributors in their calculations.

Back in 2000 China's share of the global steel production accounted for 15%. Today China's production accounts for nearly 50%. China had a limited domestic supply of obsolete scrap in the past. As a result of steel producers mostly using the BOF technology, China depended foremost on iron ore and coal as raw material supply. China's low dependence on steel scrap combined with its strong growing global share of steel production, pushed down the overall share of scrap utilization in steel production from 40% in 2000 to 34% in 2015. But over time China's steel scrap consumption grew and increased over the past 15 years.

Most Chinese scrap originated from home or prompt scrap for the past years. As more steel products reach their end of life phase the share of post-consumer scrap is increasing. In 2015 the post-consumer scrap share reached 35% and it is projected to stay on the rise.

After Vercammen et al. (2017), about 100-150kg of steel scrap is used to produce a ton of crude steel in BOF operations, whereas 550-600kg is used in EAF operations. Those amounts are lower than normally observed, because especially in EAF operations Chinese steelmakers rely on pig iron.

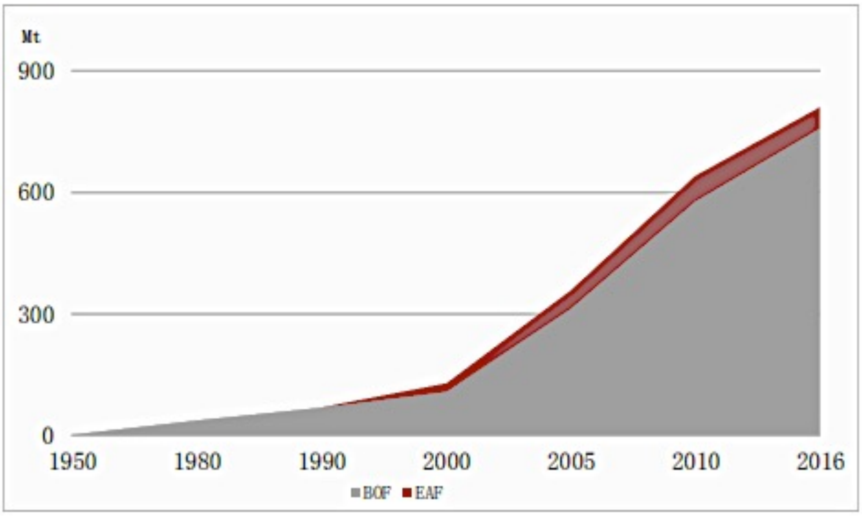

Figure 2: China's Crude Steel Production: BOF vs. EAF (Zhong, 2018)

Figure 2 shows the BOF and the EAF share of China's steel production in Mt between 1950 and 2016. The data of Zhong (2018) shows like Vercammen et al. (2017) that the EAF share of China's overall steel production capacity is very small (Vercammen et al., 2017; Zhong, 2018). Compared with China's steel production capacity, its steel scrap recycling sector is small. China targeted an increase in steel scrap usage from 13 percent in 2010 to 20 percent in 2015 (Vercammen et al., 2017). The World Steel Association (2017) reported that the country achieved a proportion of 11.1% in 2016. That shows again that data differs strongly regarding steel scrap utilization amounts.

China's future steel scrap consumption is heavily dependent on political developments including economic and environmental decisions regarding a beneficial framework for a shift from BOF to EAF steelmaking. The pace of this shift will be determining global steel scrap industry. If China increases its EAF share it will use its steel scrap domestically, otherwise there will be a major surplus of steel scrap and China would have to export these quantities. This would lead to a heavy increase of the steel scrap volume on the global market. This circumstance would change the market situation and would pressure scrap prices. After Vercammen et al. (2017) the EAF capacity would have to double until 2025 and to triple until 2030 to keep up with scrap supply utilization. Domestic scrap recycling would affect China's economy as well as its environment positively. Higher scrap usage would help to build a cleaner economy. Iron ore and coking coal are largely imported. This could be avoided by a transition from BOF to EAF and with that using the increasing domestic post-consumer scrap quantities. Thereby China would benefit not only by limiting emissions of carbon dioxide (CO2), sulfur dioxide (SO2), and dust, but also by feeding its domestic economy.

China is not only the biggest producer, but also biggest consumer of steel. With hindsight on the past years it can be said that China's domestic demand for steel peaked in 2013 at 735Mt or 540kg per capita.

Outlook: Estimates of Vercammen et al. (2017) project that China's total scrap supply will grow at 4-5% per year up to 340Mt by 2030. The share of post-consumer scrap will increase from around 45% in 2015 to not less than 70% in 2025. Forecasts expect the country's steel demand to stabilize in 15-20 years at around 400-450kg per capita (Vercammen et al., 2017).

China's steel scrap imports won't increase in the future. The opposite is the case. Amounts of imported steel scrap will decrease further through an import ban of China on six different types of waste and scrap of iron and steel, which will come into effect with beginning of July 2019 (bvse.de, 2019). The Chinese Ministry of Ecology and Environment stated that they want to phase out waste imports, which can be replaced by domestic resources (EUWID, 2018a). As Vercammen et al. (2017) described, the domestic steel scrap generation is on the rise.

3.2.4 Turkey

Turkey was the 8th biggest steel producer worldwide in 2016 with a production volume of 33.2Mt of crude steel. The country satisfied its material demand for crude steel production in 2016 by utilizing 78% of steel scrap. Turkey's annual increase in steel scrap consumption of 7.6% totaling in 25.88Mt steel scrap utilization in 2016 was higher than its annual production increase of 5.2% in 2016. EAF's are used for around 70% of Turkey's steel production, which is why Turkey relies strongly on steel scrap for its production (United Nations Environment Programme, 2015). Turkey imported 17.7Mt of steel scrap in 2016 and is thereby world's leading steel scrap importer. Based on the scrap utilization figures and the imported steel scrap amount can be determined, that Turkey's domestically collected steel scrap volume in 2016 amounted to 8.18Mt. Major steel scrap suppliers of Turkey are the EU and the USA. Figure 1 earlier in the text displays the main flows of EU steel scrap exports in 2016. 10.42Mt were imported from the EU and 3.17Mt from the USA. Another main supplier was Russia by exporting 2.46Mt to Turkey.

Turkey has an important position, as it is a considerable exporter of long steel products (such as bars & rods, wire rod, angles, shapes & section, rails, wires and bright bars) to the EU (Lee and Sohn, 2015; Ministry of Steel-GoI, 2018). EU countries such as Germany are well known for its high-quality and high-value steel products. The high product quality is one of the reasons why steel mills in Germany does not utilize as much steel scrap as Turkey. Steel scrap contains impurities, which affect the product quality. Turkey consumes the cheaper low-quality steel scrap and uses it among others for the production of long products with less stringent quality. Germany imports cleaner and more expensive steel scrap to produce higher-value products (Lee and Sohn, 2015). Infrastructural megaprojects such as tunnels, highways, bridges etc. keep Turkey's domestic steel demand on a high level (Yayan, 2017). Turkey noted its highest steel production in history in 2017 with 37.5Mt (Steel Exporters' Association, 2018).

Outlook: Turkish steel and steel scrap demand declined in 2018, because of the geopolitical and economic obstacles, such as President Trumps market foreclosure and its own monetary turmoils (World Steel Association, 2018; BVSE, 2018). Its steel demand is expected to stabilize and increase again in 2019 (World Steel Association, 2018). In turn, this would as well lead to the increase of steel scrap import demand.

3.3 The aluminium scrap market

3.3.1 Mass flows

Aluminium is the most heavily used and fastest growing non-ferrous metal. China is dominating the Aluminium production and scrap import. Only a small proportion of aluminium scrap is traded externally across national borders. Asia accounts for 60% of all scrap imports. Most scrap exports originate from North America and Europe (United Nations Environment Programme, 2015).

The global primary Aluminium production in 2016 was at 58.9Mt Government Publishing Office, 2018). 17Mt of old scrap (recovered aluminium after final consumer use, also called ‚post-consumer scrap') and 12Mt of new scrap (production and fabrication surplus material) went into the global Aluminium production cycle. According to the Aluminium International Institute 29Mt of recycled Aluminium was produced out of this scrap. Primary and Recycled Aluminium Production together totaled to about 91Mt in 2016 (Classen et al., 2007; The International Aluminium Institute, 2016). Table 6 gives an overview on the global primary aluminium production in 2016, the secondary aluminium production in 2015, global aluminium scrap use and global aluminium scrap trade in 2015.

Table 6: Global primary aluminium production in 2016, secondary aluminium production in 2015, global aluminium scrap use and global aluminium scrap trade in 2015

MASS FLOWS	Mt	year	source
Global primary production	**58.9**	2016	Government Publishing Office, 2018
Global secondary production	**29.0**	2015	The International Aluminium Institute, 2016
Aluminium scrap use (global)	**29.0**	2015	The International Aluminium Institute, 2016
Aluminium scrap trade (global)	**3.6**	2015	Eales, 2016

China dominates the global aluminium market by owning half of the global production volume. India is one of the big players behind China in the aluminium market with production amounts above its domestic demand, enabling exports to the international market.

The main aluminium processors are the transportation and construction industry. In 2014 each accounted for about 25% of aluminium consumption. Airframes, car parts, engines, train bodies, space shuttles, yachts, parts of fuel systems and many other products are fabricated out of aluminium in the transportation sector. For the construction sector aluminium is manufactured into window and door panels, roofing, frameworks, façades, staircases etc. (UC Rusal, n.d.).

Table 7 shows the major primary aluminium producers in 2016 by country. As mentioned above China clearly dominates the ranking with its primary aluminium production of about 32Mt in 2016.

Table 7: World's major producers of primary aluminium in 2016 (GOVERNMENT PUBLISHING OFFICE, 2018)

World's major producers of primary aluminium by country in 2016	**Mt**
China	31.9
Russia	3.6
Canada	3.2
India	2.7
United Arab Emirates	2.5
Australia	1.6
Norway	1.2
Bahrain	1.0
Iceland	0.9
USA	0.8
Others (countries with a production <0.8Mt per country)	9.5
Sum	**58.9**

Aluminium and alloy scrap imports and exports are measured in gross weight terms. Therefore, the total exported or imported weight contains other metals as part of the alloys. On average, mixed aluminium and alloy scrap contains around 90% of aluminium. Between 2000 and 2015, total aluminium scrap exports increased from 3.6Mt to 7.6Mt with an annual compound rate of 6%.

The six major scrap exporters in this period were the USA, Germany, Canada, France, the UK and the Netherlands. Together they accounted for more than half of the global scrap exports.

China's aluminium scrap imports constitute a main driver of international scrap trade. The PRC was the biggest importer of scrap worldwide throughout that period. Between 2000 and 2010 its scrap imports increased from 0.8Mt to more than 2.5Mt. After 2010 scrap imports declined steadily down to about 1.5Mt in 2015. In India, scrap imports increased from 0.06Mt to 0.88Mt between 2000 and 2015. USA, Germany, Italy, South

Korea and India follow China as significant aluminium scrap importers. Together with China they account for 57% of global trade (Eales, 2016).

Table 8 figures the world's major importing regions in 2015. As mentioned above China leads world's aluminium scrap imports with 1.5Mt, followed by other Asia with 1.4Mt and the EU with 0.4Mt.

Table 8: World's major importers of aluminium and alloy scrap per region 2015 (Eales, 2016)

World's major importers of aluminium and alloy scrap per region 2015	**Mt**
China	1.5
Other Asia	1.4
EU	0.4
Others (regions with imports <0.4Mt per country)	0.3
Sum	**3.6**

Table 9 shows that the North American Free Trade Agreement Region (NAFTA) as the biggest exporting region, exported 1.5Mt, followed by the EU with 0.9Mt in 2015.

Table 9: World's major exporters of aluminium and alloy scrap per region 2015 (Eales, 2016)

World's major exporters of aluminium and alloy scrap per region 2015	**Mt**
NAFTA (North American Free Trade Agreement Region)	1.5
EU	0.9
Other Europe	0.4
Middle East	0.2
Others (regions with exports <0.2Mt)	0.6
Sum	**3.6**

3.3.2 Technology

Within the aluminium market there is a differentiation between producers of primary aluminium and aluminium recyclers. Primary production and aluminium recycling require different processing steps and therefore the branches are distinguished from each other (UC Rusal, n.d.). Secondary aluminium production begins with pretreating aluminium and alloy scraps. Scraps, which are segregated by chemical composition or alloy are of high value contrary to aluminium scrap containing a mix of alloys. The sorted scrap is placed into a melting furnace and is turned into molten aluminium at temperatures around 700 degrees Celsius. Subsequently the molten aluminium is cast into ingots or billets or in some cases it is kept in its liquid state to add alloying elements to produce the desired specific product type. During the secondary metallurgy process metals and compounds can be added to finish a product (The Aluminum Association, 2019).

The aluminium market is principally divided into the upstream segment, denoting producers of primary aluminium and its alloys, the downstream segment, which labels the producers of aluminium products and as mentioned above the producers of aluminium out of processed raw material - the aluminium recyclers.

The upstream segment involves the whole raw material supply chain preceding the process of primary aluminium production. The preceding processes include mining bauxite, processing it into alumina and delivering it to an aluminium smelter. The biggest aluminium producing companies are vertically integrated in the supply chain, meaning that they mostly comprise bauxite mines and alumina refineries. Alumina production facilities can be located in the regions where the largest bauxite reserves can be found. Those regions are Southeast Asia, South America, Africa and Australia. South America, the Middle East, Oceania and Africa are focused on primary aluminium production, whereas Aluminium recycling isn't represented there because of the missing scrap availability.

Aluminium scrap has a high market value because it contains the energy, which was needed for the primary production of the material and requires considerably less energy for the remelting process. Sorted or pre-treated aluminium products can be recycled into all different kinds of aluminium applications, which is because its atomic structure is not altered during melting (UC Rusal, n.d.). Secondary aluminium production is 92% more energy efficient than primary aluminium production (The Aluminum Association, 2019).

A share of 80% of secondary aluminium (consisting of 47% secondary aluminium from new scrap and 33% secondary aluminium from old scrap) can be used to produce cast alloys, whereas the share of secondary aluminium in wrought alloy production accounts for 10% of secondary aluminium (consisting of 10% secondary aluminium from new scrap and 0% secondary aluminium from old scrap) (Classen et al., 2007). It can be concluded that secondary aluminium qualifies predominantly to produce cast alloys.

Recycling rates for aluminium used in the transport and building sectors are estimated to be about 85% to 95%. Aluminium packaging recycling rates vary considerably from 25% to 85% depending on national circumstances and collection schemes. The global average of beverage can collection rates was about 70% in 2009. The span of can collection rates varies from country to country from 30% to 99.5%. The top collecting country is China with its 99.5%. This number includes the informal collection. Brazil follows China with 96.5%. Japan has had the third strongest can collection rate in 2009 with 92.7%. Many EU countries such as Portugal, France, Greece and Italy have a low can collection rate compared to China, Brazil and Japan (International Aluminium Institute, 2009).

