GLOBAL CIRCULAR MATERIAL:

The BIG 5 – and their story behind

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About this report

The circular economy offers new answers to the question of how 9 billion people can survive on this planet, accepting that there are planetary boundaries and climate change is ongoing. The aim of this study was to identify drivers of the big five globally largest material flows by mass from a circular economic perspective and to understand their story behind.

Many scientific papers about circular economy focus on scoring countries according to their waste infrastructure, which exactly explains lacks in fulfilling the circular RESOLVE principle, incoherent policy making or strategic lacks.

In evaluating the existing, we must draw attention to the story behind the existing reality. What led to the evolvement of the system? Therefore, we have set the focus on what the evolvement of the big 5 material systems tells us about intentions. Unintended things happen, either because we do not pay full attention, the intention was wrong or cause and effect of outcomes were not known. Intention and attention are an interplay that defines the outcome. Climate change started unintendedly. In the Anthropocene, we cope with the sum of unintended effects shown in so-called rebound effects. Therefore, we are looking at the attention with which circularity systems have been implemented and look at paradigms that led intentions.

What can we learn from these materials, that have been managed circular earlier than others? Are we able to derive joint characteristics of their stories that can help us to implement circular systems, in which we can avoid rebound effects in the future? What makes up for differences between the Global North and the Global South?

What we have found is a huge gap in the overall understanding of the circular economy. Indeed, the big five globally largest material flows by mass are successfully recycled in many parts of Global North. Even closed-loop systems could be identified for specific materials. But the most material systems are lacking circular comprehensiveness of circularity. The global context was driven by resource exploitation. The lifecycle of material starts with exploiting resources in Global South and ends with exported waste in Global South again. The story behind the system evolvement shows that growth of industries and mankind's striving for freedom is accompanied by rebound effects.

By identification of intentions and rebounds we can find parallel structures that are deeply connected to intentions for freedom and must collide with the reality of planetary boundaries. Our hope is to nourish a fruitful debate on the development of elements for circular systems. And learnings from success are as important as learnings from failure.

This study might inspire industrial managers to take the right decision and pave the pathways to a circular society that is just, balances out social and ecological needs and will be a sound ground for survival of mankind on planet earth.

We have included a short **summary in the end of each material chapter**.

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1.1. Ferrous metal – Global Overview

Ferrous metal has been the most important material for the 1st industrial revolution. Mining and production characterized this period.

The level of knowledge and cognition for circular economy in ferrous metal markets is high. The recycling of steel scrap evolved and grew during unsteady times. During 1st and 2nd World War, many countries started campaigning for the collection of scrap to ensure supplies for weapon industries. Later, ferrous metal was needed to rebuilt destroyed cities and feed growing industries.

Ferrous metal is a booming material in global economy. Ferrous metal industries are key industries in the global economy. Their products are ubiquitous. The most important processing sectors include the automotive industry but also mechanical and plant engineering or construction.

The industry offers considerable potential for resource conservation and is becoming a field for strategic approaches to resource efficiency at political level. "Lifecycle efficiency" becomes key variable for competitiveness. Weight minimization, reparability and recyclability are aspects.

Life cycle assessments of the material have revealed chances to reduce CO2 emissions. Economic and environmental performance of cutting-edge technologies for CO2 reduction shows that the implementation might reduce 80% of CO2 emissions.

The necessity of overcoming rebound effects becomes clear by analysis of periods of stagnation, i.e., 1974-2000, when the ferrous metal industry experienced a boom worldwide. This boom was being driven by the dynamic economic growth of the emerging countries. Alongside Japan, the USA, Russia and India, this includes China, the world's largest producer of ferrous.

At the beginning of the new millennium, the ferrous metal boom led to a crisis due to rising prices, empty markets and overheating stock markets. It became clear that the substitution potential for ferrous metal in its applications is limited. However, the shortages in production are due to limited production capacities rather than to ore deposits. Even if there is generally no geological shortage of ores, recycling has been practiced for economic reasons since the beginning of ferrous utilization.

The industrialization process, especially in emerging economies, is dramatically increasing the demand for scarce resources. The increase in economic growth is coupled with a roughly equivalent increase in resource consumption. This coupling of prosperity/growth and resource consumption is also the cause of climate change with all its predicted effects and impacts as well as further damage to ecosystems.

Facts

- worldwide documented
- can be recycled up to 100%
- experiences little material degradation
- markets are developed
- scrap is cheaper than virgin ore
- production grew stronger than recycling
- recycling went down throughout the years
- 1,730 million tons produced globally in 2017
- 600 million tons recycled
- recycling rate of 35%

Sources: Lemken, T., Liedtke, C., Bienge, K., Salzer, 2008, pp. 14, 26; Thinking Circular, 2020.

1.2. Ferrous metal – Global North

Figures show an exponential development of ferrous metals between 1880 and today. There is a clear correlation between the economic development and steel scrap entering the material cycle.

The need for metals grew as industrial production grew and their development is shaped as much by economic crisis as well as by various needs by technologic developments.

Products made of ferrous metal are used in many different types of infrastructure and technologies. They are indispensable for modern society. The material is tied to manufacturing and construction industries. It is pulse to development, growth and employment. And it is the material most versatile of all industrial materials in the world. Without ferrous metal, modern world would not be the same.

This correlation is emphasized by the proportion of metal waste increasing in developed middle- to high-income countries. Higher income levels have a higher percentage of specific materials like organic matter in waste, paper, plastic and metal waste than they do in lower-income countries.

Not only in waste generated, developed countries are leading, but in producing ferrous metal as well. Its production is located where industrialization demands ferrous metals. Asia leads this with 71.7%. The top five steel producing regions are:

1. Asia: 71.7% of global steel production
2. Europe: 16% of global steel production
3. North America: 6.4% of global steel production
4. Middle East: 2.4% of global steel production
5. South America: 2.2% of global steel production

Other regions like Africa or Australia and New Zealand almost play no role.

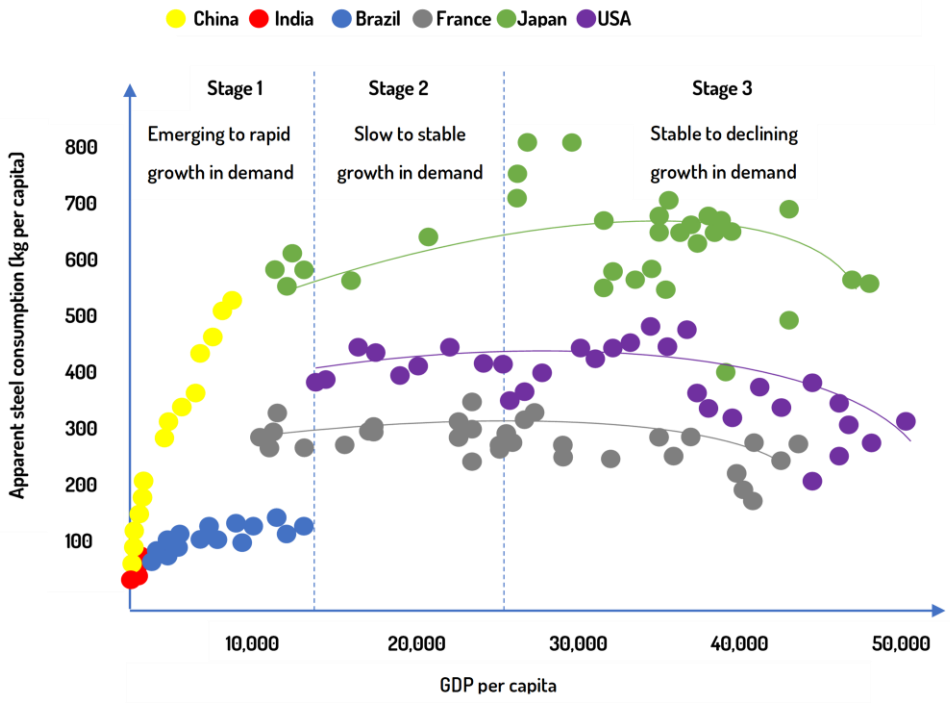
Though the Corona pandemic caused remarkable anxiety, the global economy is projected to grow 5.5 percent in 2021 and 4.2 percent in 2022 according to the International Monetary Fund.

Since 2007, emerging economies such as China and India were growing at around 7%. Population growth and further increasing urbanization processes accelerate this development. Examples of growing and mature apparent steel consumption as function of GDP can be identified as three different stages of growth like the following illustration shows.

Facts

- exponential growth
- part of basic industrial knowledge in the industrialized Global North
- used in many different types of applications
- shaped today's system
- world has become dependent
- coupling of resource consumption and growth is proved
- planetary boundaries and peak are reached
- rapid growth of emerging markets demands large amounts
- ecological boundaries even more challenged

Sources: Kaza, Silpa; Yao, Lisa; Bhada-Tata, Perinaz; Van Woerden, 2018, p. 30; Nakajima et al., 2018, p.2; Ourworldindata.org, n.d.; The European Steel Association (EUROFER), 2020, pp. 4, 13; Thinking Circular, 2020; UN Environmental International Resource Panel, 2015.



Examples of growing and mature apparent steel consumption levels as function of GDP. Own illustration based on Ernst&Young. (Pinto, 2019)

The increasing steel demand from developing nations is growing rapidly.

The story behind ferrous metals:

In the 19th century, population growth and industrialization caused the cities to explode.

The 20th century was a time of scarcities due to war. Waste became resource of high value The fight over resources started. Governments started strategic resource collection from waste.

Before World War I, the motorized garbage collection was started. The search for profitable waste recycling began. Many saw the future in incineration. For cost reasons, most cities decided to use landfills. The garbage began to proliferate everywhere in the landscape. This was the start for obligatory waste collection in cities.

After the first world war, deconstruction of destroyed industrial facilities became a business. Value from waste became an economic phenomenon.

War was one of the main drivers for recycling technology. For resourcing the German warfare industries before World War II, Krupp, one of the largest steel companies, implemented strategic steel collecting infrastructure, which was strategically enforced and managed by the NS-regime. This gave the German industry a strong push.

Sources: International Monetary Fund, 2021, p. 1; Lemken, T., Liedtke, C., Bienge, K., Salzer, 2008, p. 10; Pinto, 2019; Thinking Circular, 2020.

During World War II in Europe waste legislation got a push by the prohibition of landfill in many regions. The trade in used materials was systematically analyzed and monopolized by the state. Monopolized resource collection markets got established. Especially for steel, non-ferrous metals, ores (gold, silver, platinum i.e.).

After World War II, the culture for collection and collecting systems developed further into oligopoly structures. Krupp changed to more civil steel applications. First large capacity garbage trucks were built by Krupp.

But not only weapons for war and post-war rebuilding of infrastructures played a big role in ferrous metal market, but also ship breaking. Especially before the 1990s and after 2008, ship breaking was an important economic activity for the ferrous metal industry.

Ship breaking used to be performed in ports of industrial hub areas, especially in USA and UK. Then, the centers moved from Europe and North America to East Asia and finally, since the 1980s, to South Asia. Main reasons were lower labor costs. Weak health and environment regulations may also have been partly responsible for the development of a large ship breaking sector in South Asia.

Ship Breaking by Gas Cutting in Bhatiary Yard 01, Chittagong Bangladesh. Photo by Naquib Hossain, CC BY-SA 2.0 https://creativecommons.org/licenses/by-sa/2.0, via Flickr (N. Hossain, 2009)

Sources: Alcaidea et al., 2016, p. 379; Preuss, 2006; Sarraf et al., 2010, p. 9; Thinking Circular, 2020.