3.3.3 China

China's primary aluminium production volume accounted for 31.9Mt in 2016. This is more than half of the global production volume covered by one single country (Government Publishing Office, 2018).

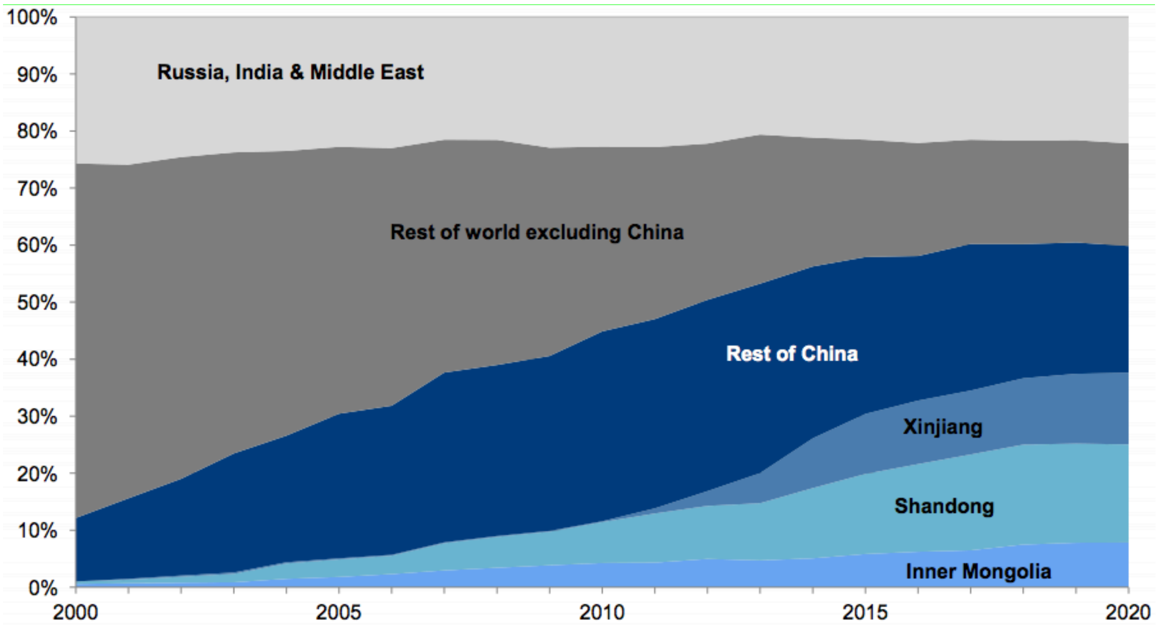

Figure 3: Primary Aluminium Production split by Region (Patel, 2017)

Figure 3 pictures the increase of China's market volume regarding the global Aluminium production over time. Furthermore, one can see that the Chinese provinces Shandong and Xinjang increased their production volume especially strong (Patel, 2017).

Based on China's total output of primary and secondary aluminium in 2015, its secondary aluminium production capacity accounted to about 6Mt in 2015. The aluminium scrap import in 2015 is 1.5Mt (Eales, 2016). This leaves a gap of 4.5Mt domestically generated scrap.

Between 2000 and 2010 China's aluminium scrap imports increased from 0.8Mt to more than 2.5Mt. After 2010 scrap imports declined steadily back down to about 1.5Mt in 2015 (Eales, 2016).

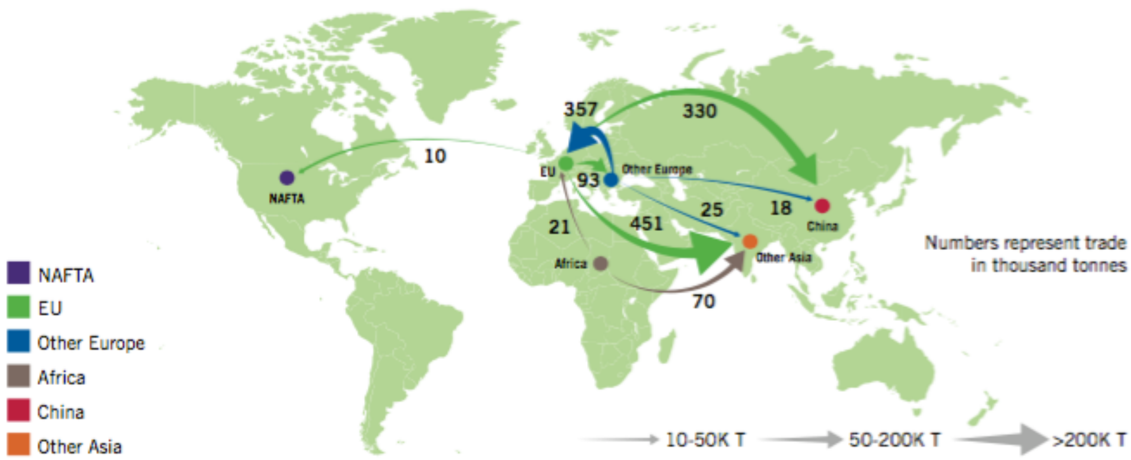

Figure 4: Exports of Aluminium and Alloy scrap in 2015 from Europe and Africa (Eales, 2016)

Figure 4 shows that a major volume of EU's aluminium and alloy scrap exports go to China, whereas the EU itself imports about 0.4Mt from Other Europe.

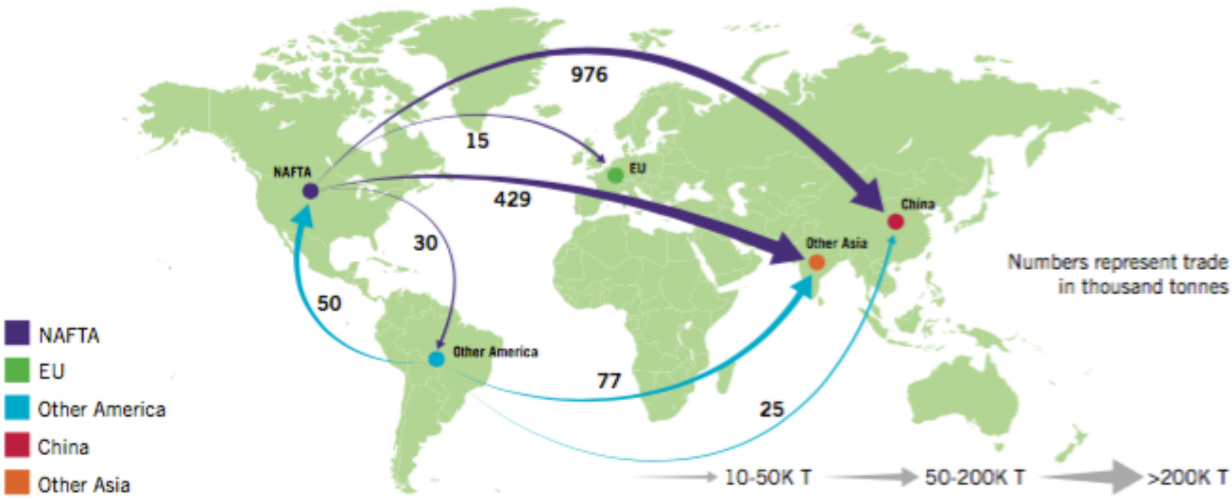

Figure 5: Exports of Aluminium and Alloy Scrap in 2015 from NAFTA & Other America (Eales, 2016)

In Figure 5 one can see that the NAFTA countries as the major exporting region is a main exporter of China.

Outlook: China's aluminium and alloy scrap imports peaked in 2010. Back then the EU was a major scrap supplier of China. Since 2010, imports decreased steadily (Eales, 2016). Amounts of imported aluminium scrap will decrease further through the import ban, which will come into effect with beginning of July 2019, which includes not only six different types of waste and scrap of iron and steel, but as well aluminium waste and scrap (bvse.de, 2019).

3.3.4 India

As mentioned before India is one of the big players behind China in the aluminium market with production amounts above its domestic demand, enabling exports to the international market (UC Rusal, n.d.). Its primary aluminium production capacity in 2016 was at 2.7Mt. Secondary aluminium production capacity is estimated based on the aluminium scrap demand to be at 1.1Mt (Reintjes, 2017).

The domestic scrap collection rate is low (Shanker, 2012). A big share of alminium is still dumped into landfills, because of insufficient awareness. 0.12Mt of aluminium scrap were collected domestically and 0.99Mt equaling 90% of the total aluminium scrap demand was imported. The automotive and power segment accounted for 75% of the domestic aluminium scrap generation. Between 2010 und 2016 India's demand for secondary aluminium has nearly doubled. The countries overall consumption of aluminium accounted to 3.3Mt in 2016, of which 30% was secondary aluminium (Reintjes, 2017). In 2011 India's aluminium recycling sector was highly fragmented into around 10 medium sized players and about 150 to 200 small players. Reasons for the high number of small players in the business are low entry barriers and low capital costs.

In India 70% of secondary aluminium is used in castings. The other 30% account for billets, re-rolling units and steel-deoxidation products. Recycled aluminium is foremost used in India's automobile industry, followed by the construction industry, consumer durable products and other industrial applications (Shanker, 2012).

India is a rapidly industrializing country with a fast growing middleclass. Cars and busses as forms of transportation are prognosed to remain as an important form of transportation. The automotive sector and the construction sector are both very material and resource-intensive sectors. The automotive industry relied very much on iron and steel in the past, but today the requirements in the automotive sector have changed. The demand for more fuel-efficient cars led to a new composition of materials in a car and with that came the decrease of iron and steel and the increased use of plastics and aluminium. The average amount of aluminium used in cars in the Indian automotive industry lies at around 40kg per vehicle, while developed countries use 140kg per vehicle on average.

Outlook: The estimated aluminium demand by the automotive industry could increase from the current aluminium demand of about 1.76Mt up to more than 10Mt during the next 15 years (Satpathy et al., 2016). Out of this can be inferred that the primary and secondary aluminium demand of India will increase in upcoming years. India's demand for secondary aluminium is expected to reach 1.5Mt by 2021 (Reintjes, 2017).

3.4 The e-waste market

Global and countrybased material utilization volumes originating from e-waste could not be determined, because of non-availability of data.

3.4.1 Mass flows

With rising numbers of information and communications technology (ICT) equipment, there are growing amounts of e-waste (electronic-waste) also called waste electrical and electronic equipment (WEEE) after its use phase. The growth of e-waste is expected to rise even faster in upcoming years, not only because of the growing middle-class in emerging countries, but also because of decreasing product lifespans. E-waste is one of the fastest growing waste streams. Calculations of the United Nations University state that about 42Mt of e-waste was generated worldwide in 2014 (Balde et al., 2015) and 44.7Mt in 2016. E-waste generation was forecasted to reach about 50Mt in 2018 (Baldé et al., 2017). Global annual consumption of new electrical and electronic equipment (EEE) totaled to around 58Mt in 2012 (Balde et al., 2015).

Table 10 shows the global WEEE generation and amount of recycled e-waste in 2016. There is a gap between the globally produced amount of WEEE and the recycled e-waste amount of 35.8Mt equaling 80% of the globally generated e-waste, which is not documented to be collected and recycled (Baldé et al., 2017).

Reliable data on the global import and export of e-waste and used electrical and electronic equipment (UEEE) are not available. The volume of globally traded e-waste could therefore not be determined.

Table 10: Global e-waste production and amount of recycled e-waste in 2016 (Baldé et al., 2017)

MASS FLOWS	**Mt**	**year**	**source**
Global production	**44.7**	2016	Baldé et al., 2017
Recycled e-waste (global)	**8.94**	2016	Baldé et al., 2017
E-waste trade (global)	**n.d.***	2016	

*n.d. = no data available

Although the Basel Convention Secretariat receives statistics from some countries, those statistics do not include all e-waste types and the countries are only partly fulfilling their reporting obligations towards the Basel Convention Secretariat. Furthermore, those statistics do not cover UEEE that is wasted but functional. Hence there is no official data about the transboundary movement of e-waste (Baldé et al., 2015). The following table shows the continental differences in e-waste generation, collection and recycling in the year 2016. Asia leads the e-waste generation with 18.2Mt, followed by Europe with 12.3Mt and the Americas (North and South America) with 11.3Mt. Those generation rates are contrasted with collection and recycling rates of 2.7Mt or 15% in Asia, 4.3Mt or 35% in Europe and 1.9Mt or 17% in America (Baldé et al., 2017).

Table 11: Global e-waste generation, recycled e-waste amounts and e-waste collection rates in 2016 (Baldé et al.,2017)

	Africa	America	Asia	Europe	Oceania
E-waste generation (kg/inh)	1.9	11.6	4.2	16.6	17.3
E-waste generation (Mt)	2.2	11.3	18.2	12.3	0.7
Amount of collected and recycled e-waste (Mt)	0.004	1.9	2.7	4.3	0.04
Collection rate	0%	17%	15%	35%	6%

Consumption and use of EEE is very high in developed countries, but it is as well fast increasing in developing countries. The less developed countries are often missing environmental standards, waste management laws and are many times lacking waste treatment infrastructure what leads to a suboptimal treatment of e-waste by the informal sector. This in turn leads to severe consequences in the form of human health and environmental dangers. Suboptimal and illegal activities regarding e-waste exists not only in low and middle-income countries but occur as well in developed countries, where large flows of undocumented e-waste were found (Baldé et al., 2015).

Table 12 offers an overview of the biggest e-waste generating countries in 2016. Together they generated 19.5Mt of WEEE, which amounts to about 44% of the 2016 globally generated e-waste volume.

Table 12: Major e-waste generating countries in 2016 (Baldé et al., 2017)

Major e-waste generating countries in 2016	**Mt**
China	7.2
United States	6.3
Japan	2.1
India	2.0
Germany	1.9
Others (countries with a generation <1.9Mt per country)	32.1
Sum	**51.6**

China is the largest e-waste producer globally. With 7.2Mt it generates a major share of the total amount of the 18.2Mt, which are generated in Asia. The United States produced 6.3Mt of e-waste. Japan and India follow the United States with 2.1Mt and 2Mt (Baldé et al., 2017). China, the United States, Japan but as well India are not only big e-waste producers, they have also relevant market shares of the electronics industry market volume as shown in Figure 6 below.

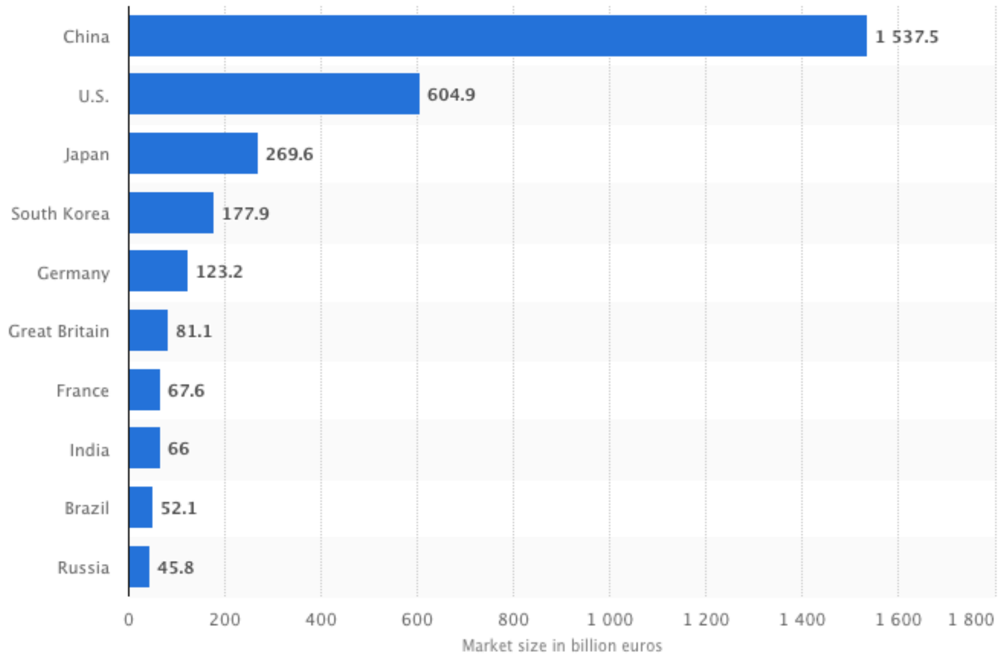

Figure 6: Leading countries in the electronics industry in 2015, based on market size (in billion euros) (statista.com, 2018)

Figure 7 summarizes and depicts the global e-waste flows in 2014. Wang et al. (2016) found out, that much of the e-waste produced by the developed nations such as the United States and Europe ends up in developing countries such as India where legislation is inefficient and irregularly enforced. Other recipient countries for example are Nigeria and Ghana. Many African countries have few or even no e-waste legislation at all (Wang et al., 2016).

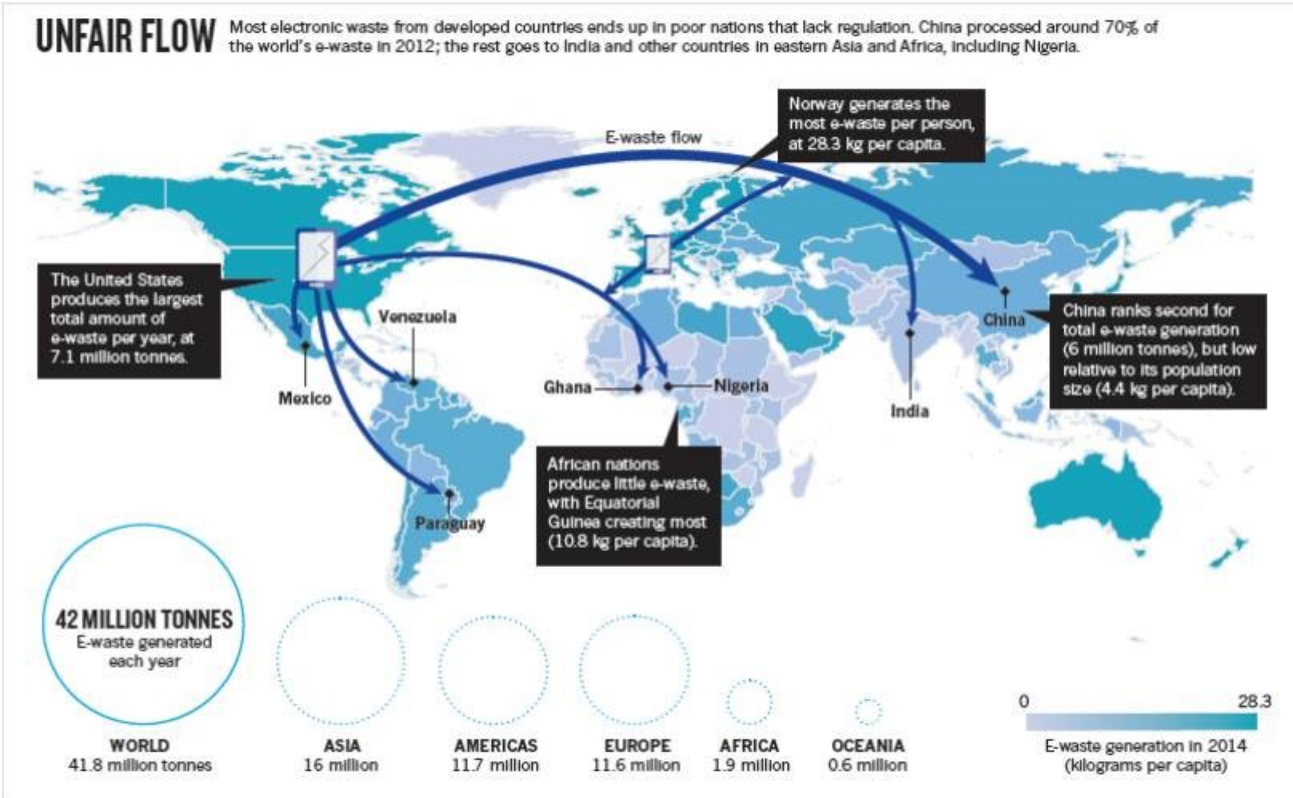

Figure 7: Global e-waste flows in 2014 (Wang et al., 2016)

Lepawsky (2014) compared several studies on e-waste imports from countries of the global North to countries in the global South and concluded, that the major share of imported WEEE is predominantly working and repairable equipment, which is repaired locally and sold to consumers. Only a small share is un-repairable (Lepawsky, 2014). After the disassembly of the un-repairable devices, metals and special metals are sold to refiners or smelters for further processing (Luther, 2010).

Furthermore, domestic sources contribute significant volumes of WEEE in developing and emerging countries. Lepawsky (2014) states that e-waste trade from developed nations to developing nations represents a moderate share of e-waste flows relative to flows within these regions (Lepawsky, 2014).

This shows that a main driver for the WEEE imports and exports are the big re-use markets in developing and emerging countries. Another important aspect, that is emphasized by Lepawsky (2014) and should not be overlooked, is the domestic e-waste generation of the countries in the global South (Lepawsky, 2014). The fast information and communications technology (ICT) growth rates in developing countries lead to higher growth rates of e-waste than those of developed countries. Rising e-waste numbers combined with the facts, that formal recycling systems in developing countries are lacking, threats from processing are greater and policy and legislation is weak or absent, leads to the conclusion that e-waste represents a much greater sustainablility challenge in developing and emerging countries (Heeks et al., 2015).

3.4.2 Technology

After Cui and Forssberg (2003) there are three major e-waste recycling steps:

- "Disassembly: selective disassembly, targeting and singling out hazardous or valuable components for special treatment

- Upgrading: mechanical processing and/or metallurgical processing to upgrade the content of desirable materials
- Refining: purifying the recovered materials using chemical (metallurgical) processing so as they are acceptable for the original use”

The disassembly of e-waste is mostly done manually with the aim of seperating certain components like casings, cables, batteries etc from e-waste. Cui and Forssberg (2003) depict that there is a wide range of upgrading and refining processes, which can be divided into mechanical and metallurgical methods. With mechanical processes various metals and materials are shredded and crushed for the purpose of better sorting and size reduction. The output fractions are sorted afterwards based on their specific physical characteristics (weight, size, shape, density, electrical and magnetic characteristics).

Tsydenova and Bengtsson (2011) determine based on Cui and Forssberg, 2003: „Final output streams are usually components taken out as a whole, a magnetic fraction (going for further treatment to a steel plant), an aluminium fraction (to aluminium smelters), a copper fraction (to copper smelter), sometimes clean plastic fraction, and waste.”

Cui and Zhang (2008) describe two different kinds of metallurgical processes:

- pyrometallurgical processes: metals are melted
- hydrometallurgical processes: metals are dissolved

According to Cui and Zhang (2008) pyrometallurgical processes became the traditional method to recover metals from e-waste.

Priya (2017) describes an alternative metallurgical process for e-waste recycling known as:

- biohydrometallurgy or biometallurgy (bioleaching)

In bioleaching biotechnological processes like the application of biocatalysts (e.g., microorganisms and enzymes) are integrated in hydrometallurgy. In the bioleaching process a diverse range of microorganisms is used to convert metal compounds into their water-soluble state. The microorganisms use CO2 as carbon source and inorganic compounds as an energy source. The following leaching process is done through conventional metal recovery methods (e.g. precipitation, adsorption, ion exchange, and electrowinning). The research in bioleaching is currently at laboratory scale (Priya, 2017).

After reprocessing WEEE, valuable metals like for example aluminium, copper, gold, silver and others depending on the content can be extracted. Those secondary raw materials in form of precious metals or others can depict cheap alternatives to virgin materials (Sawhney and Majumder, 2015).

3.4.3 China

China is a major player regarding the EEE industry. As China is the most populous country in the world, the domestic EEE demand is very high. Urban Chinese households are similarly equipped with EEE as European households in urban areas. This in turn will lead to similar per capita WEEE generation rates. As can be seen further up in Figure 6 China has a very strong EEE manufacturing industry segment.

China’s formal e-waste recycling sector grew considerably in the past years (Wang et al., 2016). With the help of subsidies, electronic retailers, take-back systems and recyclers got the chance to compete with informal WEEE collectors. The societal value structure of the urban Chinese society sees household waste including WEEE as valuable commodity and therefore expects it to be exchanged for money (Salhofer et al., 2016). Informal actors offer a door-step collection, which is generally supported by urban residents, who store their wastes at home, since they are seen as a valuable source of additional income (Steuer et al., 2014).

The informal collection rates of WEEE from households still exceed the formally collected WEEE amounts by far in many major cities in China. The formal WEEE collection schemes struggle with high costs of collection. The informal collection is value oriented, that means that end-of-life products like e.g. fluorescent lamps are not targeted, which is a problem because they contain hazardous materials, which should be taken care of in a proper way. In contrast to the formal collection, the value-oriented way of the informal collection is cost-covering. The service level offered by informal collection schemes, which includes home collection and additional payment for obsolete devices, is difficult to match for formal collection systems.

Outlook: Since amount and type of electrical and electronic devices within households of the EU and urban China are similar, the WEEE generation rates of the EU and China will adjust within the next few years (Salhofer et al., 2016). Due to China’s import policy implementation e-waste flows from the USA and the EU to China will decrease.

3.4.4 Ghana

As mentioned before and shown in Figure 7 Ghana is an important recipient-country of e-waste. In 2009, Ghana imported 0.21Mt of EEE (70% therof were used EEE), while 0.98Mt EEE were in use (which makes 41kg/per inhabitant). 179,000t of e-waste were generated of which 172,000t were collected. Studies revealed that 30% of the second-hand imports were estimated to be non-functioning. The half of the non-functioning EEE was locally repaired and afterwards sold to consumers and the other half was unrepairable. Ghana generates relatively high volumes of e-waste compared with other African countries. This is because of the direct imports of used and partly non-functioning EEE, but also because of the lower life-span of used EEE compared to new EEE. The use of EEE in Ghana is growing fast. Ghana has a penetration rate of EEE almost as high as more developed African countries like South Africa, although its development status is lower. This is because Ghana has good access to lower priced ICT equipment due to the intense trade of used EEE. The country has a very high collection rate, because its informal sector is very active in e-waste recycling. This stands in close connection to the high volumes of traded used EEE and the repairing businesses in Ghana. The report of the Basel Convention Secretariat shows that the major share of e-waste in Ghana is generated domestically. In 2009 for example 20,000t of e-waste originated out of developed countries. Another 110,000t was e-waste generated out of imported EEE, which was directly sold and consumed as products or if necessary repaired first and afterwards sold and consumed. Remaining 42,000t were e-waste generated from EEE, which were newly bought products in Ghana. Through doorstep collection informal recyclers achieve high collection rates of 95% of e-waste in Ghana. The collectors usually pay small amounts of money for each device they collect. The economic benefit for them originates from the re-use of components and the material value from WEEE. Components of WEEE with a re-use value are sold to repair shops. Remaining valuable components containing copper, aluminium and steel are collected and either directly sold to local industries like steel plants or alumnium remelters or to traders who organize bulk sales to domestic or international refineries (Secretariat of the Basel Convention, 2011).

In Accra, Ghana's capital, metal containing wastes are mostly transferred to the centrally located Agbogbloshie Scrap Metal Market, which is often mistaken as an e-waste dump from non-locals (Secretariat of the Basel Convention, 2011; van der Velden and Oteng-Ababio, 2019).

Formalized processes in the e-waste recycling chain are being developed in the form of initial manual dismantling pilot projects through either private initiatives or development cooperation projects (Secretariat of the Basel Convention, 2011). There were about 14 Ghanaian recycling companies with activities or planned activities in e-waste recycling in 2015, listed in the report 'Baseline Assessment on e-waste in Ghana' without any claim to completeness by Atiemo et al. (2016). This shows that there are as well formal recyclers of e-waste in Ghana. In 2018 Ghana launched official guidelines for environmentally sound e-waste management as first country of Africa (SRI, 2018).

Outlook: Due to the lack of current data on exports of e-waste to Ghana the author cannot give an outlook on the future development. The launch of the above-mentioned guidelines is a step further to more sound, safe and sustainable recycling processes.

3.4.5 Vietnam

In 2015, Vietnam's electronics industry was the twelfth largest exporter globally. Its electronics exports are increasing at a fast pace (Latova, 2017).

E-waste in Vietnam is generated through the disposal of EEE, from industrial processes at electronic industries and from imports of used EEE and e-waste. Vietnam imports used EEE and e-waste from countries like Cambodia and Japan and re-exports it mainly to China. These trade flows are unquantifiable amounts of e-waste. The collection and recycling of e-waste and used EEE in Vietnam rely on the informal and formal sector. The informal sector deals with larger amounts than the formal sector and is involved in all steps of the recycling chain, which are: collection, dismantling & processing and end processing. The informal e-waste recycling sector in Vietnam is very active and guarantees a nearly 100% collection rate of e-waste from households. E-waste is collected by doorstep-collection and transferred to service shops, dealers or collectors. Although e-waste is fetched directly from home, the collectors pay for the appliances. Vietnam has a pronounced repair culture for EEE. Usable parts of e-waste are reutilzed for part replacement during repair works. After being repaired or refurbished the appliances are sold as fake new ones or sold on secondhand markets. Broken EEE or EEE, which are impossible to repair or are to expensive to repair are transferred to dismantling workshops.

There are around 30 craft villages handling e-waste recycling. Craft villages are characteristic for Vietnam. Workers there dismantle and sort e-waste manually into parts at a low level of protective equipment or even without protection at all. Each village specializes on types of appliances. For example, there are workshops specialized on collection of CD and DVD players, and others are in charge of plastic collection and grinding. The tradable parts are classified for further treatment or sale after they have been dismantled.

Environmental harmful and human health endangering practices like the open burning of copper wires to extract copper, chipping and melting of plastic parts and the discharge of residues to fields and riverbanks or ponds are common. The amounts of e-waste, which are transported to and processed at the craft villages are difficult to quantify (Tran and Salhofer, 2018). Tran and Salhofer (2018) estimated the output capacity from dismanlting and sorting of one craft village to average between 40 and 50 tons per month.