Though ship breaking activities went down between 1980s and 2008, overall global metal demand increased by 87% up to more than six billion tons.

Between 1970 and 2010, global extraction of metal ores grew by more than 250%. Drivers for demand were economic growth including building up infrastructure, producing electronic devices and also the shift towards renewable energies.

Today, many countries in Global North are on their way to a circular economy. Every metal is pulled out of the waste stream through magnets for recycling. Waste management has become a technically and legally complex field. Waste, environmental and chemical legislation must be harmonized on all levels. Especially China, Europe and the USA, play an important role due to high quantities for recycling, driving future for ferrous metal markets.

The story behind the development of scrap prices:

During the 1930s and World War II, demand and scrap prices increased. The US Government took up price controls.

Later on, during the Korean War from 1950 to 1953, the phenomenon reoccurred and price controls were adopted again.

The oil price shock in 1973 and the inflation of commodity prices partly led to a strong increase of prices. Demand went down, leading to a replacement of old technology by new technology. The new technologies were dependent on scrap purchased in the market whereas as the old technology had mainly used home scrap and virgin iron ore.

This resulted in an increase for scrap demand in the mid-1970s and caused scrap prices to rise again. But the supply of new scrap decreased because it was less produced during the period. So, prices increased further.

The 1990s were again characterized by demand changes. Between 1993 and 1997, worldwide demand increased due to the accelerating growth of economies in Asia, Eastern Europe and Latin America. So did prices. In 1997–1998, economic growth and ferrous metal demand were deflated by the financial crisis in Asia. Scrap prices and Asian production declined.

In the beginning of 21st century, consumption in China and India finally recovered and scrap prices consequently increased. During the last years, China has governed the growth of world ferrous metal production.

The long-run scrap price will depend on the cost of iron ore and the cost of refining iron ore to steel.

Sources: Nakajima et al., 2018, p. 2; Preuss, 2006; Söderholm & Ejdemo, 2008, pp. 68-70; Thinking Circular, 2020; UN Environmental International Resource Panel, 2015.

The story behind the structure of the European and US Ferrous Metal Industries:

The documentation of ferrous metal production and recycling is very detailed for the USA and for Europe, reaching back until the 20th century. The development of both markets was also similar, with only minor differences.

US production of ferrous metals moved around 100 million tons during the last 20 years whereas production in Europe was higher with 190 million tons in average. Recycling rates in the USA ranged between 65% and 70% whereas recycling rates in Europe ranged between 45% and 55%. In the US, development for both, production and recycling, remained quite stable during the years. Even during the global economic crisis, recycling didn't change though production went down (but didn't crash). This was a point in time, when recycling rates exploded to over 90% due to the dropping production. As production recovered, recycling rates went down again. In Europe, development of ferrous metal markets was also quite stable but experienced more shifts, especially during global economic crisis when production and recycling both clearly went down. Despite this, development was not striking.

Both markets are characterized by oligopoly structures, thus, dominated by a few large companies. Both, Europe and USA, are important producers of ferrous metals and consume huge quantities of scrap. But the structure of their industries differs. The US industry is quite scrap-intensive, with sixty-nine per cent of its 2019 output coming from scrap-based production. The corresponding share for Europe is about fifty-five per cent. It is useful to discuss how these differences occurred in relation to industry structures.

In the past, ferrous metal production in the USA was maintained by large integrated mills. But the US ferrous metal companies failed to modernize their plants in the 1950s and 1960s due to a lack of competition in the domestic market. As US demand growth slowed down in the 1960s, scrap prices fell relative to costs. Large mills faced expensive labor agreements and increasing costs. So, manufacturers searched for cheaper sources of ferrous metal. Competitors moved into the market using so-called minimills, which were small-scale electric furnaces. They improved melting and casting and reached completely new levels of success. Side-effect was that the overall production process was less energy- and labor-intensive. Market share of minimills started to grow continuously and forced large mills out of the market. In 2005, most of US ferrous metal output came from minimills for the very first time. Due to its success, the technology spread across the world, Anyhow, growth in the USA has been exceptionally strong. It is assumed that one factor was the country's unwillingness to nationalize its industry.

Facts

- 159 million tons produced in 2019 in Europe
- 88 million tons recycled
- recycling rate of 55%
- 88 million tons produced in 2019 in the USA
- 61 million tons recycled
- recycling rate of 69%

Sources: Söderholm & Ejdemo, 2008, pp. 60-61; Thinking Circular, 2020.

In other countries, labor market politics protected large mills.

As minimills reached Europe, a restructuring of the industry took place as well. But growth was not as strong as in the US. Anyhow, minimills became important market players. In 2005, they were responsible for about forty percent of European ferrous metal output. However, large mills remained competitive. Reasons may have been that in the 1950s and 1960s, European producers made large investments in their equipment which resulted in superior technical status. It is also interesting that Western Europe minimills were often an integrated part of large mills while most North American minimills have started independently. Another reason were investment costs: Though the investment costs for minimills are low, in Europe they can often be higher than the costs of modernizing existing mills. Most European nations quite differ from the USA in terms of wages and legislation, what makes investment costs considerably higher.

In both regions, the ferrous metal market is mature since a long time. In 2009, the financial crisis led to global market break. Anyhow, the recycling rates in Europe have been lower than in the USA even before 2009. In recent years, the importance of sorting and recycling alloyed and non-alloyed metals has grown in Europe, because of the monetary value of the material. Today, people are aware of the value of scrap.

To further innovate promotion, Europe decided for a lead market initiative and for the integration of a life cycle perspective. With its technology platform ESTEP (European Steel Technology Platform), the European ferrous metal industry is already focusing on its most important application areas: Construction, Automotive, Mechanical Engineering and Metal Goods. ESTEP focuses its research and development on product development that takes a system-wide view of resource- and energy-efficiency and provides impulses for energy- and material-savings in the ferrous metal industry. This is also used within the framework of the German dialog, which plays a significant role in global ferrous metal industry.

Finished products of the ferrous metal industry from Germany in the application fields of construction, automotive industry and mechanical engineering are of great importance worldwide, as every fifth vehicle and every sixth machine imported anywhere in the world originates from Germany. Germany is the strongest crude steel producer in whole Europe, followed by Italy and France.

Ferrous metal production and processing in Germany takes place at a high technical level. Energy and material efficiency has already been steadily improved in the past and the environmental impact reduced.

Sources: Söderholm & Ejdemo, 2008, pp. 60-61; Thinking Circular, 2020.

Anyhow, for import-dependent consumer countries such as Germany, a high proportion of recycled materials is important in terms of cost savings and secure supply. The processing of secondary raw materials - above all from domestic sources - reduces the imports required. The German government also attaches great importance to increasing the recycling of metals in view of price developments on the world raw material markets.

The story behind Asia's – and especially China's – impact on today's ferrous metal industry:

Whereas the USA and Europe experienced a stable development of ferrous metal production and recycling, China was again a striking example for exponential development which is documented very well. Unfortunately, due to the strong growth in production, recycling is lagging well behind. Since 2017, recycling experiences a positive development, starting to grow after several years of stagnation. Whereas in 1999, recycling rates moved around 26%, in 2015, recycling rates were down at around 10%. In 2019, recycling rates were already moving their way up at 22%. China's ferrous metal markets were not affected by the global economic crisis, neither production nor recycling.

Asian countries have enhanced their industrialization and technological advancement daily. Consequently, the volume of e-waste generated has also been increasing with the import of lifestyle improvement e-products.

Analysis shows that among the different regions worldwide generating a total of 51.37 million metric tons of e-waste (data of 2012), East Asian countries are foremost generating around 23% of global e-waste. China and Japan are the major contributors. Other Asian countries contribute significantly, too.

East Asian countries are followed by North American countries, like the USA and Canada. But also, Mexico contributes a lot of e-waste. North America is responsible for about 22% of global e-waste. When digging deeper into the analysis, it becomes obvious that anyhow, though East Asian countries are global leader in terms of e-waste, they are not leading in per capita generation. North America is consuming and generating much more e-waste per capita though East Asia is speeding up fast.

Next region in the row is Europe. Eastern Europe is contributing the most of Europe's e-waste but in terms of per capita, it stays back widely behind Western and Northern Europe. Especially Western Europe is quite critical looking at per capita consumption. Western Europe is worldwide leader in per capita consumption with Northern Europe staying close behind.

Facts

- 996 million tons produced in 2019 in China
- 216 million tons recycled
- recycling rate of 22%
- consumption of electronics and generation of e-waste per capita is high in Global North and exported to Global South
- global e-waste is one of the major problems

Sources: Lemken, T., Liedtke, C., Bienge, K., Salzer, 2008, p. 6, pp. 11-12; The European Steel Association (EUROFER), 2020, p. 14; Thinking Circular, 2020.

Oceania and African countries as well as other smaller regions contributed relatively small amounts. Only Middle East is as high in per capita e-waste generation as East Asia and Northern Europe, but anyhow generating only small amounts of e-waste in total.

It becomes clear that regions with high per capita amount and small amount in total are exporting their e-waste to countries which have smaller amounts. Only East Asia and North America are strikingly high in both categories, e-waste per capita and e-waste in total.

As ferrous metal is not a separate waste category but part of global e-waste, there is still a huge gap in figures to describe life cycle of ferrous metal. Moreover, there doesn't exist data on scrapyards in Asia (see "Global South").

In 2004, China politically announced to introduce a circular economy. Recycling demand increased in the following years. Yet, there was no subsistence situation, so, recycling decoupled from growth.

In 2019, China banned ferrous scrap imports as part of its greening strategy, working on cleaning its waste for the introduction of the Circular Economy.

Xi Mingze, the daughter of Xi Jinping, is supporting the development through introducing the cradle-to-cradle-principle in China – the biomimetic approach of Michael Braungart that enjoys high reputation in circular economy discussions and which Xi Mingze got to know in detail when she was Braungart's scholar.

It is expected that scrap imports will resume in 2021 in China, as its steel industry is confronted with economic challenges due to the ban.

As we can see, in today's economy, resource consumption influences environmental impacts far away from the place of consumption. Economic growth and the use of green technologies for renewable energy have been associated with a rapid rise of metals and minerals.

The industrialization process, especially in emerging economies, is dramatically increasing the demand for resources. This coupling of prosperity, growth and resource consumption is cause of climate change as well as further damage to ecosystems.

Economic growth raises the question of limits. Up to what point and in what way is growth without destroying the biosphere? A dynamic strategy of restructuring our economies and societies is of paramount importance. The circular economy will not make the world a better place if we still don't close loops fully and don't think of systemic consequences, e.g., like in Global South.

Sources: Hossain et al., 2015, p. 7; Lemken, T., Liedtke, C., Bienge, K., Salzer, 2008, p. 10; Lovrinovic, Claude; Giouvanitskas, 2019; Taylor, 2020; Thinking Circular, 2020; Yong, 2007, p. 122

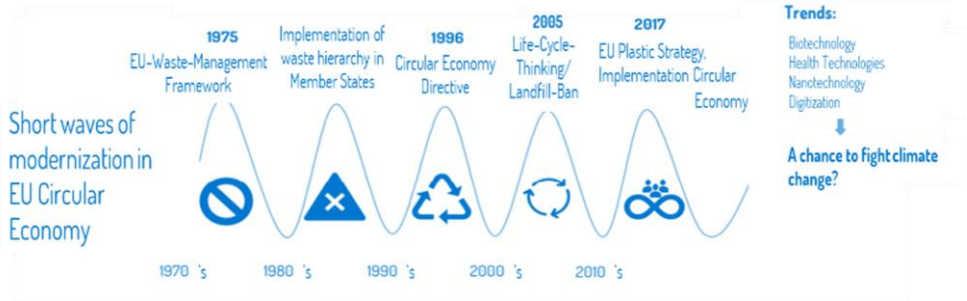
1.3. Ferrous metal – Global South

Whereas questions in Global North are about technical details how to recycle better, there is only one major question in Global South: How to recycle at all? Informality quickly arises.