Outlook: Based on missing numbers about imports, exports and generation of e-waste the author cannot give an outlook on the future development in regard to e-waste volumes moved to and within Vietnam.

3.5 The waste paper market

3.5.1 Mass flows

The total world paper and board production in 2012 comprised 400Mt. The worldwide collection of waste paper was at 230.5Mt and the consumed amount of waste paper was at 233.2Mt. The difference is explained through a shift of waste paper stocks from the previous year into 2012.

80% of the collected material is consumed within the countries by the respective national paper industry. The transboundary trade of waste paper was around 40 to 50 Mt in 2012. The following Table 13 gives an overview of the aforementioned mass flows.

Table 13: Global paper production, waste paper use and waste paper trade in 2012 (Magnaghi, 2014)

MASS FLOWS	Mt	year	source
Global production	**400**	2012	Magnaghi, 2014
Waste paper use (global)	**233.2**	2012	Magnaghi, 2014
Waste paper trade (global)	**50**	2012	Magnaghi, 2014

As shown in the table below Asia produced 181.6Mt, Europe 103.9Mt, North America 85.1 Mt, South America 20.9 Mt, Africa 4.4Mt and Australasia 4Mt of paper and board in 2012.

Table 14: World production of paper and board in 2012 (Magnaghi, 2014)

World production of paper and board in 2012	Mt
Asia	181.6
Europe	103.9
North America	85.1
South America	20.9
Africa	4.4
Australasia	4.0
SUM	**399.9**

In Table 15 world's major producers of paper and board of 2012 are represented per country.

Table 15: World's major producers of paper and board per country in 2012 (Magnaghi, 2014)

World's major producers of paper and board per country in 2012	**Mt**
China	102.5
USA	74.4
Japan	23.0
Germany	22.6
Sweden	11.4
South Korea	11.3
Canada	10.8
Finland	10.7
Brazil	10.3
Indonesia	10.2
India	10.2
Others (countries with a production <10.2Mt)	102.6
SUM	**400.0**

Main producer of paper and board in 2012 was China with 102.5Mt. China was also main consumer of paper and board with 100.3Mt. Second biggest producer and consumer are the USA with a production of around 74.4Mt and a consumption of 71.8Mt (Magnaghi, 2014).

Ashna (n.d.) writes that the global demand for paper and board in 2020 is estimated to reach 640Mt.

Table 16 shows the world's major importers of waste paper, clearly headed by China with import numbers of 30Mt in 2012. China absorbs the surpluses of waste paper from western countries.

Table 16: World's major importers of waste paper in 2012 (Magnaghi, 2014)

World's major importers of waste paper in 2012	**Mt**
China	30.07
Germany	4.00
Netherlands	3.20
India	2.31
Indonesia	2.29
South Korea	1.47
Mexico	1.30
Begium	1.29
Others (countries with imports <1.29Mt per country)	4.07
Sum	**50.00**

Table 17 shows world's leading exporters of waste paper headed by the United States with an exporting amount of 20Mt (United Nations Environment Programme, 2015).

Table 17: World's major exporters of waste paper in 2012 (Magnaghi, 2014)

World's major exporters of waste paper in 2012	**Mt**
USA	20
Japan	4.93
UK	4.49
Netherlands	3.6
Germany	3.09
France	3.05
Belgium	2.02
Italy	1.94
Others (countries with exports <1.94Mt per country)	6.84
Sum	**50.00**

Germany has state-of-the art paper factories, which have high utilization rates of waste paper and high paper production capacities, which is why Germany is a net-importer of waste paper (BVSE-Fachverband Papierrecycling, 2018).

The dutch paper and board producing factories have high input rates of waste paper like the Germans do. Significant about the Netherlands is that their wood pulp production is nominal with 46000t compared to its paper production capacity with 2.76Mt. For that reason the Netherlands import pulp in big amounts (UNECE, 2015). The Netherlands are a transit place in terms of waste paper owing to its geographic location and seaport infrastructure (Magnaghi, 2014).

North America is major producer of virgin fiber for wood pulp as shown in Table 18 and at the same time the USA is major exporter of waste paper with 20.04Mt in 2012.

Table 18: Global virgin fiber production per region in 2012 (Magnaghi, 2014)

Global virgin fibre production per region in 2012	**Mt**
North America	67.42
Europe	45.47
Asia	41.31
South America	22.04
Australasia	2.94
Africa	2.03
Sum	**181.21**

Around 600,000 tons of waste paper, are annually used for producing thermal insulation, asphalt cardboard and gypsum card panels. Additionally, there is a share of paper boxes and newspapers, which are used for packaging (e.g. in a supermarket) and other uses. These amounts escape hereby the waste paper collection. Hygiene paper products, wallpaper and a great majority of papers used in food and liquid packaging, as well as multilayer and special papers mostly don't enter the usual recycling cycle at all. These papers cover around 20% of the global paper and board production (Magnaghi, 2014). It has to be stressed that regional variations in price and availability of wood pulp influence the waste paper market (United Nations Environment Programme, 2015).

Table 19 shows the Paper and Board Production by Region in Percent in 2015. The global paper and board production in 2015 was at around 407Mt. Asia produced nearly 50% of this amount, Europe about 26%, North America about 20%, South America 5,3% and the Rest of the World about 2% (Confederation of Paper Industries, 2017).

Table 19: Paper and Board Production by Region in % in 2015 (Confederation of Paper Industries, 2017)

Paper and Board Production by Region in 2015	**%**
Asia	46.1%
Europe	26.1%
North America	20.4%
South America	5.3%
Rest of the world	2.1%

3.5.2 Technology

Recycled pulp made from waste paper can be used as a substitute for virgin pulp in the paper and board production. Manufacturing paper from primary resources such as virgin timber consumes 60% more energy than using recycling paper. The fiber of waste paper is reusable six to seven times.

Waste paper is segregated into different waste paper grades before it goes into the pulp production. Paper sorting can be done manual or automated. Automated paper sorting systems are classified in two categories:

- mechanical
  or
- optical systems.

There are different types of sensors, such as lignin-, gloss-, stiffness-, mid-infrared-, infrared- and color- sensors.

Automated paper sorting systems offer significant advantages over manual paper sorting systems in terms of human health (dust, dirt and funghi exposure with risk of infections caused by manual sorting), throughput, speed, and accuracy. Therefore, the automation of the sorting process is favourable for efficient, safe, and clean recycling.

In the paper manufacturing process, the different grades are used for the manufacturing of different papers in a targeted manner. For example, for old news papers are used to manufacture newsprint paper, ehite paper is used for white paper production and old corrugated cardboards or old news papers are used to produce new cardboard (Rahman et al., 2013). Recycled paper as raw material is predominantly used to produce newsprint, tissue and paperboard products.

The papermaking process consists of three main steps:

- Pulping
- Papermaking
- Finishing

In the paper factory the sorted waste paper is transported in bales or loose on a conveyor belt to the pulper. Printed paper, such as office- and newspapers have to get the ink removed before they can be processed into new graphic paper grades. The ink-removal process is called de-inking. The two main processes of de-inking are washing and flotation. During the washing process, waste paper is placed in a pulper - a big tank with large quantities of water, in which the paperfibres are liberated from the paperweb through agitation and are broken down to slurry as a result of this process. Undesirable material, such as staples are removed by centrifugal screens. This diminishes the risk of damages in the following processing stages. Hereafter, most of the water containing the dispersed ink is drained through slots or screens, that allow the ink particles to go through but not the pulp. Adhesive particles are removed by fine screening.

In the following flotation process further contaminants are removed. Through adding special surfactant chemicals to the slurry, a froth is produced on top of the pulp. Air is blown into the slurry and the remaining ink adheres to the airbubbles and rises to the surface. Together the bubbles form a foamlayer on top of the pulp, which traps the ink. Then the foam is removed before the bubbles break. After this process the clean, useful fibre can be used in the following papermaking processes (Confederation of Paper Industries, 2013).

3.5.3 India

India has the fastest growing paper and board market in the world. Its paper market increases at a growth rate of about 6 percent annually. In 2012 India produced 10.2Mt and consumed 11.8Mt of paper and board. The two main segments of the market are paper & paperboard (writing, printing, packaging, specialty and tissue paper) and newsprint (newspapers, flyers and other printed material intended for mass distribution) (Ashika Stock Broking Ltd., 2016). The Indian paper and pulp production capacity was at 12.7Mt in 2015 (Ashika Stock Broking Ltd., 2016) and is projected to reach the 20Mt mark in 2020 (United Nations Environment Programme, 2015). India collected 3.4Mt of waste paper and board domestically in 2012 and consumed 5.7Mt of waste paper. That shows that India accounted for imports of 2.3Mt of waste paper (Magnaghi, 2014). India is denoted with a strong paper demand. The increasing demand in paper and board products is caused in the fast growth of the Indian middle-class, which comes along with the growth of sectors such as fast-moving consumer goods (e.g. pharmaceuticals, cosmetics, etc.). Compared with the EU or the USA the Indian per capita paper consumption remained low. Although in 2010 India had 15% of the world’s population it only consumed 2% (Dixon et al., 2012). In 2017 India consumed around 16Mt. That is 4% of the global paper and board production, measured at a global production of 400Mt.

India became an investment destination with great potential in the paper industry, but among others there were some challenges concerning the availability of raw materials to supply the paper mills with wood, recycled paper and residues from the agriculture industry for its pulp needs. Compared with the USA and the EU, the wood availability in India is very low. Forestlands are declining. The Indian government owns the countries forestland and doesn’t provide the forestlands for plantations by the pulp and paper industry. The paper industry suggested the usage of degraded forestland for plantations to meet the demand for fibers. Negotiations by the government about the topic are ongoing for over 15 years. Not only the pulp and paper industry would benefit from the proposed projects, but also the population could benefit from newly created jobs. However, the Indian government does not come to an end in this debate. Paper companies came up with partnerships in which paper companies work together with farmers to support tree plantations. This agro-forestry initiative, launched by the Indian paper industry helps farmers to earn money by planting trees and the paper industry by producing a small percentage of pulpwood, but that's by far not enough to meet the demand (Dixon et al., 2012). According to the Indian Paper Manufacturers Association (IPMA) agricultural residues such as bagasse, rice, wheat straws or cotton stalks provide around 20% of fiber sources for the industry (Dixon et al., 2012). The wood-based raw material supply accounted for 31% in 2011 and the wastepaper-based supply for 47%. The production from waste paper increased strongly from 35% in 2001 up to 47% in 2011, caused by the high number of small and medium-sized paper mills, which rely strongly on waste paper (Suresh and Bhati, 2014).

Brought about by the absence of a well-functioning collecting and recycling system the biggest share of waste paper is imported to meet the demand for fiber substitute. The USA and other western countries are the suppliers for this demand. The high demand for waste paper of China combined with the reduction of paper consumption in developed countries led to high prices of waste paper in recent years.

The Indian literacy level increased through governmental initiatives, which led to an increasing demand for textbooks, notebooks as well as print media such as newspapers. Lifestyle changes led to higher usage of hygiene paper, as well as a rise in corporate activities led to raised paper demand and usage. As a consequence, thereof, increased commercial activity brought higher numbers of packaged goods, which again benefits the paper industry. The strong growth rate of around 15% (between 5 -15%) annually of the printing and packaging industry fuels the demand for paper. The increased GDP growth rate (from 3.7% in 1961 to 7.2% in 2017) led to increased affluence of the population, which again led to increased consumption per capita of paper products.

Obsolete technology characterizes the state of the art of the Indian paper industry. Most paper mills have a small or medium-sized capacity. Compared to the paper industry of the EU or the USA the machines in India have a very high energy consumption, which, in turn leads to high cost of energy for the mill owners (Worldbank, 2019; Dixon et al., 2012). In 2012 there were around 88 mills with a high production capacity over 50,000 tons a year, covering 53 percent of the overall capacity of the industry (Suresh and Bhati, 2014). Back in 1951 India had only 17 paper mills with a capacity of 0.14Mt. Today there are around 825 paper mills in India with a capacity of 15.3Mt (Suresh and Bhati, 2014). Environmental groups and regulations demand investments in state of art pollution prevention equipment and technologies. These investments could have positive effects on other players in the value chain like machine manufacturers and chemical suppliers too (Dixon et al., 2012).

In 2017 India imported 0.8Mt more waste paper than in the year before. This equals an increase in demand of imported waste paper of 25% during one single year. India's waste paper import rose even faster with 133% in between six months from April-September of 2018 (Jha, 2018).

Outlook: The projected paper production by 2025 for India is 22Mt (Ambati, 2017). Based on this outlook, India's waste paper demand will stay on the rise in upcoming years. Caused by the Chinese import ban, which came into effect in the beginning of 2018 there was a shift from waste paper exports from the USA, the UK and the EU away from China. As a consequence, India's increasing waste paper demand may be satisfied through that shift of big shares of exports in the future (Hook and Reed, 2018). (Please see chapter 3.7 for further details on the import ban.) The EU for example exported 200% more waste paper to India during the first half of 2018 compared to 2017 (Khadka, 2019).

3.5.4 China

With 102.5Mt in 2012 China is the biggest paper and board producer and consumer worldwide. Back in 2012, 44.7Mt of waste paper were collected and 75Mt were consumed (Magnaghi, 2014). By consuming 30Mt of transboundary traded waste paper, China dominated this trade by consuming 60 to 75% of all traded waste paper worldwide. This meant that China was the largest waste paper importer in the world. The PRC has increased their control over the waste paper supply chain by letting large paper companies acquire or establish paper merchants operating in high income countries (United Nations Environment Programme, 2015).

2011 was the first year for China to become the biggest paper and board producer worldwide. In 2012 the domestic per capita consumption increased up to 74.4kg. The USA were China's major waste paper supplier, followed by the EU and Japan (Magnaghi, 2014). Feng (2014) points out that there is an intrinsic shortage of raw materials for paper production in China. There is a continuous increase in demand of wood pulp and waste paper. Feng writes that this ever-growing waste paper demand cannot be satisfied by the domestic waste paper supply. Based on Chinese Forestry reports Feng states that China is short in forest resources. Based on Tang et al. (2015) China's forest-coverage accounts for 20% of its land area. This size represents 67% of the world average. Planted forests contributed to higher levels of forest products production, but the outcome bears no relation to the wood pulp demand by China's paper making industry. China's economic growth is a key driver of waste paper imports. According to Tang et al. (2015) little research has been done on China's waste paper trade. What can be stated is that China relied heavily on increasing amounts of imported waste paper. With an annual growth rate of over 6 percent in paper and paperboard consumption, China's consumption has more than tripled in the past 17 years between 1995 and 2012 from 26Mt up to over 100Mt in 2012. Since 2006 demand and supply of paper products in China are identical. That means that the Chinese industry produces as much paper and board products as the country consumes. Despite this balance, China depends on waste paper imports for its paper and board production.