Recycling of TVs in Global South. Source: Photo by Maruf Rahman from Pixabay.

70% to 98% of the waste in Global South is still ending up in open dump or landfill. In mega cities of Global South, incineration has grown up to 26% within 5 years and is substituting landfill. In the industrialized waste sectors, incineration makes up for 12-27%. Depending on the region, open dump and landfill are fully substituted. In North America, both categories are illegal. North America is also the region with the worldwide highest recycling share with 33% on average for all waste in total.

But learning is taking place in waves – looking to Europe for instance:



Evolution of waste management in EU. Source: Own illustration.

Facts

- reserves are estimated at 81,000 billion tons iron ore
- most of reserves are located in Global South as well as in China
- no clear recycling documentation in quantity in Global South

Sources: Garside, 2020; Preuss, 2006; Sabour et. al, 2020, p. 2; Thinking Circular, 2020.

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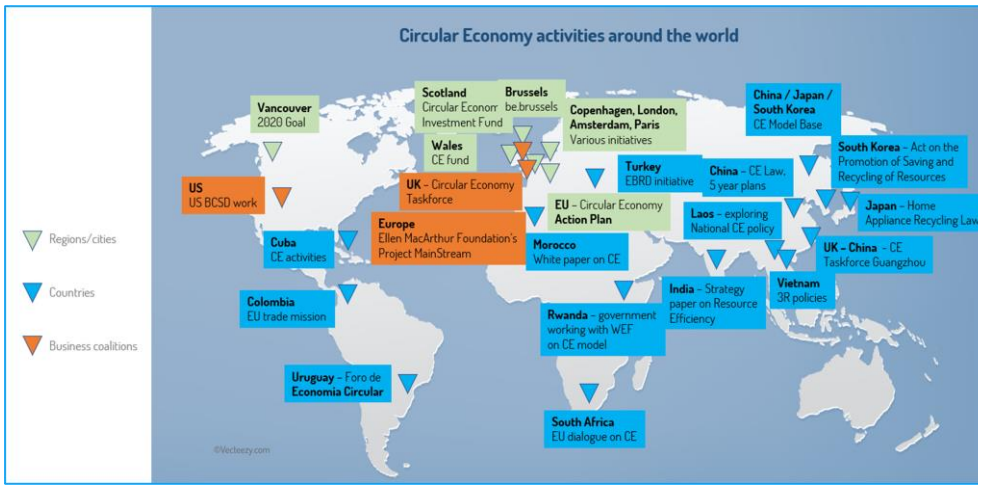
Waste management in Global North still lacks closed loops and Global North tends to sell its waste to Global South, but a chain of historic events has led to an understanding of how to handle waste. Global North was learning from times of scarcities (war) and a following period of economic development and prosperity which in the end resulted in exploding waste problems in growing cities. Still, there is a need for waste to be handled as there is a clear correlation between income and waste generation. Prospering regions with high GDP have larger quantities of waste.

One consequence for Global North was to early implement waste legislation and circular economy initiatives which can be seen in the following map. The vast majority of countries without data on waste legislation are in Sub-Saharan Africa, where laws are still being developed.



Circular economy activity around the world. Own illustration based on (Preston & Lehne, 2017, p. 6).

Enforcement of laws is a common challenge. It requires adequate staffing, implementation of penalties, and cultural alignment with legislative goals. Two best practices may be mentioned here:

In Malaysia, the National Solid Waste Management Policy was created to standardize and improve waste management across the country. However, challenges were limited financing, low staff technical capacity, and ambiguity in the policy's guidelines.

In Rwanda, a national plastic bag ban was enforced using border patrol guards to prevent illegal imports and multiple penalties for offenders. Part of the history of the circular economy is the cognitive adaptation in people's minds. Rwanda is quite a good example for the cognitive development of circular economy: They do street cleaning every month!

Facts

- higher income countries have higher waste generation
- waste is shipped to Global South

Sources: Cotta, 2020, p. 256; Kaza et. al, 2018, p. 3, p. 87, p. 90; Preuss, 2006; Thinking Circular, 2020.

People participating in Kigali's monthly clean-up day, where all able-bodied people aged 18-65 are required to participate. Photo by Stuart Forster/REX Shutterstock. (Mourby, 2015)

It's not a volunteer project. Police monitor the streets and can stop Rwandans who aren't participating and make them clean up on the spot. Rwandans who don't participate in the cleanup can be fined 5,000 francs, nearly $6, not a small sum when average income is about $150 a month.

Economic development in Global South may still be lacking behind – which is why scientists generally make a difference between developed and developing countries. Nevertheless, economic development of Global North has become a problem to Global South, as well. Because in the last decades, it was a common practice of Global North to shift waste to Global South. Ferrous metals are a common example for scrapyards.

Photo of disposing trains. Photo by Scdnr / CCBY-SA (https://creativecommons.org/licenses/by-sa/3.0)

Sources: Cotta, 2020, p. 256; Thinking Circular, 2020.

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We are having a figure gap. The picture of the scrapyard demonstrates that scrapyards exist. But data doesn't.

Anyhow, taking other countries' waste was an action of hardship for Global South. The ship breaking industry illustrates this. The global center of the ship breaking and recycling industry is located in South Asia: in Bangladesh, India, and Pakistan. These three countries account for more than two-third of the international recycling market for maritime vessels. China and Turkey are covering most of the rest of the market. Outside these five countries, only 5 percent of the worldwide volume is scrapped. The shift of the ship breaking and recycling industry to South Asia in the 1980s has contributed to significant economic development in that region. It makes sense to look at the historic development to fully understand the ferrous metal market in Global South.

The story behind the structure of the Ship Breaking and Recycling Industries:

First of all, it is useful to remind on the fact that ship breaking took place in industrialized ports before it was shifted to South Asia. So, the story of ferrous metal recycling in Global South begins where the story in Global North ends – in the 1980s.

Ship breaking is of economic means by quantities especially for India, Bangladesh and Pakistan. The increase in ship breaking activity is deeply connected to demand conditions in the region, especially in Bangladesh.

In the early 1990s, ships imported for dismantling in Gadani, Pakistan, one of the major players for ship breaking at that time were imposed with a 45 percent customs duty. After the stagnation and the slow growth in the 1990s, and before the global economic crisis in 2008, shipping markets experienced an exceptional boom starting in 2001 and peaking in 2007. But as a consequence of the global demand for more shipping transport in terms of global e-commerce structures, the supply of vessels for scrapping from the shipping sector varies largely. As a result of high demand for shipping transportation between 2004 and 2008, shipping needed to face extensive freight rates. Moreover, this demand needed old ships to be still in operation during that period. Consequently, the number of vessels being offered for scrapping was extremely low for the very first time in history. But after global economic crisis and the following economic recession, the demand for shipping transportation declined again. World trade volumes and shipping activity collapsed at the same time, and freight rates completely broke down, for some vessels by as much as 99 percent. After world recovered from the crisis, rates recovered simultaneously. In addition, as the crisis hit in 2008, owners failed to cancel new ship orders.

Facts

- ship breaking as one of the most important activities in Global South
- global shipping industry relies upon the developing world to dispose scrap vessel
- avoiding to follow standards for hazardous waste

Sources: Sarraf et al., 2010, pp. 2, 9; Thinking Circular, 2020.

At once, many more ships were available for scrapping and recycling because owners returned ships which were on time charter and had become unproductive assets. They wanted to take them out of service and even tried to dispose them through demolition. This was a clear contrast to the previous shipping boom years, when high freight rates had limited the supply of scrap vessels and turned prices up. The after-crisis-situation, and suggestions of even more uncompetitive excess capacity in the future, turned rates down. At the same time, short- and medium-term supply of older vessels for scrapping increased again.

Overall, the supply of scrap vessels grew significantly since late 2008. As a result, the price that owners could get for scrap vessels declined strongly in fall 2008. However, as shipping volumes started to rise again and rates began to improve, there was a partial recovery of the price in 2009. The year 2009 then experienced an increase in ship breaking, with the recycling levels of 2000 already in sight. From 2010 to 2015, the volume handled in the industry was expected to increase further with the implementation of International Maritime Organization (IMO) regulations for the phase-out of single-hull tankers.

Today, most of the world's fleet is still dismantled in countries on the Indian subcontinent, especially in India, Bangladesh and Pakistan, and are still booming.

To dispose scrap vessels, the global shipping industry relies upon the developing world. In doing so, the industry avoids the duty to follow developed world standards for the management of hazardous waste. Occupational and environmental health (OEH) risks associated with ship breaking are critical. Rates of components in HSLA-Steel that are potentially hazardous (toxic) in the recycling process are high. Ferrous metals enter the food chain via plant uptake. This so-called bio-accumulation is moving up the food chain and may lead to a high intake in animals and humans. Concerns about these risks arose in the late 1990s and are moving around the world. Domestic organizations try to gain power for global and domestic OEH reforms through activism.

Besides health issues, recycling in the Global South reaches limits through its environmental and social issues not taking into account global SDGs for production and recycling. Mining often involves worst forms of child labor. Greenhouse gas emissions are generated during the production of ferrous metals. Land clearing and erosion lead to resource scarcity, degradation, potentially contaminating soils and water and impact on land due to open pits and mining waste. Biodiversity loss leads to further degradation of landscapes and ecosystems.

Sources: Alcaidea et al., 2016, pp. 378-379; Chowdhury, 2020, p. 173; Rousmaniere & Raj, 2007, p. 359; Sarraf et al., 2010, pp. 3, 9, 13-14, 17-18; Thinking Circular, 2020; UN Environmental International Resource Panel, 2015.

Large consumption of water in mining and production can impact groundwater and surface water resources. Ponds, tailings dams and mine waste lead to seepage.

It becomes clear that shifting waste from Global North to Global South can't be the solution.

Sources: Thinking Circular, 2020; UN Environmental International Resource Panel, 2015.

Summary

Ferrous metals can be recycled up to 100%. They experience little material degradation.

The most of global iron ore resources are located in Global South as well as in China.

Production grew stronger than recycling, especially after the global economic crisis. Recycling rate went down throughout the years. For Global South, there is no clear documentation of quantitative scrap recycling.

The level of knowledge and cognition for circular economy in ferrous metal markets is high. The recycling of steel scrap evolved and grew during unsteady times. During 1st and 2nd World War, many countries started campaigning for the collection of scrap to ensure supplies for weapon industries.

The industrialization process, especially in emerging economies, is dramatically increasing the demand for scarce resources. The increase in economic growth is coupled with a roughly equivalent increase in resource consumption. This coupling of prosperity/growth and resource consumption is fire to climate change with all its predicted effects and impacts as well as further damage to ecosystems.

One of the major problems is global e-waste of which ferrous metals are part. Consumption of electronics and generation of e-waste per capita is high in Global North and exported to countries of Global South. 70 to 98% of the waste in Global South is still ending up in open dump or landfill. Especially ferrous metals are a common example for scrapyards. Figure gap is huge.

Especially before the 1990s and after 2008, ship breaking was an important economic activity for the ferrous metal industry. Ship breaking used to be performed in ports of industrial hub areas, especially in USA and UK. Then, the centers moved from Europe and North America to East Asia and finally, since the 1980s, to South Asia. Main reasons were lower labor costs. Weak health and environment regulations may also have been partly responsible for the development of a large ship breaking sector in South Asia.

In 2019, China banned ferrous scrap imports as part of its greening strategy, working on cleaning its waste for the introduction of the circular economy. That caused trouble on global ferrous metal markets because countries are suddenly confronted with huge amounts of scrap recycling.

E-Waste and shipbreaking in the Global South make clear, how metal waste from the linear systems of the Global North still ends up in the Global South. It illustrates part of the global waste rebounds that we must overcome to develop a pure circular system.

2.1. Aluminum – Global Overview

Closely linked to the evolution of aeronautics, aluminum is THE material of globalization. The story of aluminum shows how deeply the economic development is connected to the paradigm of freedom above the skies, even out into space:

It is not long ago that humans were dreaming about flying but never thought it could and would happen. It was in 1890 that French engineer Clément Adler, who was actually the inventor of the term "avion" and one of the fathers of aviation, said: "Whoever dominates the sky will be master of the world!"

This expression already shows that aluminum is a metal strongly contributing to the paradigm of higher, faster, further. It made the paradigm reality. "Higher" became a new context and laid the basis for "faster" and "further". Suddenly, it became possible to jump into an airplane to have a meeting on the other side of the planet. Jumping between time zones meant that for the first time, time itself became a new meaning to individuals and society. And all this happened within a blink of an eye compared to human evolution. What happened in the last 70 years?

In 1855, the first industrial production of aluminum started. It was then considered as very noble and was even more expensive than gold. Due to its fast celebrity, the metal got exhibited at the Paris Fair in the same year industrial production started, where the material called the attention of the famous French emperor Napoléon Bonaparte. Napoléon was fascinated by the specific material characteristics being strong and light and thought about the possibilities that could open up to him when he would be able to use aluminum for military purpose.

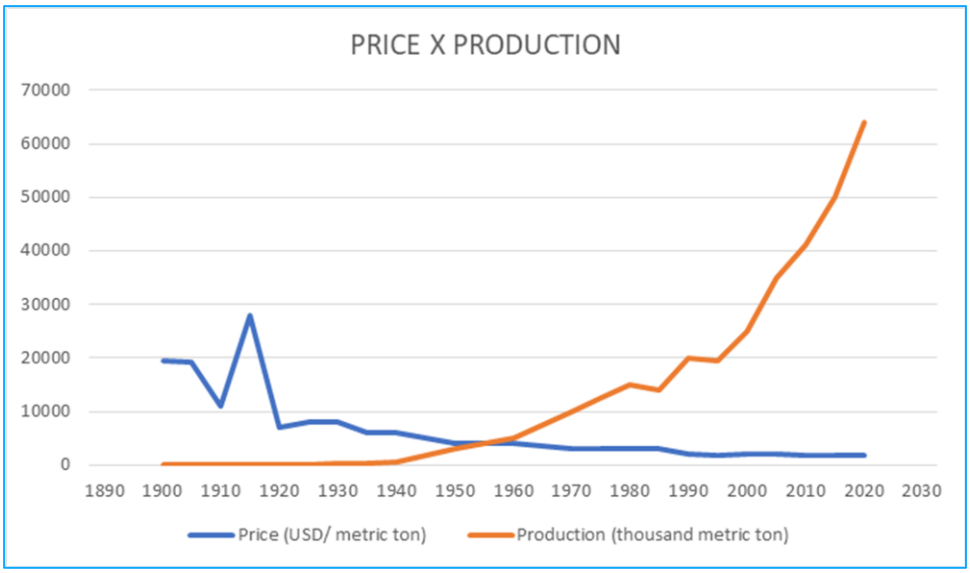
He started financing the research and production of the material. Ten years later, using aluminum for flying purpose was still a vision. In 1865, Jules Verne published his novel "From the earth to the Moon" where he described the transportation vehicle as aluminum-made spacecraft. In 1867, the next Paris Fair presented aluminum products like wires, foil and plates.

More than twenty years later, aluminum became part of everyday life by supplementing tableware made of copper and cast-iron, leading to price declines for aluminum. In 1903, the German metallurgist Alfred Wilm discovered that aluminum hardness could even increase by alloying it with other metals, such as copper. Around the same time, it was discovered that aluminum does not impair during repeated melting, casting and forging. Extensive recycling of metal scrap from production started, leading to further declines in aluminum prices and increasing demand. A comparison between primary aluminum production and aluminum price shows its unfolding since 1900. Whereas production increased exponentially from zero in 1900 to 63 million tons globally, price decreased from 20,000 US$ per metric ton to 200 US$.

Facts

- recyclable up to 100%
- 19 million tons produced in 1990 globally
- 5 million tons recycled
- recycling rate of 26%
- production grew
- recycling grew along, but still lags behind
- gap between production and recycling has become smaller

Sources: Devezas, 2020, pp. 4, 7; Thinking Circular, 2020.



Comparison between the unfolding of aluminum price and primary aluminum production since 1900 (Y-axis valid for both curves). Own chart based on (Devezas, 2020, p. 7)

Facts

- after 2008, production and recycling went down
- recovered in 2010
- since then, numbers for production and recycling increased significantly
- 63 million tons produced in 2018 globally
- 19 million tons
- recycling rate of 30%

It took 53 years of innovation after Napoléon started financing the material until the first flight attempts were made in 1908. In 1909, Wilm patented his invention as "Duralumin" which immediately caught attention of the aviation industry. In 1914, airplanes were technically so mature that they could be used as weapons in World War I. Major governments demanded large shipments of aluminum for light strong airframes.

It became common practice that governments subsidies factories and supply systems. But as supply couldn't satisfy demand (the material was not only needed for airplanes but also for other war equipment), recycling became important practice. During the Golden Twenties, aluminum prices reached a historical minimum as production exceeded demand. About ten years later, the beginning of civil aviation and modern airplane engineering was marked by the introduction of the first Boeing 247 and the Douglas Aircraft DC3.

In World War II, again, airplanes were used as weapons for tactical maneuvers. In 1947, the first flying machine made its supersonic flight. Fourteen years later, the first manned hypersonic flight took place. In 1967, the Concorde is launched as the first supersonic passenger aircraft. Only two years later, Jules Verne's vision becomes true: Neil Armstrong being the first human to walk on the moon was a breathtaking moment for mankind. In the end of the 20th century, aluminum production and aviation were inseparable and aluminum lost its noble myth and became just one material of industrialization and globalization. People started to trade the metal at stock exchanges at very low prices. The general trend of declining prices endures until today.

Sources: Devezas, 2020, pp. 1-2, 7-9; Thinking Circular, 2020.

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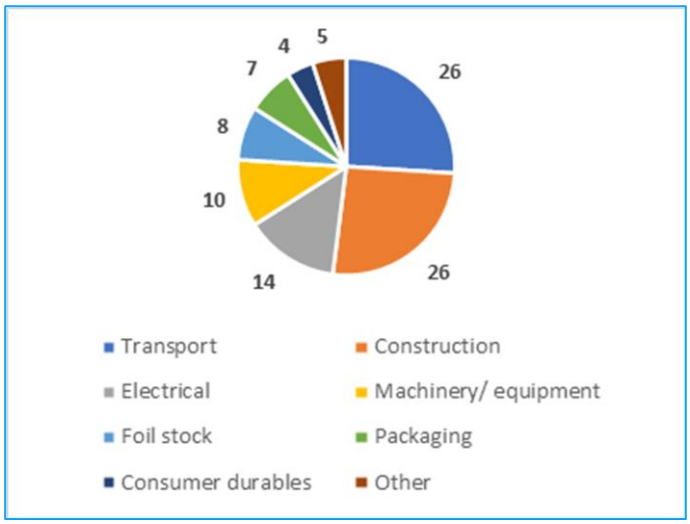
Aluminum made mankind fly. Many applications are made of aluminum. Industry sectors which make large use of aluminum applications include transport, construction and electrical sectors. Like the following chart shows, aluminum applications are important für machinery/ equipment, foil stock, packaging and consumer durables, too, as well as for many other sectors.



Aluminum applications breakdown by industry sector (%). Own illustration based on (Devezas, 2020, p. 4)

Sources: Devezas, 2020, pp. 1-2, 8-9; Thinking Circular, 2020.

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2.2. Aluminum – Global North

Aluminum is well traced and documented. Market developments are part of basic industrial knowledge in the industrialized Global North. In Europe and North America, recycling rate reaches 100%.

The story behind United States aluminum industry:

In the end of the 19th century, many flight experiments were made using vapor propelled airplanes and gliders. Otto Lilienthal, a German, made several flights on its gliders between 1891 and 1896. His insights into construction and fly control were the most important contributes to the success of the Wright brothers in the United States less than ten years later. The Wright brothers were building a biplane without fuselage and made of wood with wings that were covered in fabric. The famous machine called "Flyer I" was propelled by a water-cooled Diesel engine made by the Wright brothers and flew for the first time in Kitty Hawk, North Carolina, USA in 17th of December of 1903. A video documentation of this historic momentum of the Wright Brother's first flight can also be found online.

Though this invention prepared the ground for the later marriage of aviation and aluminum, aluminum itself did not yet enter the stage as material for airplane construction. Anyhow, aluminum industry already existed in the USA at that time. The U.S. Geological Survey mentions that even recycling of aluminum was common practice in the early 1900s though it was not industrialized and records of aluminum production reach back until 1913. Between 1913 and 1918, production was continuously increasing and then became unsteady during the Golden Twentieth because demand declined from time to time.

The Great Depression in the 1930s then brought radical changes to United States' aluminum industry. Production broke down, prices rose from 1930 to 1940. Recycling went down as well, but was not hit as hard as production. Because of the economic downturn, energy prices began to be largely subsidized by the state, not only in the USA but also in Europe. This brought incentives to the use of aluminum as a civil engineering material, being used in construction sectors. The Works Progress Administration (WPA) initiated projects to expand the hydroelectric generation capacity. Incentives and initiatives then led to an increased production capacity of primary aluminum again.

The aviation industry entered the stage again, launching the Boeing 247 in 1932 operated by United Airlines and DC-3 (Douglas Commercial, a strong competitor of Boeing at that time) in 1935 operated by TWA. Both used hardened aluminum alloys (Duralumin) for the construction of their airplanes. Modern commercial aviation was born. The Aluminum Association was formed and its first meeting was held in New York City in 1935.

Facts

- In North America, documentation of recycling in quantities reaches back until 2014
- recycling rate of 83% in 2014
- since then, recycling volumes remained stabled whereas production went down
- 5 million tons produced in 2018
- 5 million tons recycled
- 100% recycling rate

Sources: António & Vieira, 2013, p. 3; Kiessling, 1933, p. 208; Thinking Circular, 2020; United States Geological Survey, n.d.

The upcoming time of World War II then caused pressure on aluminum industry to find ways of cost-effective production of aluminum and develop strong and light aluminum alloys. Short before the World War the material was declared strategic and of extreme importance, due to its intended usage in aircraft production. United States Administration urged the aluminum production monopolist "Alcoa" in the United States at that time to expand its production. During the war, production peaked which is why a great share of the aluminum produced in the USA and Great Britain was then sent to the Soviet Union between 1941 and 1945, to be used in military engineering for both airplanes and tank engines.