Tang et al. (2015) describe the two main reasons why there is a gap between wood pulp demand and actual production of China. First, there is the lack of forest resources. Second, in the late 90ies after a devastating flood of parts of the Yangtze River, logging restrictions in natural forests as part of the Natural Forest Protection Program were introduced, leading to a decrease of wood pulp production. Waste paper consumption surpassed wood pulp consumption in the period between 1995 and 2012. Waste paper consumption increased with an average annual growth rate of 12% from 9Mt in 1995 to around 75Mt in 2012.

China’s technical progress concerning waste paper usage in the last 20 years is one of the reasons accounting for the difference between waste paper production and consumption. That technical progress made it possible to substitute input resources with waste paper. Therefore, waste paper became a very important raw material in China’s paper and board industry. The economic growth of exporters has impacted the raw material supplies to China as well, but considerably less than China’s own economic growth. For the future the fast-growing and high-yielding planted forests (e.g. eucalyptus) will be an important raw material source in form of wood pulp for the paper and board producing industry. Additionally, China’s waste paper collection rate is growing steadily. Those facts combined may influence the future of China’s paper industry in terms of supply.

The Chinese waste paper imports peaked in 2013 with imports of 31.65Mt. In the subsequent years this number was decreasing steadily to around 26Mt in 2016. That shows that the all-time high in terms of waste paper imports could already have been reached in 2013. The consumption of printed-paper products decreased strongly parallel to the increased use of information technologies in developed countries. The same development could occur in the future in China and would in turn impact waste paper imports (Tang et al., 2015).

Household paper consumption can reflect the standard of living of an individual. Household paper includes tissue paper, facial paper and other hygienic paper products for household, industrial and commercial uses. The household paper consumption in developed countries is mostly higher than that of people living in developing countries. China’s rapid development in the past years led therefore to an parallel increase of household paper production and consumption (Shi, 2013).

Tissue and packaging paper are two product types in the Chinese paper industry with strong growth, whereas the output of newsprint and coated printing paper is decreasing (Yongxin, 2016). Estimations show that China could produce a third of all tissue paper worldwide in about 10 years (Elhardt et al., 2018).

Table 20 shows the production of main paper and board grades in 2014 and 2015 in Mt, as well as the change in terms of the production amount in percent. In this Table the decrease of newspaper with about -9%, together with the increase of Household, specialty and other papers and boards are the biggest changes in Chinas paper producing industry.

Table 20: Production of Main Paper & Board Grades in China in 2014 and 2015 (China Paper Association, 2016)

Production of Main Paper & Board Grades	Mt in 2014	Mt in 2015	Change in %
1. Newsprint	3.3	2.95	-9,23
2. Uncoated printing & writing papers	17.2	17.45	1,75
3. Coated printing papers	7.8	7.7	-0,65
Coated art papers	6.9	6.8	-0,73
4. Household paper	8.3	8.85	6,63
5. Packaging paper	6.5	6.65	2,31
6. White board	13.95	14	0,36
Coated white board	13.45	13.4	-0,37
7. Liner board	21.8	22.45	2,98
8. Corrugating medium	21.55	22.25	3,25
9.Specialty papers and boards	2.5	2.65	6
10. Other papers and boards	1.95	2.15	10,26
Sum	**104.7**	**107.1**	

Waste paper can be used in the production of all paper types to an extent of around 90% except tissue paper with around 60% (Confederation of Paper Industries, 2013).

Outlook: With implementing the import ban in 2018, China's waste paper imports have been consciously cut back by its government. Therefore, there will be no further increase in waste paper imports by China.

3.5.5 South America and Africa

Africa and South America have lowest and second lowest per capita consumption of paper and board with 4.15kg and 34.9kg worldwide. In the following table this data can be compared to other regions in the world.

Table 21: Apparent per capita consumption of paper and board in kg in 2012 (Magnaghi, 2014)

Apparent per capita consumption of paper and board in 2012	kg/cap/yr

North America	242.0
Europe	137.0
Australasia	112.6
Asia	43.0
South America	34.9
Africa	4.15

3.5.5.1 South America

South America produced 20.98Mt of paper and board and consumed 13.1Mt of waste paper in 2012. They collected 12.2Mt of waste paper themselves, exported around 1Mt and imported 1.9Mt (Magnaghi, 2014). South America is today where China was 20 years ago. Low labor cost, big work force, a good investment spot for the manufacturing industry. The chemical pulp-producing sector in South America plans to expand up to 30Mt until 2020. South America has a small paper and board production capacity in comparison to the USA or the EU, but expansion plans signal a strong growth regarding wood pulp production capacity as South America is a wood pulp supplier of China (Deloitte Global Services Limited, 2013). Between 2007 and 2015 Brazilian pulp capacity experienced a cumulative annual growth rate of 9.8% from 7.5Mt of produced wood pulp in 2007 up to more than 16Mt in 2015 (Burns, 2017).

Oulook: South America’s waste paper import demand won’t grow in the near future because of the continuously increasing domestic wood pulp production.

3.5.5.2 Africa

Africa produced 4.42Mt of paper and board in 2012 and consumed 2.6Mt of waste paper that same year. 2.75Mt of waste paper were collected. 193,000t were exported and 36,000t were imported. The paper recycling potential in Africa is huge. In 2015 the paper recycling rate was at around 25% (FAO Forestry Department, 2016). South Africa has had a 2.3% increase up to 1.6Mt in terms of wood fiber production in the year 2012, that shows that there is a small but growing pulp and paper industry (Magnaghi, 2014). But despite this fact the industry in South Africa and Africa in general won’t play a major role in the global context of the waste paper market after all.

Outlook: Although Africa is a huge continent there is almost no paper industry at all. With around 4Mt of paper production there is no domestic demand for waste paper. Africa is even exporting a share of their collected waste paper, because it cannot use it respectively doesn’t need it for its own domestic paper industry.

3.6 The plastic scrap market

3.6.1 Mass flows

As can be seen in Table 22, the global production of plastics in 2012 was around 288Mt and the annual volume of globally traded plastic scrap around 15Mt (Velis, 2014). After Geyer et al. (2017) the global plastic scrap use was estimated to be around 50Mt in 2012. Global production of plastics went up to 299Mt in 2013, to 322Mt in 2015 and to around 335Mt in 2016 (Plastics Europe, 2018). That shows that there has been a growth of 10-15Mt in global plastics production per year between 2012 and 2016. In 2015 the amount of globally traded plastic scrap increased from 5%wt. of the annual new plastics production in 2012 (Velis, 2014) up to around 10%wt. in 2015 which equals about 32Mt (Plastics Europe, 2016).

Table 22: Global plastics production, plastics scrap use and plastics scrap trade in 2012

MASS FLOWS	**Mt**	**year**	**source**
Global production	**288**	2012	Velis, 2014
Plastics scrap use (global)	**50***	2012	*Estimates of the proportion of recycled plastic waste based on data in Geyer et al. (2017) (incineration excluded).
Plastics scrap trade (global)	**15**	2012	Velis, 2014

The PRC dominated the international plastics recycling market. Plastic scrap imports in China increased rapidly in recent years. There was a strong dependence from Europe and North America on China to absorb its exports. Countries such as Vietnam, Malaysia and Indonesia imported plastic scrap to reprocess it and afterwards re-export the reprocessed plastic scrap to China, as well as their domestically collected plastic scrap (Velis, 2014).

As shown in Table 23 China imported around 14.7Mt of all plastic scrap globally traded in 2012. As second-, third- and fourth-biggest importers follow the USA, the Netherlands and Belgium.

Table 23: Top plastic scrap importers in 2012 in Mt (Velis, 2014)

Major plastic scrap importers in 2012	**Mt**
China	14.66
USA	0.41
Netherlands	0.38
Belgium	0.33
Others (countries with imports <0.33Mt per country)	0.07
Sum	**15.85**

Table 24: Top plastic scrap exporters in 2012 in Mt (Velis, 2014)

Major plastics scrap exporters in 2012	**Mt**
China	3.87
USA	3.69
Japan	3.31
Germany	2.45
United Kingdom	1.07
Others (countries with exports <1.07Mt per country)	0.04
Sum	**14.43**

Table 24 shows the top exporters regarding plastic scrap in 2012. The biggest share of exports with nearly 27% was exported by China, which equals 3.9Mt, followed by the USA with 25.6% amounting to 3.7Mt. Japan is the third biggest exporter. Germany and the UK are forming fourth and fifth strongest exporters.

The overall sum of worldwide plastic scrap imports in 2012 were 15.8Mt and the overall sum of worldwide exports was 14.4Mt. Figure 8 stresses the size of the overall secondary plastics production in contrast to the overall primary plastics production from 1950 until 2015 in the total plastic production cycle.

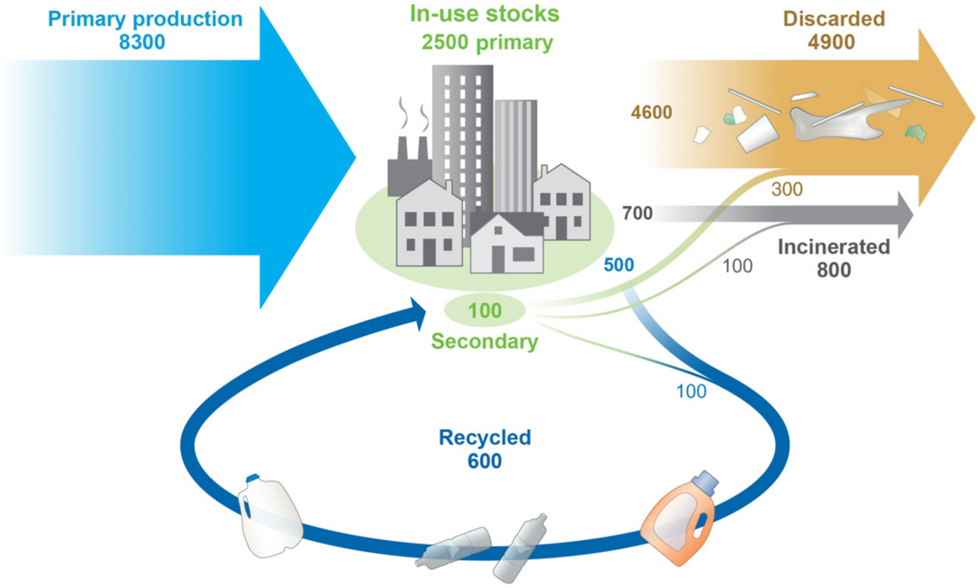

Figure 8: Global production, use, and fate of polymer resins synthetic fibers, and additives 1950 to 2015; in million metric tons (Geyer et al., 2017)

Table 25: Plastics Production by region in Mt in 2015 (Plastics Europe, 2016)

Plastics Production by Region in 2015	Mt
China	89.5
Europe	59.6
NAFTA (North American Free Trade Agreement region)	59.6
Rest of Asia	53.8
Africa	23.5
South America	14.2
Japan	13.8
CIS (Commonwealth of Independent States)	8.4
Sum	**322.4**

Table 25 depicts the plastics production of 2015 by region in Mt. China is the clear leader with nearly 90Mt, followed by Europe and the North American Free Trade Agreement region with 59.6Mt each (Plastics Europe, 2016). Asia alone produced 50% of the globally produced thermoplastics and polyurethanes which account for the major share of 84% of the global plastics production in 2016 (Plastics Europe, 2018).

The packaging industry is estimated to be the fastest growing end market for recycled plastics. It is the largest user of virgin and recycled plastics. Rising population growth numbers and the resulting need for more consumer goods drive the demand in the packaging industry. Governmental initiatives and the increased consciousness about the arising environmental benefits going hand in hand with the utilization of recycled plastics were a major reason for the growth of recycled plastic usage in the packaging industry (Research and Markets, 2018).

Eriksen et al. (2018) classified plastics after their requirement specifications for plastic application areas based on EU legislation. They defined three quality levels. High-, medium- and low-quality. The high-quality level is assigned to materials approved for food contact, which represents the strictest legal material requirements. The medium-quality is assigned to materials that can be used for toys, pharmaceuticals, and electrical and electronics, representing lower and varying legal material requirements. The low-quality is assigned to materials with minimal legal requirements. Eriksen et al. (2018) emphasize that high quality recycled resins can only be recovered out of high-quality plastics in the first place. So, the high-quality level can be used as a substitute for all virgin polymer types, but not the medium- and low-quality plastics.

However, there is increased use of recycled resins in the food and beverage packaging segment. This growth is reasoned in a relatively new technological advancement that made it possible to use recycled resins in food packaging in the first place. The MarketandResearch Institute has estimated Polyethylenterephthalat (PET) to be the fastest-growing resin type in the recycled plastics market. PET is easier to recycle compared to other plastic types. PET bottles have the advantage, that they can be easily collected and sorted.

For the period between 2017 and 2022 North America is forecasted to be the fastest-growing market for recycled plastics. The recycled plastics market growth in North America can be attributed to several initiatives promoting the use of recycled plastics. Coca-Cola, Unilever, Walmart, Target Corp., Procter & Gamble Co., Ecover, Evian, L'Oréal, Mars, M&S, PepsiCo, Campbell Soup, Amcor Werner & Mertz, and Keurig Green Mountain Inc. united to the Association of Plastics Recyclers (USA) to raise the share of recycled plastics in their products. Recycled plastics are increasingly used in the packaging, automotive, electrical & electronics and textiles industries. Additionally, there are many initiatives by governments in many countries, who are promoting the use of recycled plastics. Problematic factors, which are restraining the growth of the recycled plastics market are the high cost of recycled plastics and the fierce competition from virgin plastics in terms of performance (Research and Markets, 2018).

Market and Research found that Asia Pacific constituted the largest market for recycled plastics in 2017. The large manufacturing sector combined with the big work force, competitive cost base and growing consumer demand together with rising spending power will lead to an expected further drive of the industrialization of the region (Wood, 2018).

Figure 9 shows the market shares of the global packaging industries by geography based on the total market size of 400 Billion $. The pie chart shows a relatively even distribution of market shares between North America, Europe and Asia and the Middle-East & African countries. South America (depicted 'Latin America' in the figure below) on the contrary has a share of about 5%. The global packaging market is segmented in food packaging, beverage packaging, health care packaging, cosmetics packaging and other consumer goods packaging. Figure 10 depicts the global packaging market shares by end markets based on the total market size of 400 Billion $. Food packaging had the major share of 51% of the global packaging market volume in 2012.

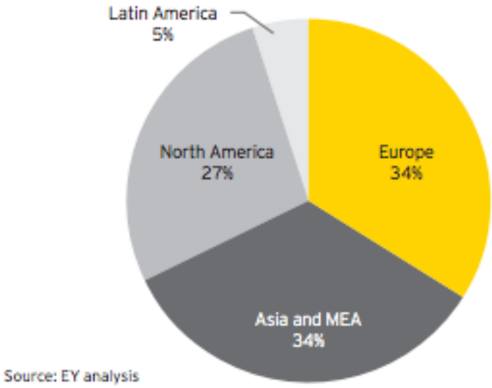

Figure 9: Global packaging market shares by geography – 2012, Total market size = 400 Billion $ (Neil-Boss and Brooks, 2013)

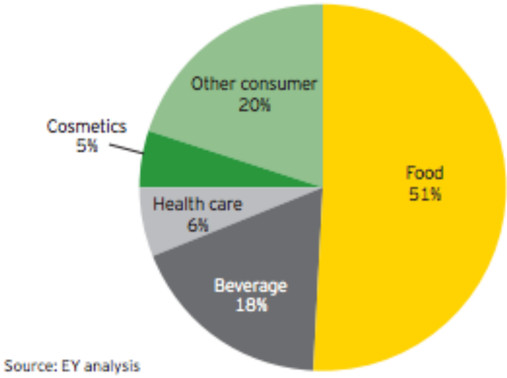

Figure 10: Global packaging market shares by end markets – 2012, Total market size = 400 Billion $ (Neil-Boss and Brooks, 2013)

The packaging market volume growth in the Asian-Pacific region will make up 63% of the global growth in the packaging industry (Association for Packaging and Processing Technologies, 2016).

As far as virgin plastic prices do not drop below those of secondary plastic resins there will be future demand for secondary plastic resins in the USA, Europe and in the Asian-Pacific region especially in India and China. Steady demand will come from North-American packaging companies and consumer brands, because of new targets regarding the utilization of secondary plastic content in their packaging they set themselves (Research and Markets, 2018). As an example, for such a new target, Amcor as one of the biggest packaging companies worldwide, has set itself the goal to develop all of its packaging to be recyclable or reusable by 2025. Furthermore, the company wants to increase its use of recycled materials and become a leader in recyclable packaging (Mordorintelligence.com, 2018).

3.6.2 Technology

Plastics recycling is classified in three main categories:

- Mechanical recycling
- Feedstock recycling
- Energetic utilization

Mechanical recycling means the recovery of the raw material, whereby it can be used again in the manufacturing process of new products. Fossil-based primary plastics are processed into powders or granules. The concepts for storage, transport and processing of the plastics processing industry are designed for it. This is why reprocessed plastic scrap are also processed into granules, regrinds or agglomerates.

High quality in terms of plastic scrap means the purity of a certain plastic type without any impurities or contaminants. The quality characteristics are defined by the desired end product (Mellen and Becker, 2018). Due to the variety of different plastic end products there is a broad width of different qualities of reprocessed secondary plastics reaching from high-, medium-, to low-quality plastics as Eriksen et al. (2018) classified in their study (Mellen and Becker, 2018; Eriksen et al., 2018).

The typical steps for reprocessing post-consumer plastic scrap are:

- Sorting
- Shredding
- Metal separation (ferrous and non-ferrous)
- Secondary crushing
- Washing
- Sorting based on particle level (e.g. colour or density)
- Drying
- Agglomeration
- Granulation
- Compounding

Feedstock recycling means the use of the characteristics or the component parts of a plastic type. For example, plastics can be used as reductant. During the production of crude steel, carbon is needed for the reduction of the share of oxygen in ferrous oxide. Plastic scrap can be used as carbon carriers for chemical reactions like this (Mellen and Becker, 2018). Al-Sabagh et al. (2016) describe methanolysis, glycolysis, hydrolysis, ammonolysis and aminolysis, which are chemical recycling steps used in the PET recycling process.

The energetic utilization uses the calorific value of the plastics. Plastics have high calorific values due to their chemical composition and the relation to coal and oil. With values above 30,000kJ/kg they can be used as alternatives for fossil fuels to produce steam, electricity and heat (Mellen and Becker, 2018). Those alternatives for fossil fuels are foremost used in cement production, conventional power-plants and mono-combustion plants (Beckmann and Thomé-Kozmiensky, 2006).

3.6.3 China

China produced nearly 90Mt of plastics in 2015. Velis (2014) states that China is the key player in the global plastic scrap market. China has received 56%wt. of global plastic scrap imports in 2012. The EU exported in recent years around half of all collected plastics for recycling. 87%wt. of all EU-exports was going to China in 2012.

As mentioned above China is the biggest plastics producer and at the same time the biggest plastic scrap importer worldwide. The country imported 14.66Mt of plastic scrap in 2012 (Velis, 2014). The domestic plastic scrap collection increased from 7 to 15 Mt between 2006 and 2011 (United Nations Environment Programme, 2015). Based on estimates the domestically processed plastics scrap in 2011 (domestically collected scrap plus plastic scrap imports) was around 26Mt (United Nations

Environment Programme, 2015). Like many other countries the USA strongly depended on China as their plastic scrap buyer. In the past years the USA was China's largest plastic scrap supplier.

Hong Kong distinguished from Mainland China in having more lax import rules and enforcement of these rules. Therefore, it is speculated that Hong Kong was frequently preferred over direct export to Mainland China, because it was used as an entry point for the Chinese market. Hong Kong was a key destination for plastic scrap exports from the UK. In 2010 they exported nearly 90% of their plastic scrap to Hong Kong. The advantage of exporting to Hong Kong instead of Mainland China was that Hong Kong accepted imports of mixtures of plastic scrap whereas Mainland China would only accept mixtures of plastic scrap that include polyethylene (PE), polyvenyl chloride (PVC), polystyrol (PS) and PET. It was also noticeable that Hong Kong was exporting most of the domestically collected plastic waste arisings. In Hong Kong preliminary sorting and cleaning took place. Afterwards the material was exported to Mainland China.

A study by the University of Leeds found out that countries of the Association of South-East Asian Nations, mainly Vietnam, Malaysia and Indonesia served as intermediate plastic waste processors between Western countries and Mainland China. They imported plastic scrap and re-exported it afterwards to China for further processing and usage as secondary raw material in the plastics industry. Much the same as Hong Kong, they exported their own domestically collected plastic scrap to Mainland China.

Over the past years the long-term demand of China for plastic scrap was closely related to the fact that China couldn't satisfy its own high demand. Therefore, China had to import huge amounts of primary material. Back in 2012 China almost imported half of their demand of primary material. Recycled plastics were a welcome opportunity to substitute primary materials and satisfy demand for plastics (Velis, 2014). The institution ‚More Recycling' reports that 52% of post-consumer film plastic and 34% of post-consumer non-bottle rigid plastic acquired in the USA were exported primarily to China and that even if the USA wouldn't want to export the material, they would have to because they lack the domestic sorting capacity (More Recycling, 2017). In 2016 China imported significantly lower volumes of plastic scrap compared with the years before. China started to implement its intentions to close down highly polluting factories and announced a change in import regulations (Chiao et al., 2017).

China's plastic reprocessing industry consists of thousands of plastic reprocessing facilities with varying degrees of technological and operational sophistication. Back in 2009 the key province involved in the reprocessing of recovered plastics imported from the UK was Guangdong, which is the closest province to Hong Kong. The end markets for recovered plastics vary depending on the plastic grade (WRAP, 2009). There are thousands of low-tech reprocessors in China. In 2008 nearly 40% of the plastic reprocessor entrepreneurs went out of business as a result of the economic crisis. Those low-tech companies often operate without rules for operation, quality standards or inspections. Therefore, there is no quality guarantee for recycled products made by low-tech companies. Products like plastic bags, disposable dishware or stationary items are produced in large quantities and after that sold to retailers at low prices. People believe incorrectly that those cheaply manufactured products from China are sold to Europe or the USA, but that's not happening. The big part of the products containing imported plastic waste is consumed in China.

The characteristics and with that the quality of domestic plastic scrap is diverging from that of imported plastic scrap. Domestic plastic scrap is of lower quality than imported plastic scrap. Chinese manufacturers tend to add high amounts of additives like cheap fluorine surfactants. By doing that they are reducing the recyclability of the plastics at the same time. Therefore, two types of recyclers were distinguished based on the type of plastics they were reprocessing. The ones reprocessing imported plastic scrap and the ones reprocessing domestic plastic scrap. The importing recyclers have higher labor productivity due to higher quality inputs. The applied technology in plastic recycling facilities in China was improving in the past years. The application of optical sorters as well as bottle and flake systems increased (Velis, 2014). Velis (2014) writes that more than 50% of plastic scrap are recovered as energy in China. Due to impurities it's not possible to incorporate all imported plastic scrap into products. Chinese importers maintain some stock of the material with which they are trading, so they can better negotiate while purchasing and are not reliant on buying at poor and fluctuating market conditions (Velis, 2014).

Packaging and agriculture are the largest markets for recycled plastics in China. As part of a survey conducted by WRAP (Waste and Resources Action Programme) 100 Chinese plastic reprocessors were examined on what they produce out of imported plastic scrap from the UK. The major share of them manufactured the plastic scrap into recompounded pellets. The smaller share produced plastic fiber, plastic film, clean flake and a product different from plastic film or fiber out of it. Those plastic products are mainly applied in non-food packaging with 31%, in agriculture with 13% (e.g.: cover feature), textile 13%, construction 10%, automotive 1% and others 21%. 11% of their end applications are unknown.

Recycled polyvenyl chloride accounts for the largest proportion of polymers in the construction market in China. It is difficult to identify the type of polymers and associate them with products they are used in, because there is such a huge diversity of products. Recycled high density polyethylene (rHDPE) is applied in buckets, recycling bins, bottles, pipes etc. Recycled low density polyethylene (rLDPE) is often used in agricultural film and in the south, it is used for packaging and shoe manufacturing. The PET recycling market in China is well developed. PET bottles have been collected in China for decades. Most collected PET bottles are reprocessed into spun yarn, which is used as fiber for non-woven fibers, filament fibers and fiberfill (Velis, 2014). Recovered PET is mostly used in fiber applications, like fillings for anoraks, sleeping bags, toys, upholstery and applications such as insulation, roofing felt, rope and automobile lining (WRAP, 2009). A share of the recycled PET bottles is converted into non-food bottles and some non-bottle PET is used in paints and wood varnishes. Pipes, trays, battery cases of cars etc. are made out of imported waste polypropylene (PP) (Velis, 2014). A study by ‚More Recycling' about ‚End market demand for recycled plastic' found out that lumber and fencing has the highest level of post-consumer resin (PCR) content out of all reported products of their study with nearly 100% PCR content on average. Furthermore, the study found that rigid applications like carts and plumbing products have PCR content of 25-100%. Whereas bottles and bags have a PCR content of 25% on average (More Recycling, 2017).

In 2013 Chinese customs implemented a campaign called the 'Green Fence Operation' (GFO) by enforcing legislation on the quality of imported waste scraps like plastic scrap. In this way China wanted to reduce illegal shipments, increase the quality of imported waste scraps and minimize illegal scrap trading within the country. At this point in 2013 many western countries were already dependent on Chinas demand for secondary raw material in form of waste scraps. They were used to China as a key customer. Back in 2013 when China started to enhance the GFO, doubts were developing about the future of the recycling industry as the western recycling companies were used to. The implemented measures affected global plastic scrap export markets immediately and had an impact upon the entire value chain.

By enforcing Chinese legislation through the GFO, business between sites licensed to import plastic scrap and third-party recyclers has been reduced. In the course of enforcement of the corresponding laws China's government closed small factories and allowed waste import licenses to expire when there was evidence that operations were not carried out to the required standard (Velis, 2014).

Outlook: As further described in the next section, China implemented a ban on different types of wastes including household plastic scrap in 2018. This led to a shift of trade routes away from China to Southeast Asian countries like predominantly Malaysia, Vietnam and Indonesia. Malaysia for example imported nearly the fourfold amount of plastic scrap compared to the year before from the EU and it also became the top destination for exporters like the USA and the UK. Malaysia and Vietnam decided after the flood of plastic scrap imports to limit those imports as well (Reuters, 2018; EUWID, 2018b).

3.7 China's import ban

Following the GFO initiative from 2013 China decided to forbid the import of solid wastes that are highly polluted, as the countries' government stated in their notification to the World Trade Organization (WTO) in July 2017. The impacts of the 2013 launched GFO initiative were successful but have only been temporary, therefore China had to set stricter measures in terms of imports. With the start of the year 2018 China implemented a ban on imports of 24 types of waste under four categories. These four categories include types of mining slag, household plastic scrap, unsorted waste paper and waste textiles. China set a contamination limit of 0.3% for the waste imports of those 24 waste types. The recycling industry states that this limit is impossible to reach especially for products such as mixed paper, and PET plastic bottles (Allington, 2017). For the USA, countries in the EU and many more, the import ban led to tons of scrap material that had to be stored in warehouses, ports or recycling plants. Recyclers had to rent storage facilities to store the built-up bales of waste material (Phillips, 2017).

For past decades the shipment of waste from the USA to China was profitable because the shippers offered the companies discounted prices, elsewise they would have had to send empty ships back to China. In short, the cheap exports were possible because of the big import volume of manufactured goods from China.

The USA, as well as the EU and other countries used to ship waste to China and imported cheap finished goods in return. The last decades these trade relations brought China the reputation as the world's garbage dump (Allington, 2017). Besides other countries the USA is now in a situation where they have a surplus of waste paper and plastic scrap as well as additional trade losses caused by empty shipping's to China. Recycling companies in the USA try to find byers in other regions of Asia for example in India, Vietnam and South Korea (Phillips, 2017).

The UK is pressurized like the USA by China's ban on imported plastic scrap. Its recycling industry lacks capacities to process the amounts of scrap, which were usually exported to China for the past years. The UK relied strongly on China regarding the recycling of their waste. According to UK's Environment Secretary Michael Gove the

UK's government did not prepare for the ban on waste imports from China and underestimated the impact of the Chinese waste import ban. The country is now realizing that they have to start investing in recycling plants and recycling infrastructure (Musaddique and Gabbatiss, 2017). Allington from the USA-Bureau of National Affairs emphasized the role of Wang Jiuliang's 2016 documentary ‚Plastic China' in regard of China's environmental policy shift and the pushing through of the import ban. In this documentary China's mostly unregulated recycling industry as well as the concomitant environmental pollution and human health endangerments are shown (Allington, 2017).

3.8 Price volatility of secondary raw material

Secondary raw materials are price volatile. They are even more price-volatile than primary materials. They were used in the past to substitute bottlenecks of primary material. In recent years it became clearer that there can be an economic and environmental benefit in using secondary raw material resources. According to the United Nations Environment Program, primary and secondary raw material prices are both becoming more and more volatile. The market instability which was created through price crashes like back in 2009 during world recession or back in 2014 during the slump in oil prices poses a major threat to the sustainability of recycling programs around the world (United Nations Environment Programme, 2015).

Raw material prices are influenced by different factors than secondary raw material prices. Secondary raw material prices are dependent on cost and efficiency of waste collection and processing. In the secondary resources market, acute price volatilities appear and drops of raw material prices based on changes e.g. of the oil price can lead to negative market conditions. Secondary raw material is sidelined as soon as there is intense competition in the form of lower-priced virgin material available on the market.

The circular economy cannot succeed as long as there are market guidelines missing for a stable circular economy with reliable and predictable off-take markets. The entire supply chain is affected by stagnation at the off-take markets. Over the past years, drops in the oil price have lowered the price of virgin plastics to below that for recovered plastics several times (European Federation of Waste Management and Environmental Services, 2015). Plastic price crashes happened for example during spring 2015 and as well during spring 2016 (Clark, 2015). Depressed prices are leading to hard circumstances for recyclers and reprocessors. They are unable to compete if prices of virgin material fall below that of recovered material. This puts the entire secondary raw material value chain at risk for the concerned materials (European Federation of Waste Management and Environmental Services, 2015).