The surge in scrap metal after World War II and the emergence of a "secondary aluminum" market and industrial supply chain led to a further expansion of aluminum industry after World War II. Recycled aluminum was brought into the U.S. production supply chain. Aluminum became a recyclable resource. Research for this historic development leaves the impression that the rise in recycling even led to a reduction in primary aluminum use in the United States. But different sources suggest that the decline in primary aluminum in the American and European Union production sectors was due to the high cost of energy at that time.

Recycling of aluminum was a low-profile activity until the late 1960s when recycling of beverage cans finally became conscious to public. Sources for recycled aluminum then included automobiles, windows and doors, appliances, and other products. However, the recycling of aluminum cans seemed to have the strongest influence.

In 1950s and 1960s, post-war effects on aluminum industry abated. Aviation industry again became major driver. But flying was very expensive at that time. Estimates show that in the 1960s more than 80% of North Americans had never been on an airplane. The reason for that were government-imposed rules and price restrictions on airlines. But as jet airliners entered the market, the sector experienced strong growth. That forced radical changes in the market, resulting in the publication of the 'Airline Deregulation Act' of 1978 in the USA. Soon, other countries were following. Ticket prices declined steadily. This decline was further encouraged by the democratization of air travel that started also in the 1970s. Since 1978, airfares have fallen by about 50%. Low-cost airlines concepts started and expanded rapidly to Europe after the creation of easyJet and Ryanair in 1995.

Whereas the 20th century United States aluminum industry was characterized by innovation and largely dominated by monopolist "Alcoa", the millennium already looked different: In the year 2000, 12 companies operated 23 primary aluminum plants in the United States.

Sources: Devezas, 2020, pp. 2, 7; Kiessling, 1933, p. 209; Plunkert, 2000; Sheller, 2019, p. 230; Thinking Circular, 2020; United States Geological Survey, n.d.

Market has become mature. Today, the Aluminum Association mentions 190 plants in North America.

The story behind European aluminum industry:

Just as in the USA, the aviation industry was starting point for a developing aluminum industry, reaching back until late 19th century. Interest in flying grew rapidly in Europe and the USA alike, in a way that new flying machines appeared everywhere. In 1909, large scale production was started in France, marking the beginning of the aeronautical industry.

And just as for the United States, World War I was a driver for the development of aluminum industry in Europe. Governments, recognizing the importance of the aircraft for war, took control of production to ensure supply. This led to a strong growth of the industry especially in France, UK and Germany. Industry was established so fast that by the time the USA entered the war, the American industry was already lagging behind in terms of production and expertise.

Germany emerged as the world's leading producer of aluminum. During World War II, the country prematurely realized that aluminum supply would become short, which is why it started an ambitious program of aluminum recycling after the United Kingdom was attacked in 1940. Germany even requested public to help through donating any household aluminum for airplane building – what indeed happened in large scale.

After war, industry became mature and was only affected by common market practice until the global scenario of airplane construction was shaken in the late 1960s and early 1970s. In 1967, the idea was discussed by aircraft manufacturers in France, UK, and Germany to develop larger airliners. The idea was born reaching an agreement in 1969. Manufacturers decided for a European collaborative aerospace program. In 1970, a very important player came into life: The Airbus Industrie GIE, which is known today as Airbus SE, was founded in Toulouse (France) as result of this collaboration.

Airbus introduced a series of breakthrough innovations feeding the new efficiency paradigm and presented new ways to aircraft engineering. These innovations changed the arena of aircraft production effectively and also affected aluminum industry. As a result of the 1970s oil shocks, Airbus took efforts to reduce aircraft weight aiming at reducing fuel consumption. Aluminum was gradually replaced by composite materials, such as carbon fiber and glass fiber composites. In 1972, Airbus introduced the world's first twin engine. This was a valuable contribution to the democratization of air-travel. Corresponding with the new efficiency paradigm, the machine involved the production of a number of aircrafts with larger passenger capacity and was soon followed by similar projects of larger airliners in 1982, 1988 and further.

Facts

- Europe is scrap exporter
- recycling quantities are higher than production
- 2 million tons produced in 2019
- 7 million tons recycled
- recycling rate of 100%
- recycling experienced a striving development during past 20 years
- recycling volumes stayed much higher than production
- production went down during and after the global crisis
- recycling continued to grow

Sources: António & Vieira, 2013, pp. 3, 6; Devezas, 2020, pp. 2, 4; The Aluminum Association, 2020; Thinking Circular, 2020.

Since the 1990s, the competition between Airbus and Boeing characterized a duopoly in the airliner market. The reason lies in a series of mergers within the global aerospace industry, with Airbus beginning as a European organization while the American Boeing absorbed Douglas Commercial in 1997. Many other manufacturers withdrew from the market and directed its productive capacity to more specific sectors of aviation.

In 2005, Airbus launched the world's largest ever built passenger airliner, with a capacity of carrying 850 people, challenging the dominance of Boeing in the long-haul market.

In 2010, the European Commission introduced the "ACARE" initiative to push innovation and competitiveness of the European aeronautical industry. With its «Flightpath 2050» report, the initiative set goals for the industry in general and for the aircraft in particular. Overall goal is to keep up Europe's leading position and market share with more than 40% for the decades to come. The report exerts pressure on the aeronautical industry demanding to deliver the best products and services worldwide and to decrease development costs.

Recognizing how important it will be to the future to work on a greener industry, the report also sets ambitious goals for reducing environmental impact: 75% reduction in CO2 emissions per passenger kilometer, 90% reduction in NOx emissions and 65% reduction in noise emission. Benchmark is a typical new aircraft. Moreover, the aircraft shall be emission-free when taxiing, needs to be recyclable and shall increasingly use alternative fuels.

In 2020, some of these important changes have already been implemented. Aircraft emissions have been decreasing steadily: 70% reduction in CO2 emissions since the 60's, 40% reduction in NOx emissions since the 70's and 50dB reduction in noise emission for jet engines.

To accomplish all goals set, more innovation is necessary. The entire aircraft will have to be developed differently, e.g., the propulsive systems. It is also necessary to consider aircraft design and production, as changes in these phases have a generous impact in downstream life-cycle.

That means that also recycling and circularity of aluminum will play an important part.

In 2020, the European Association "European Aluminium" has answered the question of how to achieve this with releasing the Circular Economy Action Plan.

Sources: António & Vieira, 2013, p. 66-68; Devezas, 2020, p. 4; Thinking Circular, 2020.

Goal is to achieve aluminum's full potential for a circular economy by 2030. This will require both innovation and investment. The Association plans to maximize collection and reduce losses, improve sorting and pre-treatment, remove remaining barriers to the internal market, maximize decarbonization potential and incentivize investment in recycling activities

Within 30 years, 50% of demand could be met with post-consumer aluminum. To achieve this, policies will also play a major role. And the industry needs to work on different initiatives in parallel.

As Russia and China are emerging as new economic powers and competitors, the civil aeronautical production is still a quite bipolarized sector today. The new players will challenge the established domain of Europe and the USA in this sector for the next years. It makes therefore sense to look to China directly.

The story behind Chinese aluminum industry:

China's modernization started in the 1980's and sped up to a great degree in the 1990's. In 1992, China's annual GDP growth reached the incredible mark of 14,3 %. In the second half of the 1990's, growth slightly declined, but in the first decade of the twenty-first century, the country continued to grow unrelenting. The two digits mark maintained during most of this period. Along China's growth, the worldwide production of aluminum strongly increased.

China even continued to grow at rates over 9% during the global economic crisis in 2008–2009. In 2010, China became the world's second largest economy, and now more than twice as large as that of Japan.

China's economy doubled four times in 30 years and resulted in a huge expansion of civil construction including housing, commercial buildings, industries, roads, and much more.

Of course, this was reflected in material flows, which increased alongside. China was dependent on massive material imports. To manage these, a large global infrastructure needed to be implemented. Besides its nomination as the second world's largest economy, China also became the world's leading manufacturer and importer of goods – a converse trend to any dematerialization ambitions.

Tied to this economic growth and its transport demand was also commercial aircraft production. The transport of passengers for example has increased at around 6.5% per year since 2002.

Hot spots for air transport increase were Asia and Middle East. This increase resulted in new orders for airplanes. Reasons were not only to satisfy demand but also, to replace old cost-inefficient airplanes.

Facts

- in China, statistics are missing latest figures
- documentation of recycling started in early 21st century
- recycling rate went up
- 4 million tons produced in China in 2002
- 1 million tons recycled
- recycling rate of 25%
- 20 million tons produced in 2012
- 6 million tons recycled
- recycling rate of 30%
- production grew exponentially in the past two centuries
- recycling is keeping up

Sources: António & Vieira, 2013, pp. 12-13; Devezas et al., 2017, pp. 287-288; Devezas, 2020, p. 3; European Aluminium Association, 2020, p. 32; Thinking Circular, 2020.

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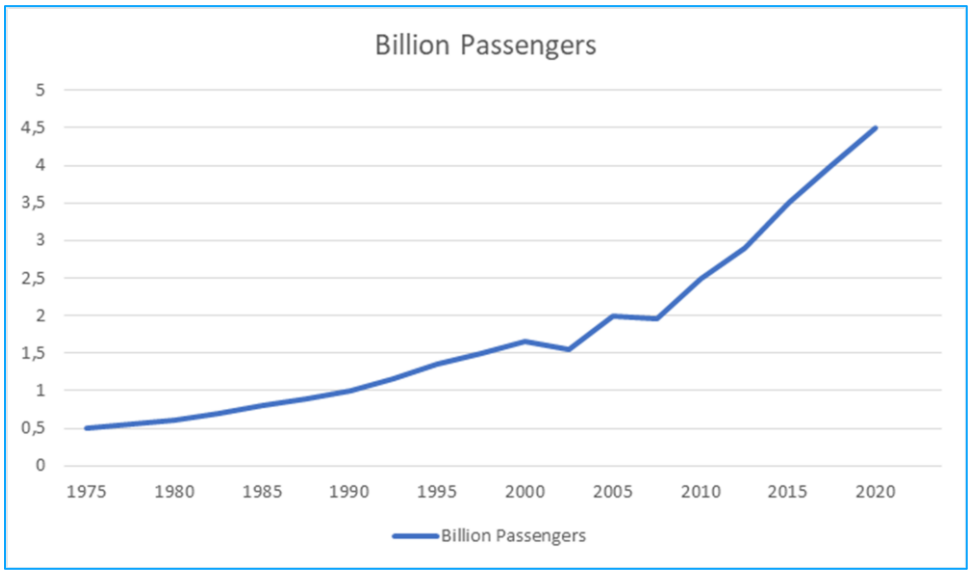
Orders and production were growing almost simultaneously, reaching levels never reached before in aeronautic production history. Taking Airbus as example: In only seven years, the manufacturer astoundingly produced 4682 aircrafts.

Summed up, China's modernization not only sped up global economic growth but also provoked a fight in the trends of materialization vs. dematerialization. Meanwhile, the country produces and consumes almost twice as much as all other countries taken together. Population is further growing and an emerging middle class is asking for better housing, better living standards and even more materials. In terms of emissions, China produces already more than the double of what Europe produces. The question of the rebound effect quickly arises.

The causality between economic growth, materialization and its consequences for environment is quite logic: Airplanes become lighter, more efficient and bigger which leads to cheaper flight tickets and results in more people flying, which fly more often. All in all, more kilometers are flown. In 2016, the number of passengers carried per year already reached the incredible mark of 4 billion passengers as the following graph shows.



Yearly number of passengers carried according to World Bank, 2020. Own illustration based on (The World Bank, 2020)

Causality reaches even further. As the story behind China has clearly shown, a growing economy not only demands more materials but also more infrastructure and more suppliers. Aircraft engineering uses advanced, specialized technologies, so the construction of an airplane needs many different parts and components.

Sources: António & Vieira, 2013, p. 12; Devezas et al., 2017, p. 289; Devezas, 2020, p. 7; Hatayama et al., 2012, p. 13; Thinking Circular, 2020.

To serve the worldwide demand for more airplanes, this means suppliers all around the world needed to collaborate and build production networks. Moreover, due to initiatives fostering industries to become even more efficient and cost-diminishing, manufacturers faced high pressure and needed to find solutions how to run on tight budgets and timescales. Thanks to globalization, industries could reach over to low-labor-cost countries like China. This complex network of suppliers makes cheap flying reality as parts produced in Asia can be shipped to Europe or the USA for final assembly.

For aluminum, that means stock and demand in the future will derive from developing countries like China and India, whereas markets in developed countries already seem mature for traditional products.

The demand for conventional vehicles is projected to diminish whereas the demand for electric vehicles and hybrid electric vehicles is projected to rise. Along with electric vehicles, cast alloys and demand for aluminum for cast alloys will grow. Vehicles will be responsible for 25% of aluminum demand and discard. The displacement of conventional vehicles means that a lot of cars will have to be recycled which could result in a surplus of 6.1 million tons of unrecyclable scrap in 2030, for Europe, the United States, Japan and China.

The interaction of material life cycles, supply side and waste streams happens time-delayed which is why risks of rebound effects will remain.

Sources: António & Vieira, 2013, p. 13; Hatayama et al., 2012, pp. 8-14; Thinking Circular, 2020.

2.3. Aluminum – Global South

China is world leader in aluminum production with India ranking second (6%) and Russia ranking third (6%).

Aluminum is an element that makes up 8% of the Earth's crust. Of all elements, aluminum is the third most abundant one. Anyway, it is no element that can be found right away, but only combined with other elements which is why it needs to be separated through processing.

One of the most important resources for aluminum is bauxite, which is a rock that can primarily be found in Global South. To produce one ton of aluminum, four to six tons of bauxite are needed. Bauxite market is oligopoly. Only a handful of significant market players exist which operate large-scale mines.

As of January 2021, global bauxite reserve is estimated to be 55-75 billion tons (32% in Africa, 23% in Oceania, 21% in South America, 18% in Asia, 6% elsewhere) which means that global future aluminum demand should be met well.

For South America, Jamaica also plays an important role in bauxite production. For Asia, Malaysia and Vietnam are further important. For Eurasia, Kazakhstan and Russia are of major interest. And for Middle East, Saudi Arabia is producing country, too.

Global bauxite production takes place where reserves are located, favored through climatic conditions as well as through low labor cost.

Anyhow, a transformation in global bauxite industry can be obtained: As demand for it rises and is projected to further rise, new player move into the market under the paradigm of an efficient "faster and further". The new mines are smaller, containing less bauxite ore, and therefore shorter in supply, but they are many.

So, industry is currently changing from a few large-scale operating players to many small-scale operating players.

Mining characterizes numerous environmental impacts also due to unsustainable practices. To address these, some countries started to answer with bans on mining and shipping. To get situation under control, the International Aluminium Industry Association has written guidelines on sustainable mining practices in consortium with other important market players, like Brazil and Australia.

Environmental risks are: huge environmental footprints, loss of biodiversity, destruction of indigenous land, displacement of local people, land and water grabbing and much more.

Facts

- Australia, China, Guinea, Brazil, India and Indonesia are responsible for 88% of global **bauxite** production
- China, Middle East, Other Asia, Europe, North and South America are responsible for 91% of global **aluminum production**
- China, Europe, North America, Other Asia, South America and Japan are responsible for 100% of global **aluminum recycling**

Sources: Bray, 2018; Bray, 2021; International Aluminium Institute et al., 2018, pp. ii, 1; International Aluminium Institute, 2020d; OECD Environment Directorate, 2010, p. 12; Plunkert, 2000, p. W1; Thinking Circular, 2020.

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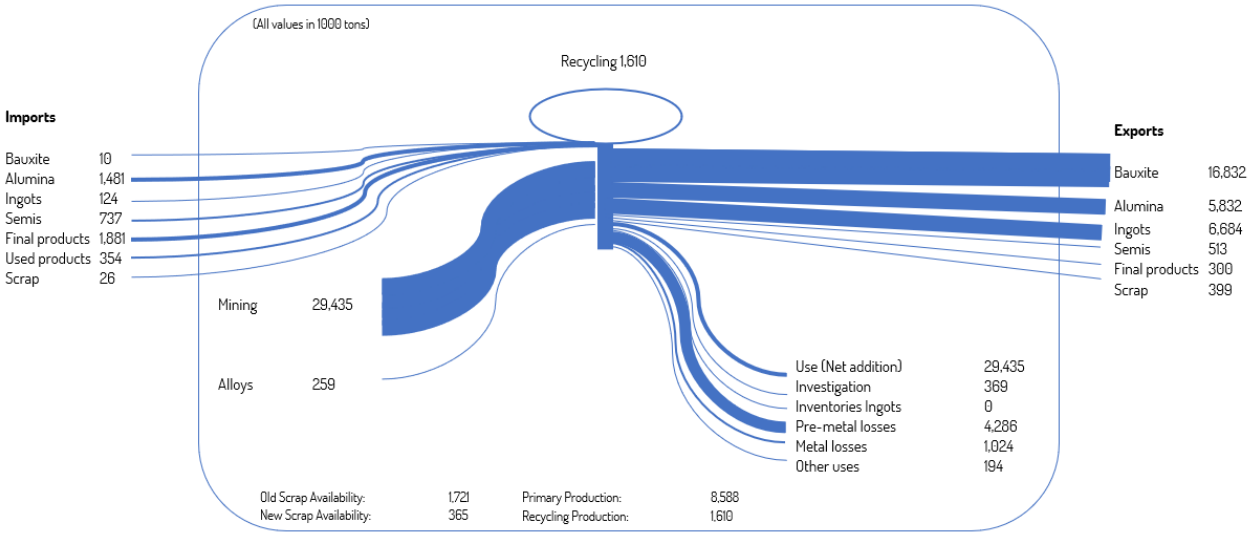
To gain a deeper understanding for Global South' aluminum industry, it makes sense to take a look at the major players of Global South.

Gladstone Port for Alumina and Bauxite shipping in Queensland, Australia. Photo by Vicki Nunn via Pixabay.

Australia and Guinea are both famous for their rich bauxite resources. The following sanktay diagram shows also other countries beside Australia and Guinea but gives an impression anyhow how aluminum industry is organized in oligopoly structures:



The diagram shows, mining of bauxite is main activity and bauxite is main export good. Finished products are only a small number that is exported but main good for imports. Beyond mining, aluminum gets also produced in primary production. Though scrap is available, recycling is not in the focus. Scrap exports are higher than imports. Recycling rate still almost reaches 20% compared to aluminum primary production volume. Nevertheless, looking at mined bauxite as comparative, it becomes clear that recycling is a drop in the ocean with about 5%.

Sources: International Aluminium Institute, 2020b; Thinking Circular, 2020.

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Behind Guinea as third most important mining country in the world, comes Brazil in fourth place. Bauxite mining is the most important activity for Brazil's aluminum industry. Here again, we can find oligopoly structures.

Bauxite querry. Photo by Massimo Virgilio via Unsplash.

Mining of bauxite is main activity. But unlike in Australia and Guinea, bauxite is not main export good. Instead, alumina – processed bauxite – is main export good. Finished products are only a small number that is exported but main good for imports though quantities imported are also quite low compared to the size of the country. Beyond mining, aluminum gets also produced in primary production, but only in small quantities. The government has passed a 6% tariff on unwrought primary aluminum imports as long as power prices permit domestic production. 173 thousand tons are allowed to be imported without tariff.

Scrap is available, but recycling is not in the focus. Anyhow, recycling rate is surprisingly high compared to aluminum primary production volume, reaching 100%. Scrap imports are also higher than exports. Nevertheless, looking at mined bauxite as comparative, recycling rate only reaches about 17%, which is already quite higher than in Australia and Guinea. This shows that the shift from bauxite mining to aluminum recycling comes to happen with lower bauxite resources.

Just as Australia, Guinea and Brazil, India and Indonesia show oligopoly structures. Mining of bauxite is main activity but not as strong as in Australia, Guinea and Brazil. Bauxite is not main export good. Most of the mined bauxite is used domestically for production. Finished products are main export goods and also main goods for imports. A large quantity of scrap becomes also imported. It seems like beside mining, recycling becomes focus. Recycling rate is surprisingly high compared to aluminum primary production volume, reaching 100% (just as in Brazil). Looking at mined bauxite as relative number (number is quite higher than aluminum production number of course), recycling rate still reaches the incredible number of 65%.

Sources: Bray, 2020, p. 5.5; International Aluminium Institute, 2020a; International Aluminium Institute, 2020c; Thinking Circular, 2020.

This again underlines the shift from bauxite mining to aluminum recycling in countries with lower bauxite resources.

It is expected that the global trend of closing older smelters or modernizing them in order to comply with environmental regulations, increase efficiency, and reduce costs is expected to continue. Most high-cost smelters outside of China had already been shut down by the end of 2015. An expansion of new capacity is expected in locations where power costs are relatively low, most notably in the Middle East and Russia.

Sources: Bray, 2020, pp. 5.6-5.7; International Aluminium Institute, 2020a; Thinking Circular, 2020.

Summary

Aluminum is a material that can be recycled up to 100%. Closely linked to the evolution of aeronautics, aluminum is THE material of globalization. Aluminum made mankind fly.

Mining of bauxite (main resource for aluminum) takes place in Global South. Environmental risks are huge environmental footprints, biodiversity loss, destruction of land, displacement of local people and land and water grabbing.

Production and recycling of aluminum grew, but recycling is still lagging behind with about 30% global recycling rate. In Europe and North America recycling experienced a strong growth. Aluminum is recycled up to 100%.

Unsteady times caused pressure on the industry. Shortly before World War II, aluminum was declared strategic material of extreme importance due to its usage in aircrafts. The secondary aluminum (=recycling) market emerged.

Today, emerging markets are demanding huge amounts of aluminum. Hot spots for air transport increase are Asia and Middle East.

A strong demand for aluminum causes rebound effects. China produces and consumes almost twice as much as all other countries taken together. Population is further growing and an emerging middle class is asking for better housing, better living standards and even more materials. In terms of emissions, China produces already more than the double of what Europe produces.

The causality between economic growth, materialization and its consequences for environment is quite logic: Airplanes become lighter, more efficient and bigger which leads to cheaper flight tickets and results in more people flying, which fly more often. All in all, more kilometers are flown.

Causality reaches even further. A growing economy not only demands more materials but also more infrastructure and more suppliers. Aircraft engineering uses advanced, specialized technologies. The construction of an airplane needs many different parts and components. Suppliers all around the world need to collaborate and build production networks. This complex network of suppliers makes cheap flying reality as parts produced in Asia can be shipped to Europe or the USA for final assembly.

The story about the flying paradigm was not connected to linear or circular questions. But climate change now questions the paradigm of an unlimited transports in the sky or in space, but a paradigm for freedom, overcoming physical dimensions flying and entering space might explain why environmental aspects – not being in the focus – led to a climate rebound. No light has been shed on the flying paradigm before, but climate change forces the industry to reflect developments.

3.1. Paper – Global Overview

Paper is one of the most circular materials in the world. But paper regulatory framework differs from country to country and region to region.