4. Recycling practices in low- and middle-income countries

Asia is the most important global player in the recycling market. The People's Republic of China (PRC), India, Indonesia and other Asian developing and emerging countries are importing materials for the purpose of recycling from high-income countries. The imported materials are essential resources for these fast-growing economies. Over the past decades the low labor and operating costs, as well as the different manufacturing quality standards have led to the outsourcing of intensive manufacturing industries and raw material extraction from developed to developing countries. Another reason for outsourcing of manufacturing industries are the missing environmental standards or the not so stringent environmental regulations compared to developed countries such as the EU, the USA, Canada and Japan. Developed countries have been avoiding compliance costs and have been generating benefits by selling waste to developing countries. Therefore, exporting wastes is profitable for developed countries because of the avoided costs and potential profits, as well as for developing countries because they acquire valuable amounts of secondary resources (United Nations Environment Programme, 2015).

After a short systematic approach on the risks, environmental- and human health-damages originating from crude recycling processes, the author gives examples of recycling processes for each treated material stream, except aluminium scrap because of lacking data.

4.1 Risks, environmental and human health damages

Recycling processes in the informal sector pose huge occupational hazards for the workers (Toxics Link, 2011). This stems from the fact that informal workers often are not aware of the risks and effects originating of handling waste without proper safety protection. First and foremost, they have no access to safety equipment like gloves, helmets or respirator masks (Plastic China, Wang, 2016).

Informal recyclers contribute to collection of waste, reuse, reprocessing and recovery of secondary raw material, but they are forced to use primitive techniques to recover those materials. For example, such a primitive technique is the open burning of wires. The wire insulation usually contains polyvinyl chloride (PVC) or brominated flame-retardants (BFRs). If burnt, the emissions and ashes of these substances contain high levels of toxics like brominated and chlorinated dioxins and furans, which are both persistent organic pollutants (POPs), as well as cancer-causing polycyclic aromatic hydrocarbons (PAHs) are also highly likely to be present in the emissions and ash (Puckett et al., 2002). Primary pollutants are contained in the product, whereas secondary pollutants are generated by using crude processing methods.

Informal recyclers are exposed to a range of pollutants, injuries, respiratory and dermatological problems, infections and many other serious health issues, which highly affect their life expectancy. Additionally, the mismanagement of waste exacerbates environmental pollution of air, soil and water. The originating environmental pollution is diverse in toxicants and depends on the levels of exposure. The contamination of air, soil and water can reach extremely high levels near to informal recycling sites. Toxic heavy metals, such as lead, chromium, as well as the above-mentioned POPs, PAHs and BFRs are common contaminants. Due to insanitary working conditions and a lack of washing facilities, informal workers can transport toxic substances to their homes (Yang et al., 2018).

4.1.1 Steel scrap from ELVs in China

Zhao and Chen examined the Chinese End-of-Life Vehicle (ELV) recycling system. They found that China has a large number of illegal dismantlers. Vehicles are dismantled by them, but also by the car owners themselves. The illegal dismantling activities harm the environment to a great extent. Unprofessional dismantling activities lead to leaking waste oil into the ground and randomly dumping toxic substances, which cause serious pollution of land and groundwater. Cables are burnt to obtain copper, in full disregard of air pollution.

Qualified recyclers start the dismantling process by collecting the waste fluids, waste oils and hazardous materials. The usable parts and components of the vehicle are dismantled by hand (e.g. wheels, tires, fenders, engines, transmission...) and sold afterwards without any inspection and processing, based on eye observation and experience to determine whether they can be reused. The remaining parts of the ELV are cut into blocks for easier transportation before they are shredded in a next step. After that the metal is sent back to the steel industry and remelted in the steel production process.

Zhao and Chen (2011) compared the Chinese ELV recycling process with the Japanese recycling process. They describe China's dismantling plants as generally small, lacking of professional equipment, experience, management specifications and technologies. Furthermore they have a low dismantling efficiency, combined with low recycling rates and environmental pollutive proceedings. After Zhao and Chen (2011), the revenue from selling scrap metal is the main benefit of the automotive recycling companies (Zhao and Chen, 2011).

4.1.2 Printed circuit board recycling in China

Beside recyclers in the formal sector, wich are conducting the mechanical recycling process of printed circuit boards (PCBs), primitive technologies are used by the informal sector in China for recycling of PCBs. Workers use chisels, hammers and cutting torches to open solder connections and separate various types of metals and components. The dismantling of PCB assemblies is more difficult. To disassemble the assemblies, they are cooked on a coal-heated plate and melted in a wok or on an iron plate. Black fumes rise from the cooked scraps, as well as a pungent smell emenates from the workshops where those ways of proceeding take place. The goal is to obtain the chips and other recovered components of the PCBs in order to resell them for further processing and furthermore recover the solder remaining on the board by exposing it to a temperature higher than its melting point. Informal recyclers improved this crude recycling technique by using electric heating plates, which are semi-enclosed, temperature-controllable, and comprise a gas collector for exhausted gases. During the desribed PCB assembly and dismantling processes toxic products from resins and adhesives are decomposed (Zeng et al., 2012).

4.1.3 Low-tech paper sorting in Brazil

In one of the first waste pickers' collectives in Brazil called ASMARE standing for ‚Association of Paper, Cardboard, and Recyclable Materials', waste pickers sort waste paper by sorting through heaps of material piled on the floor with their bare hands. The recycler collective has his own warehouse space where they sort and store the recyclables they collect.

They have no technical equipment. The paper sorting process goes off with workers forming a circle around the material on the floor, sitting on buckets or empty boxes and bending over to a pile of paper to sort the material. To remove glue inside of books, they rip them apart and peel off the binding. The workers there don't wear gloves, so therefore the paper sorting causes many small paper cuts on the workers' hands and the wounds come in contact with dirt. The waste dust inside the warehouse is another negative working condition, which can cause respiratory tract irritations. Women often do the sorting processes. They mostly prefer the job in contrast to the pushing and pulling of the heavy carts, which are used for the collection and transport of recyclables. The collective sells the sorted paper to middlemen, which sell the material to paper manufacturers (de Brito, 2012).

4.1.4 Low-tech plastic recycling methods in China

Around 2008 Wang Jiuliang started investigating the landfill pollution around Beijing. In 2011 he published the documentary film ‚Besieged by waste' and photo exhibition with the same name. From 2012 until November 2016 he worked on the documentary film ‚Plastic China' which deals with plastic recycling in China (plasticchina.org, 2017). The film material reveals insights about the biggest plastics recycling industry in the world. Based on the documentary it can be stated, that at the time the documentary was made, there were around 5000 small recycling companies in Shandong. They were located in about 30 villages. Wang filmed two families for one and a half years living at a plastic recycling plant and documented their everyday lives, including working conditions and surroundings in the documentary.

The plastic processing method on the site is a low-tech plastic pellets manufacturing plant. The workers sort the plastics by hand. They live directly where they work. The workers sleep, cook and eat and wash themselves right on the plant between the heaps of plastic waste. Plastic foil is used to make fire under the cooking stove. The occurring vapors and fumes of processed and burned plastics are constantly inhaled. Crude recycling methods are used, which becomes obvious when the movie displays that the workers don't wear gloves or respiratory masks. The polluted wastewater is directly discharged into the local river. Plastics of all kinds constantly surround kids and adults. The workers report that it's foremost imported plastics. The documentary furthermore shows that the plastic wastes also include medical wastes (Plastic China, Wang, 2016). Illiterate workers are sorting plastic scrap based on the sound the plastics make when thrown to the ground or by smelling them. The plastic waste is melted down by low-end machines, which pose a threat to the air, water and people's health (Sun, 2015).

Wang Jiuliang opines that on the example of the Shandong area it becomes apparent on who's cost Chinas economic growth originated. Wang says that big profits are made, but at the same time the environment and human health is heavily damaged. He furthermore reported that all rivers in the surrounding area are polluted by the direct discharge of wastewater from the recycling plants. Soils, as well as the surface waters are full of plastic chips. Although the recycling plant owners have to pay wastewater fees, no sewage plants are built. Workers there have no rights at all. They get arbitrary paid by the plant-owners. They get no insurance despite there are often on-plant accidents. Women must get back to work 5 days after they gave birth to a child. The newborn babies are carried on the back during work. Children usually play in the heaps of rubbish until they are old enough to start working on their own. The heaps of garbage are dangerous playgrounds. The children often hurt themselves and get injured because of the dirty and sharp materials in the garbage. The injuries often become infected.

One of the company owners told that he gets many different types of plastics delivered. He reported that he is able to ascertain some of the different types of plastics (e.g. polyvenyl chloride (PVC), polyester (PES) or S-benzene and polyoxymethylene) by burning it, observing the smoke development and the discoloration of the plastic part and furthermore smelling the smoke (Plastic China, Wang, 2016).

Wang sees himself as a proponent of recycling. But he stresses that recycling does not have any environmental benefit if realized with raw methods, without any kind of protection, whereby more environmental pollution than benefit is caused (Zhao, 2017).

5. Results

5.1 Demand of low- and middle-income countries for secondary raw materials

The main underlying question of this thesis was if there is high demand of low- and middle-income countries for secondary raw materials. Additionally, the author examined why recycling processes in developing countries are different from processes in developed countries.

The results of the thesis show that there is high demand in some low- and middle-income countries, but a generalized high demand of low- and middle-income countries could not be recognized. The research showed that there are some countries, which are especially involved in secondary raw material trade. It was found that there are main importers and main exporters as well as primary routes for secondary raw materials. The United States, Europe, China and countries in Southeast Asia are the hotspots between which secondary raw materials are traded. China and Southeast Asia are major players in regard of secondary raw material demand. China played the most important role as recipient in the global secondary raw material market during the past years.

China as one of today’s great powers has an enormous big industrial capacity in many different manufacturing sectors. It demands and consumes primary and secondary resources on such a large scale, that it has become the main importer of aluminium and alloy scrap, waste paper and plastic scrap. Until a few years ago secondary raw material demand was increasing steadily in all three aforementioned material streams, but between 2010 and 2013 China’s import demand declined because market maturity was reached in different areas of application, domestic collection rates were growing and regarding aluminium, the domestic scrap availability increased.

China’s import ban which came into effect in March 2018 influences the global secondary raw materials market structure to a big extent, because every other market player was used to China being the main importer of the above-mentioned material groups over the last decades. Especially the United States, as well as the European Union as main exporters of secondary raw materials became dependent on China as their main recipient of big shares of their wastes.

Economic advantages for developed and developing countries are the main drivers for the global flows of secondary raw materials. Summarizing can be stated that apart from steel scrap, where Turkey is the main recipient, the primary routes for secondary raw material trade ran from the USA and the EU to China and India. India’s economy began to follow China’s rapid economic development. Research showed, that the economic rise of this country with its 1.3 billion inhabitants accordingly leads to an increasing demand in resources and therefore also to a high demand for secondary raw material. South America, Africa and Australasia play a minor role in transboundary trade of secondary raw material. Especially Africa’s industrial capacity is too small to play a relevant role in the paper, steel, aluminium or plastics market. Regarding e-waste trade there is a difference. The big re-use market in Africa, combined with its lacking e-waste legislation and low labor cost led to the current state of affairs in which huge volumes of e-waste are exported to Africa.

5.1.1 Steel scrap

In terms of steel scrap trade the main importing country is Turkey. Although China produces the major share of steel worldwide, it does not import big amounts of steel scrap. The reason for this lies in the different steel production technologies used by the two countries. The steel scrap usage ratios differ widely between countries in general, because in the EAF technology steel scrap is used to a high percentage, whereas in the BOF technology, steel scrap is used to a much smaller extent. The fact that China uses almost only the BOF technology to produce its steel explains why the country is not the major importer of steel scrap. Turkey on the other hand uses the EAF technology and produces long steel products, for which low-quality steel scrap can be used. Those facts combined explain why Turkey is the main importing country of steel scrap.

5.1.1.1 Market outlook

Import demand for steel scrap by China is decreasing since 2016 and its domestic steel scrap availability on the other hand will increase strongly in the upcoming years. The decline in import demand will continue. Especially, after China announced another import ban on six different types of waste and scrap of iron and steel, which is coming into effect in July 2019.

Turkey's scrap demand is influenced by the difficult geopolitical situation with regard to President Trumps market foreclosure and its own monetary turmoils, but its steel demand is expected to stabilize and increase again during 2019. This would also mean, that the steel scrap import demand will increase again.

5.1.2 Aluminium and alloy scrap

Major importer of aluminium and alloy scrap is China followed by India. The reason behind the trade routes of secondary aluminium is primarily the high industrial aluminium production of China and India. Concerning the aluminium production, there is no such difference in technologies as there is in the steel production.

5.1.2.1 Market outlook

China's aluminium scrap imports declined since 2010. The import ban coming into effect in July 2019 will lead to further aluminium scrap import declines by China. Increasing primary and secondary aluminium demand in India will be maintained in the years to come. As India's automotive industry as a major consumer of aluminium is expected to increase strongly during the next 15 years, there will be increasing import demand for aluminium scrap by India.

5.1.3 E-waste

The big re-use market and reassembly industry in developing and emerging countries especially in Africa and Asia are the main drivers for the e-waste trade routes. The demand for the secondary raw material is of subordinate interest. For European and North American recyclers, it is much cheaper to export e-waste to developing countries than dealing with it on their own under legal compliance of WEEE-directives or hazardous waste directives. High growth rates of e-waste generation in developing and emerging countries even exacerbate the challenge of e-waste recycling.

5.1.3.1 Market outlook

Domestic e-waste generation rates in China, Ghana and Vietnam have been strongly increasing during past years, but due to the lack of data on import and export volumes of e-waste the author cannot give an outlook on the development of transboundary trade volumes for the upcoming years.

5.1.4 Waste paper

China was dominating the waste paper trade until the end of 2017 by consuming 60 to 75% of the overall traded waste paper worldwide. This stems from the fact, that China has the biggest industrial paper production globally. Additionally, they are short in forest resources what led them to become the biggest importer of worldwide available waste paper to enable meeting their fiber demand. Furthermore, the decrease of newspaper production and the increase of tissue paper production led to further changes in China's waste paper demand. This was because waste paper cannot be used to the same extent in the tissue paper production as in other product streams (Confederation of Paper Industries, 2013). The results about the paper market furthermore show, that North America is the largest producer of virgin fiber globally. Combined with the fact that the USA is the largest exporting country of waste paper, this shows that they have enough virgin fiber to supply their domestic paper industry and can afford to export a major share of their own waste paper arisings.

South Americas intensified wood pulp production combined with its low paper & board consumption figure explains, why waste paper demand marginally exists in this world region. Africa's paper production is so low that Africa is even exporting a share of their collected waste paper, because its own paper production capacity is too small for its use.