As paper is a material with a long tradition and history, it is strongly involved with humans' lives: It was and is used as sanitary product, to store knowledge, as payment instrument, as wallpaper i.e. People have understood the value of the material and its collection. Recycling technology is worldwide available. Paper evolution was driven by printing process evolution and by peoples desire to document and share knowledge. This derives from the freedom of mind and it offers an infrastructure to voice.

In 2018, there were 420 million tons paper produced of which 221 million tons got recycled on a global basis. Recycling rate is 53%. 422 million tons of paper were consumed.

The development of paper production characterizes typical industrial market developments. Production is growing during the past centuries but doesn't experience exponential growth. In 2008, global paper markets went down due to global economic crisis, but recovered fast. Since then, production is still growing but quite slowly. Global paper recycling is not documented as detailed as paper production and documentation got started after the economic crisis. Anyhow, recycling rates remained relatively stable throughout the years at around 50%.

The average rate is pulled down by countries that do not have waste management or on an informal basis only. But overall, many countries are already doing quite well. In countries of Global North recycling rates are very high but even in the Global South, recycling rates are much higher than for other materials. African countries did surprisingly well. Australia is global leader in terms of paper recycling, with recycling rates coming close to 100%.

The continuous evolution of paper technology and production processes has become increasingly responsive to environmental concerns. New technologies are in place to make paper lighter, reduce energy consumption and to generate biofuels. In Europe on 16th July 2020, the Confederation of European Paper industries (CEPi) announced the development of a lifecycle assessment tool to enable any CEPi member to calculate product lifecycle assessments and validate their green claims within the Green Deal context.

The removal of inks is one of the key problems in the whole paper recycling technology. Liquid toner printed material should be avoided for recovered paper from de-inking and should be directed towards corrugated board production. There is an urgent necessity for the development of new methods for de-inking.

The latest developments, especially the import ban imposed by China, have disrupted the recovered paper market. These developments represent an immediate challenge for recycling companies recovering paper.

Facts

- biogenic material
- long tradition
- recycling technology available
- definite number of loops before fiber gets too short
- number of loops for newsprint is ca. 5.1
- for packaging paper up to 3.6
- for household and sanitary products up to 1.9
- managed in a technical cycle due to contaminations
- deinking must be solved

Sources: Confederation of European Paper Industries, n.d.-a, 2020a; EUWID Europäischer Wirtschaftsdienst GmbH, 2019; Meinl et al., 2016, pp. 18, 20; Sardjeva & Koeva, 2015, p. 25; Thinking Circular, 2020.

3.2. Paper – Global North

Production and recycling of paper is well traced and documented. In Asia (where China plays a big role) in 2018, there were 204 million tons produced of which 98 million tons got recycled. That makes a recycling rate of 48%. In Europe in 2019, there were 90 million tons produced of which 49 million tons got recycled. That makes a recycling rate of 54%. In North America (where the USA contributes the most) in 2018, there were 76 million tons produced of which 52 million tons got recycled. That makes a recycling rate of 68%.

Globally, 13.7 million employees work in the forestry sector. That's equivalent to around 0.4% of the total labor force. Including the three sub-sectors logging, wood processing and pulp & paper, 60% of total employment is concentrated in only ten countries: China (accounts for 26% of total employment), USA, Brazil, Russia, India, Japan, Germany, Indonesia, Italy, Malaysia. So, unlike for metals where mining is concentrated in Global South, resource supply is taking place in Global North as well.

The pulp and paper industry is one of the largest industries in the world and characterized by oligopoly structures. The three largest paper producing countries are China, the United States, and Japan. They produce more than half of the world's total paper. Leading paper importing and exporting countries are Germany and the United States. The top four producers of paper and board also led the world in terms of apparent consumption: China, USA, Japan, Germany.

Though many paper applications are shifting from hard copy on paper to electronic forms, the industry grows by 1.1% per year. Market value and paper demand is forecasted to rise steadily from 420 million tons up to 495 million tons globally until 2030.

The global production of packaging paper and board is already growing since 2010, but graphic paper is declining. After a short break-in after the global economic crisis in 2008, packaging paper and board has strongly increased from 190 million tons globally in 2008 to 260 million tons in 2018 whereas graphic papers went down from 150 million tons in 2008 to 120 million tons in 2018.

The COVID19-crisis made clear how verticalized digital consumption drives the board production due to accelerating demands for packaging.

Anyhow, projections for growths of product types differs from region to region. Global North is already characterized through digitization but Global South is keeping up. Looking at the annual growth rates for tissue, packaging papers, hardwood pulp and softwood pulp, we can find growth rates of over 2% for Latin America, Eastern Europe and other Asian countries than China.

At the same time, countries of Global North are further increasing paper recycling rates.

Facts

- global average consumption of paper and cardboard is 57kg per capita
- Luxembourg (277 kg), Germany (251 kg), Austria (247 kg), USA (222 kg), Japan (214 kg) are having the largest footprint for per capita paper consumption
- continents with highest consumption footprint are North America (215 kg), Europe (125 kg) and Oceania (113 kg)

Sources: Berg & Lingqvist, 2019; Bureau of International Recycling - Paper Division, 2020, pp. 16-17; Confederation of European Paper Industries, n.d.-b; Confederation of European Paper Industries, 2020, p. 3; Confederation of European Paper Industries, 2020a; Haggith et al., 2018, pp. 10, 14, 19-20; International Labour Organization, n.d.; Statista, 2019a; Statista, 2019b; Statista, 2020a; Statista, 2021; Thinking Circular, 2020.

Recycling technology exists worldwide. Directories mention globally about 3,000 companies that produce equipment for paper waste processing and recycling. In comparison, recycling equipment for paper hits the second place globally:

1. 4,500 recycling equipment manufacturers for plastic
2. 3,000 for paper
3. 2,300 for ferrous metals
4. 1,900 for organic material
5. 1,000 for glass

Moreover, paper is one of the materials for which worldwide a large number of recycling plants exist: Directories mention 7,300 recycling plants for paper and about 5,000 companies that receive, separate and prepare recyclable paper materials. In comparison:

6. 12,300 recycling companies for paper
7. 12,100 for ferrous metals
8. 8,400 for plastic
9. 5,000 for organic material
10. 2,800 for glass

In the EU (still incl. UK), there is a polypoly market structure with about 2,850 paper recycling companies mentioned. Most of the companies are small- and medium-sized businesses located in Germany and in UK.

In North America, there are bigger, oligopoly market structures with about 650 paper recycling companies mentioned. Almost all of them are small- and medium-sized businesses located in the USA.

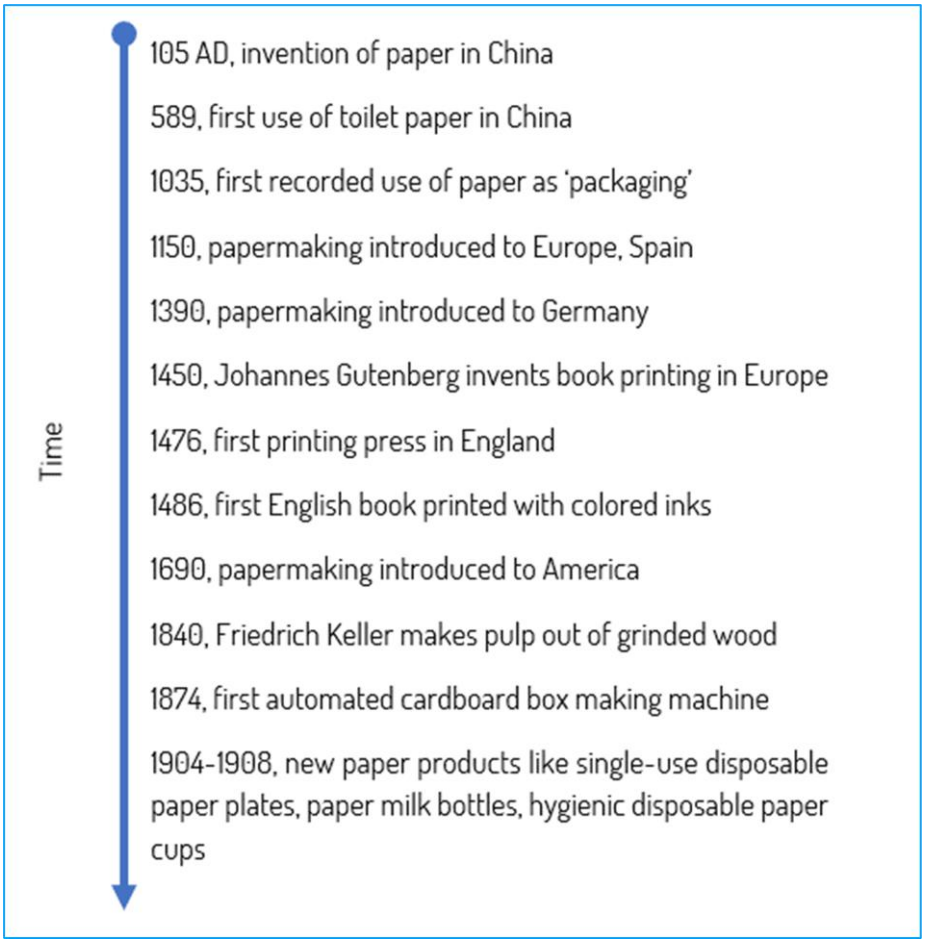
In the developed countries of Asia (China, Japan, Hong Kong, Singapore) there are about 700 paper recycling companies mentioned. About 550 companies are located in Japan, where paper market structures are similar to the US. Only 100 companies are located in China. Most of them are small- and medium-sized businesses as well.

The story behind paper:

Paper has a long anthropogenic history. It was used for the development of new hygienic standards, for the storage of knowledge, as payment instrument and medium, and much more.

Sources: ENF Recycling Ltd., n.d.-c; Haggith et al., 2018, p. 20; Thinking Circular, 2020.

History plays an important role in the development of paper markets:



Paper Timeline. Own illustration based on Paper Industry Technical Association, 2015

Facts
- culture-driven material
- invention of book printing by Johannes Gutenberg accelerated development
- digitization and e-commerce are driving market developments

History shows that paper is already going back almost 2,000 years. Letterpress printing with movable types was one of the outstanding inventions of the Middle Ages. For this invention, Johannes Gutenberg was also elected "Man of the Millenium". The invention influenced the economic, political and cultural development up to the present day. One of the most famous and important books printed by Gutenberg in his hometown of Mainz was his "Biblia Latina," a Latin Bible also known as the Gutenberg Bible. In the last century, innovation has slowed down.

Today, paper markets and recycling markets are globally established for numerous qualities. The main reasons for this global success are connected to its history. The material has multiple economic and social benefits since its invention. Collection is culture-driven.

Thinking Circular® Experts

Sources: Confederation of European Paper Industries, n.d.-b; Confederation of European Paper Industries, 2020, p. 3; Confederation of European Paper Industries, 2020a; Haggith et al., 2018, pp. 20, 21; Paper Industry Technical Association, 2015; Thinking Circular, 2020; Two Sides, 2016, p. 13.

Environmental pressure makes people and industry conscious for print and paper waste as valuable resource being high in market demand. Paper industry is aiming to become even more circular. For doing so, recycling mills need to get the right kinds of recovered fibers, in quantities large enough, for the specific products they are making. Many countries have to increase recycling collection to meet the expanding demand. It is projected that global recovery will increase to 64% by 2028.