5.1.4.1 Market outlook

Indias paper production is projected to increase strongly in the upcoming years. Therefore, India will develop further as an important recipient of waste paper exports by the USA and the EU and will continue to increase its waste paper import volumes. China on the other hand consciously cut back its waste paper imports by implementing the import ban in 2018. China won't change its chosen direction and will keep on conducting its strict import policy. South America will keep on increasing ist wood pulp production and therfore will not increase the waste paper import demand.

5.1.5 Plastic scrap

Trade flows of plastic scrap led mainly from the USA and the EU to China. A major cause is China's huge industrial capacity in the packaging-manufacturing sector. The packaging manufacturing sector is the fastest growing end market for recycled plastics. The Asian-pacific market in the packaging sector will increase strongly in the upcoming years, but the leading demand for recycled plastics is prognosed to come from North America.

The American plastic packaging producers, as well as food and beverage manufacturers realized that they have to act more sustainable and enforce plastic recycling, so that they are able to prevent sale losses. Unilever reports: 'Sustainable brands are growing 46% faster than other brands and make 70% of overall sales growth' (Unilever Deutschland GmbH, 2018). This explains why an increased commitment in secondary plastics usage is forecasted for future years. The more sustainable the company image, the better are its sales numbers. Major corporations like Nestlé and Procter & Gamble made announcements about their new targets to increase the share of their recyclable packagings in upcoming years and at the same time help to develop a better circular economy and support the development of stable end use markets for PCR (More Recycling, 2017). NGO's like Greenpeace question the corporation's serious interest in a more sustainable future and allege that their actions are greenwashing baby steps (Askew, 2018). Until today the market for recycled plastics is concentrated in China, India and South East Asian countries.

5.1.5.1 Market outlook

China's import ban, including household plastic scrap in 2018, led to a drastic decrease in plastic scrap imports. As a consequence, Southeast Asian countries like predominantly Malaysia, Vietnam and Indonesia had become the new major recipients of plastic scrap from the USA and the EU on the global market. After these countries have been flooded with plastic scrap they started to limit plastic scrap imports as well. The global plastic scrap market is currently unstable. The upcoming month and years will show how the industry and politics will handle the plastic waste challenge, that arose out of China's import ban.

5.2 Differences of recycling processes in developed and developing countries

The recycling examples given in chapter 4 show that recycling technologies and processes in developing countries differ widely from developed countries because abundant labor resources and low labor cost enable the manual processing of secondary raw material. China and India are highly populated and are situated in a completely different development stage as societies. Further reasons are lacking environmental laws, but even more the missing law enforcement, a low literacy level of the workers, missing workers' rights and no industrial safety.

Those factors create the framework for the working conditions of workers in developing and emerging countries. The examples showed that the economic performance of the manufacturing sector is prioritized over workers' rights and environmental protection. This was the case for about three decades in China but is as well daily fare in other countries.

The comparison carried out by Zhao and Chen (2011) between the ELV recycling processes in China and Japan gives insights on the differences of recycling processes in developed countries and developing countries. Zhao and Chen (2011) conclude that Chinese recyclers do not care about the environmental impacts of their actions. They focus above all on their economic advantages, whereas Japanese ELV recyclers pay close attention to environment conservation. Even subsidies for dismantling enterprises were not used for its purpose of dealing with toxic substances. Japanese recyclers dismantle, separate and recover ELVs generally automatic, whereas in China most dismantling steps are done manually. The majority of the Chinese dismantling plants are ill informed about environmental protection and sound disposable techniques. Moreover, Japanese car manufacturers actively involve in ELV recycling, again China's car manufacturers rarely involve in ELV recycling and they also do not provide dismantling information for recyclers, which would be crucial for an effective recycling process (Zhao and Chen, 2011).

This shows furthermore, that the consciousness of the manufacturing sector about its responsibility regarding the end-of-life phase of its products and its active cooperation with the recycling sector is an important part in a circular economy.

6. Discussion

The research topic that has been investigated based on a literature review is the increasing transboundary trade of secondary raw materials between developed and developing countries, as well as recycling technologies in low and middle-income countries. The major findings of the thesis show that China was the main player in the secondary raw material market. Asia, together with the USA and the EU form the three biggest market participants. Countries in the EU and the USA mainly constitute the exporters and countries in Asia mostly the importers. The main share of secondary raw material trade happens between those three regions. The drivers for the global trade of secondary raw materials are economic advantages for the developing and the developed countries.

Contrary to expectations China is not the biggest steel importing country, however Turkey turned out to be the most important importer of steel. The results of Vercammen et al. (2017) show that China's steel demand peaked in 2013. This corresponds with the information of the Worldsteel Association, who call the current period the post-peak era and state that the time of high-speed growth in the Chinese steel industry is over. As well as Vercammen et al. (2017), Zhong, (2018) writes that China's domestic scrap supply will be sufficient for an increase of EAFs in the future. There is even the possibility of an oversupply. Moreover, he writes that obsolete scrap will become a major source for the Chinese scrap supply, which again agrees with the results of Vercammen et al. (2017) about the ongoing decrease in demand of steel scrap imports. Different from Vercammen et al. (2017), Zhong, (2018) writes that there is a limited economic value in replacing the BF/BOF capacities with EAFs. He writes that the BF/BOF capacities are too new for a replacement (Zhong, 2018). After Vercammen et al. (2017) a technological shift from BOF to EAF would lead to a more resource effective and environmentally friendly steel production in China. Not only because of the much higher usage rate in terms of steel scrap made possible by the EAF technology, but also because of the limited emissions of carbon dioxide (CO2), sulfur dioxide (SO2) and dust (Vercammen et al., 2017).

Data on steel scrap imports, as well as data on the amount of domestic steel scrap usage was not consistent. Vercammen et al. (2017) wrote of about 180Mt of steel scrap use and the BIR mentioned 90.1Mt, whereby the calculation methods obviously differ from each other. The question arises why the China Association of Metal Scrap Utilization (CAMU) excluded contributors, such as small steel plants, foundries and estimates used in the grey economy in their calculations. Shouldn't especially the CAMU have access to this data?

Future steel scrap trade routes are largely dependent on political developments in China including economic and environmental decisions regarding a beneficial framework for a shift from BOF to EAF steelmaking. This shift could determine the global steel scrap market. Furthermore, is still unclear how the metal tariffs within the scope of the trade war will affect the metal scrap market.

The results of the aluminium market showed again the market-dominating position of China. The decline in demand of China for aluminium and alloy scrap based on the domestic increase of scrap availability and additionally the metal tariffs on aluminium exports to the USA in the frame of the trade war will influence future developments in the aluminium and alloy scrap market.

While China reduced electricity from coal-powered stations for their steel and aluminium production, President Trump pushed the aluminium production based on coal-power in the USA through his tariffs on aluminium imports. Based on the new import tariffs, which were enacted in spring 2018, aluminium production of the American aluminium industry leaped. While in other parts of the world the industry tried to cut down carbon emissions from the aluminium and steel production process, the president of the USA was welcoming the outdated pollutive production style once again (Alter, 2018; Xu and Daly, 2018). The leap of the American aluminium industry could lead to a decrease in aluminium and alloy scrap exports. As a result of the simultaneous decrease in demand of China for aluminium and alloy scrap that would not affect the Chinese industry.

Unlike the steel and aluminium scrap-, waste paper- and plastic scrap-trade routes, the e-waste trade routes do not exist predominantly because of the demand for the secondary raw materials (including precious metals), which they contain. The main driver is much more the reuse of the functioning and repairable EEE. The issue of e-waste trade has been simplified for a long time, but there is more to e-waste trade than the bad global North and the poor global South. It is important to take into account, that the bigger part of imported e-waste in Africa and Asia is functional and or repairable EEE (Lepawsky, 2014). The debate is complex, especially as long as there are no consistent standards on how to register trade of used electronics and WEEE. The Global E-waste Statistics Partnership is an effort to change the knowledge gap and transform it into validated statistics on used electronics and e-waste collection and recycling, as well as the import and export of used electronics (Baldé et al., 2017).

Brooks et al. (2018) research corresponds with the result of the thesis, that the Chinese import ban will have an enormous impact on global plastic recycling and the global trade routes of plastic scrap. But Brooks et al. (2018) make another important point in connection with the import ban. They emphasize, that the restriction of certain types of plastic waste within the frame of the import ban could increase the illegal flow of plastic waste (Brooks et al., 2018). The UN Comtrade data, which is the basis for the import/export data of plastic waste of this thesis, cannot display the whole global picture of waste trade. Moreover, the illegal waste trade quantities remain unknown. Another fact, mentioned by Brooks et al. (2018) is that the UN Comtrade Database lacks specific data on two of the most commonly used polymers, PET and PP, because trade codes for these waste materials are not yet harmonized. The author agrees with Brooks et al. (2018) that the countries, which were exporting the major share of plastic waste to China can use the import ban as an opportunity to reduce plastic packaging and put effort in redesigning products to be more recyclable in the future (Brooks et al., 2018). Existing recycling capacities should be expanded and the take-off markets of secondary raw material could be supported by lowering taxes or by the implementation of other policy instruments.

With increasing recycling goals on the one hand and the relatively new Chinese import ban in effect on the other hand, the global plastic waste challenge got even more difficult than before. At the same time those developments could lead to the long-needed insight, that we instantly have to optimize waste management systems and create awareness about the importance of the topic so we can altogether manage rising waste volumes.

7. Conclusions & Outlook

The thesis described which materials and quantities of secondary resources are traded globally and what the underlying drivers of those imports and exports are. Five secondary raw material flows were analyzed whereby an overall picture over the secondary raw material market was created. The main players of the secondary raw material market have been identified, as well as it has been recognized that South America, Africa and Australasia are almost absent in the global secondary raw material market.

The drivers behind the imports and exports explained the global secondary raw material flows and elucidated that economic performance has a higher priority in recipient countries than worker- and environment protection. This let's see through why recycling is even done with low-tech methods under poor conditions regarding environmental and human health impacts. Out of an environmental perspective it is hard to understand, but as soon as the drivers are looked at, one can comprehend why secondary raw material flows trend the way they do. Velis (2015) points out that the larger part of production and manufacturing processes has been outsourced to Asia over the last decades (Velis, 2015). This development strongly influenced the demand for secondary raw material by China. Limitations, like it has been the case in terms of wood fiber supply and the low domestic availability in steel scrap, aluminium scrap and plastic scrap have further contributed to the high demand. Import demand for secondary raw material in China will level off or decrease, because of the gain of domestic material availability, market saturation and of course China’s import ban, while India records an upsurge in secondary raw material demand. India is developing to be an important player in the secondary raw material market in the years to come.

The results show that significant impact could be achieved by encouraging waste management and best practice projects especially in South-East Asia, because on the one hand very high volumes of wastes are already processed there and on the other hand the domestic waste volumes in this region will rise strongly in the future. Additionally, waste volumes, which have been imported by China until the import ban will find new buyers in neighbouring regions.

The knowledge about the importance of Southeast Asia as important secondary raw material processing region, combined with the research of Hoornweg and Bhada-Tata (2012) who forecasted waste generation rates in low-income countries to at least double until around 2030, let's see clear that global institutions, associations and governments should work together to create a strategic plan to improve the living- and working conditions for informal recyclers, spread knowledge and best-practice examples and as well awareness for risks and how to be able to safely handle them. Governments should acknowledge the positive impact and valuable service of informal recyclers for societies and support them.

Trade flows of plastic scrap and other waste types will change in the future, caused by the significant import ban implemented by the Chinese government. Together with the ongoing trade war the year 2018 was a game changer for the global waste industry, which recorded noticeable market changes in the secondary raw material market.

8. Summary

Globalization plays an important role in the big picture of recycling. Waste imports by developing countries have increased strongly over the past years. The goal of this thesis was to examine the reasons behind the increase of the waste imports, as well as to describe the further recycling processes of the imported wastes into secondary raw material in low- and middle-income countries. As part of the description of the secondary raw material markets the usage of each secondary raw material in the industry was examined. Based on a literature research this thesis provides an overview on the global secondary raw material market, analyzes the biggest importers and exporters of five significant globally traded secondary raw material streams and gives an outlook on the future development of the biggest importing countries of each material market. Several examples of recycling processes in low and middle-income countries are treated to examine why there are differences between developing and developed countries. The thesis showed that there is no high demand of low-and middle-income countries in general, but it was found that there is particularly high demand of a few low-and middle-income countries like China, India and Turkey. The global perspective showed that there are four main regions in the secondary raw material market. Those three regions are the EU and the USA as main exporters plus Asia (predominantly East- and Southeast Asia) as main importer. South America, Africa and Australasia play a subordinate role in the secondary raw material market.

The results of the steel market showed that although China is dominating the steel market, Turkey is the main importer of steel scrap because of the applied technology. China largely uses Basic Oxygen Furnaces, which only allow a low usage of scrap compared to the Electric Arc Furnace (EAF) technology, which is mainly used by Turkey and rests on steel scrap input for the predominant part. Turkey mainly produces long-steel products for which low-quality steel scrap is used. This is another reason for the high steel scrap imports by Turkey.

Major importer of aluminium and alloy scrap is China. The reason behind the high demand of China is caused in their former low domestic aluminium and alloy scrap availability combined with their huge aluminium production capacity. Concerning the aluminium production, there is no such difference in technologies as there is in the steel production.

Research about the global e-waste flows revealed that there is a lack in data about e-waste trade. WEEE and UEEE are mixed together in the containers, in which they are shipped. Therefore, it is hard to tell how much e-waste is actually traded. Despite there is no exact data on how much WEEE and UEEE is transboundary traded it is known, that the main exporters are the USA and the EU and the main importers are developing countries like Ghana, Nigeria, China and India. The main drivers are the re-use market and the reassembly industry in the recipient countries combined with the economic benefit of cheap disposal costs for WEEE for the developed nations.

Regarding waste paper trade China consumed between 60 and 75% of the worldwide traded waste paper. Its huge paper industry combined with its low stock in forest resources were the main reasons for the large imports. India has the fastest growing paper market worldwide and will be an important player in the secondary raw material market especially regarding waste paper in few years. China also dominated the imports regarding plastic scrap. The PRC has a huge industrial capacity in the packaging-manufacturing sector, which is the main user of recycled plastic resins. The market for recycled plastics is concentrated in China, India and other South East Asian countries.

The examples of recycling methods in developing countries demonstrate that low-and middle-income countries have available such an abundant labor force combined with low labor cost that it is the norm that, where possible, wastes are sorted and processed manually. Lacking environmental laws, but even more the missing law enforcement, a low literacy level of the workers, missing workers' rights and no industrial safety lead to poor working conditions in the recycling sector in low-and middle-income countries. The examples showed that the economic performance of the manufacturing sector is prioritized over workers' rights and environmental protection.

The Chinese import ban together with Chinas decreasing demand for secondary raw materials will change the future secondary raw material market. India will record an upsurge in secondary raw material demand and is developing to be an important player in the secondary raw material market in the years to come.

The thesis showed that significant impact could be achieved by encouraging waste management and best practice projects especially in South-East Asia, because on the one hand very high volumes of wastes are already processed there under poor conditions and on the other hand the domestic waste volumes will rise strongly in the future.

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