In Global North, recycled fibre collection is reaching high levels and is reaching the maximum that can be practically achieved. In Europe, collection rates are about 60%, in the USA rates are about 70%, and in Japan rates reach nearly 80%. It's not possible to reach 100% collection rates because some paper gets destroyed or becomes too contaminated; others cannot be recovered because they are kept for long periods of time (books) or archived (records).

In the past, China has been building up its own internal wastepaper collection system and increasingly implemented import rules that escalate requirements for high quality materials, reduce imports.

High added-value and environmental sustainability were and will be key mantras for the industry. Paper is made from renewable resources by an industry whose future depends on planting more trees than it consumes and which is progressively improving standards in the whole supply chain. Scarce resources are a threat but also an opportunity.

Facts
- deinking is major problem
- inks and other contamination lead to downcycling

Paper regulatory framework for doing so differs from country to country and region to region. Overall, it can be said that in Global North, standards are set. It makes sense to look a little deeper into regions.

European paper market:

The documented history of paper production and recycling reaches back decades. In 1991, there were 65 million tons of paper produced of which 25 million tons got recycled, making up for a recycling rate of 38%. The development of paper production and recycling was a parallel movement since then. During the 1990s as well as before the global economic crisis in 2008, statistics about this development were available but didn't include much data. After the economic crisis, research interest grew and statistics became much more consistent. Since then, paper market is documented quite well. After the economic shortfall in 2008 and 2009, paper markets recovered fast and continued to grow in the same pace just as before 2008. In 2011, production and recycling peaked and slowed down. Since this peak, production and recycling even decreased slowly but surely. Whereas production of paper was 102 million tons before the crisis and 106 million tons in 2011 (of which 62 million tons got recycled), there were only 90 million tons produced in 2019 (and 49 million tons recycled).

Sources: Confederation of European Paper Industries, n.d.-b; Confederation of European Paper Industries, 2020, p. 3; Confederation of European Paper Industries, 2020a; Haggith et al., 2018, pp. 20, 21; PG Paper Company Ltd., 2018, pp. 12-13; Sardjeva & Koeva, 2015, p. 16; Thinking Circular, 2020; Two Sides, 2016, pp. 11, 13, 19-20.

On a European level, this means that recycling rate was overall improved from 38% in 1991 to 54% in 2019 on European average.

The European paper industry is a leading region in terms of paper recycling. Collection and recycling volumes have remained at a very high level. Paper is recycled about 3.5 times a year. Europe's paper producers use more recycled fibers than virgin fibers. Every second, two tons of paper are recycled. In some European countries, recycling rates today range up to 75%, which is likely the practical maximum recycling rate. Coming nearer to its practical maximum, growth has slowed down, which is why it is likely that the current balance of recycled and virgin fibers remains steady. Packaging is one of the most collected paper products. And in comparison, to other packaging material, paper-based packaging is the most recycled in Europe. Collection rates with over 80% are mentioned. That's equivalent to an area of the size of Greater London that's prevented from going to landfill every four months.

The European paper industry plays a big role in the circular economy. The industry has worked decades to make its industrial model sustainable and circular. Now, it is one of the most sustainable industries in Europe.

In 1996, recycling started due to the implementation of the environmental label „Blue Angel ".

Facts

- since 2005, EU paper market has achieved a 27% decarbonization
- EU paper market leads in terms of industrial symbiosis, sharing materials, energy heat and water

Blue Angel Label, English version. Photo by Publicgarden GmbH, CC BY-SA 4.0 https://creativecommons.org/licenses/by-sa/4.0, via Wikimedia Commons

In 1999, the Europe-wide paper garbage can was introduced. In 2006, recycling rates dropped because EU15 became EU27. East European countries were joining and dragging down recycling rates. Anyhow, Europe was further improving. In 2008, the Directive 2008/ 98 EC Waste "loss" defined waste-related terms and waste hierarchy.

Looking forward to 2050, the EU pulp, paper and wood industry has the ambition to be at the heart of the bio-economy, an essential platform for a range of bio-based products and the recycling society. Growth of the industry was expected – before Corona – to continue in line with EU GDP, by about 1.5% a year for the next 40 years.

Sources: Confederation of European Paper Industries, n.d.-b; Confederation of European Paper Industries, 2018, p. 8; Confederation of European Paper Industries, 2020, p. 3; Confederation of European Paper Industries, 2020a; Haggith et al., 2018, p. 20; Sardjeva & Koeva, 2015, p. 16; The Umweltbundesamt, 2014; Thinking Circular, 2020; Two Sides, 2016, pp. 11, 13, 19.

North American paper market:

The documentation of paper production and recycling in North America is similar to statistical documentation in Europe but contains less data. Research and statistical observation on North American level for paper recycling started after global economic crisis whereas production data reaches back until decades (though they are not complete as well). Since millennium, overall production of paper in North America decreased from 107 million tons to 76 million tons in 2019. Recycling statistics reach back until 2011. Recycling development have remained stable since then which makes up for the effect that recycling rates grew: In 2011, 60% of paper was recycled. In 2019, 68% of paper was recycled. Compared to Europe, rates are quite higher which is due to the fact that European average is pulled down by developing countries whereas in North America, regional scope includes only developed countries like the USA and Canada.

In North America, a voluntary, market-driven product recovery system has been fostered. The industry's success in paper recovery is largely attributed to this system. It's already 50 years ago that large-scale community recycling programs began. The recovery rate for paper has nearly doubled since 1990, when they first committed to setting and reaching paper recovery goals. After 1990, fees for landfill increased significantly. In 2009, the recycling rate for paper and paper-based packaging started growing due to a federal initiative in the USA. To prepare legal regulation on waste, the Environmental Protection Agency (EPA) was assigned to collect data. Since 2009, the recycling rate for paper and paper-based packaging remains strong, meeting or exceeding 63 percent every year (in 2018, 68%). Goal is to exceed 70 percent paper recovery for recycling, as part of the American Forest & Paper Associations' sustainability initiative "Better Practices, Better Planet".

Today, more than twice as much paper is recycled than is sent to landfills. Every ton saves 3.3 cubic yards of landfill space. By weight, more paper is recovered from municipal solid waste streams than glass, plastic, steel and aluminum combined, according to the EPA.

As for other countries, China was an important market for the U.S. in the last years. The U.S. exported 12 million tons to China in 2019 (EU to China: 8.8 million tons).

But since China has closed doors to imports, they went down from 77.5$ to almost zero $ in 2018, which also had a strong effect on waste paper prices.

Moreover, the degree of contamination for imports was reduced to 0.5%, instead of the worldwide usual 10%. As a consequence, imports of contaminated fibers in the USA increased and filled landfills according to US Trade Commissioner Sarah Scott.

Sources: American Forest & Paper Association, n.d.; American Forest & Paper Association, 2019; Bureau of International Recycling – Paper Division, 2020, p. 8; EUWID Europäischer Wirtschaftsdienst GmbH, 2019; The Seattle Times, 2018; Thinking Circular, 2020.

Asian paper markets:

Similar to North America, documented history of paper production and recycling more or less started after the global economic crisis in Asia. Though statistics of the development of paper production are not sufficient, single data is available reaching back decades. The increase in production is very strong, mainly due to strong economic growth in China. In 1990, Asia produced 55 million tons of paper. In 2019, it was already 204 million tons. Recycling statistics on cross-country Asian level started in 2011. To that time, recycling rate was 52% which was quite a good average. Since then, recycling of paper has remained stabled whereas production further increased. In 2019, 98 million tons of 204 million tons got recycled, making up for a recycling rate of 48%.

China produces around one-fourth of global paper and cardboard production. This and the fact that its political announcement is disrupting the whole paper market, makes China a major player on Asian paper market. Anyhow, acceptance for recycled paper in society is on a medium level. Therefore, Chinese Government suggested to increase acceptance and is further supporting growing recycling rates which were reaching almost 48% in 2018.

China's political announcement to introduce a circular economy was in 2008. The announcement led to statistical research in the following years how much is actually recycled. But due to the country's strong growth in the past years, circular economy is lagging behind. While the country imported huge waste paper quantities, mainly from North America and Europe, an own internal wastepaper collection system was built up. So, China increasingly implemented import rules that escalate requirements for high quality materials, reducing the volume of imports to almost zero.

China's import and contamination ban was one of the biggest industry news. Once, the country was the world's biggest recipient of overseas trash. The reason why it began importing was that the country wanted solid waste as a source of raw materials in the 1980s. This strategy supported economic growth but harmed and still harms the environment and public health. Due to this environmental damage and resource depletion that was occurring from its industrialization process, China adopted the circular economy. Important legislation that has been implemented in the last decade for the development of China's circular economy are: The Law for the Promotion of the Circular Economy, The Circular Economy Development Strategies and Action Plan, and The 12th Five-Year plan. Amid the country's green development and circular economy drive, China's imports of solid waste have continued to drop.

Sources: chinawaterrisk.org, 2015, 2016; East China University of Science and Technology, 2019; EUWID Europäischer Wirtschaftsdienst GmbH, 2019; Geng, Yong; Doberstein, 2008, pp. 231-239; Haggith et al., 2018, pp. 20, 21; Mathews & Tan, 2011; State Environmental Protection Administration et al., 2008; Statista, 2020b; Statista, 2021; Thinking Circular, 2020; Xinhuanews, 2020.

The announcement to pose import bans started in 2008. Since then, China is active in developing policy aimed at establishing more sustainability practices and economic growth in future decades.

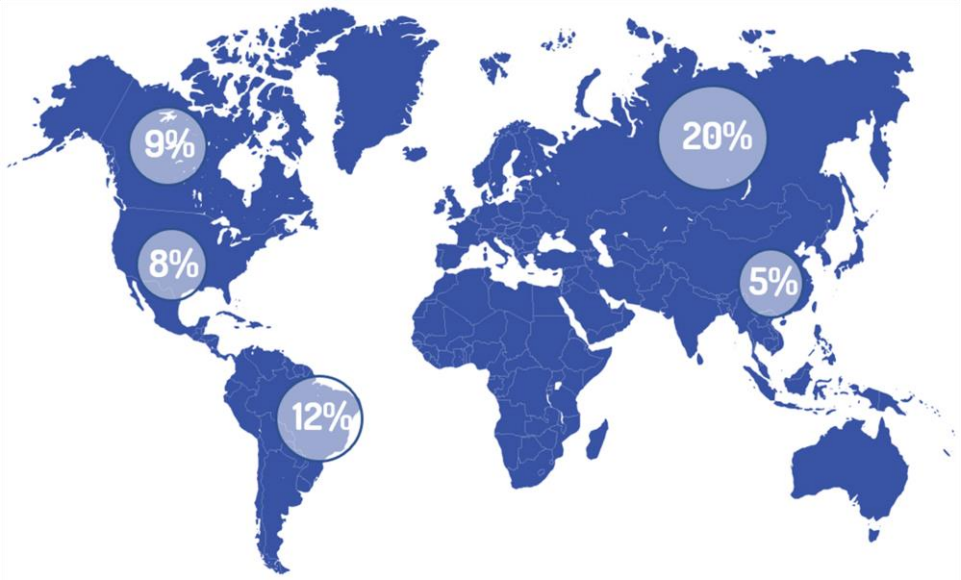
China uses Material Flow Analysis (MFA), Life Cycle Analysis (LCA), CO2 emissions and economic returns to measure the performance of their circular economy initiatives in regional and industrial park areas. Though they are criticized, these performance indicators are helpful in measuring the effectiveness of the government's initiatives. Furthermore, it was discussed to introduce an indicator system using accounting indices and ratios, where it is capable of measuring the performance of resource generation and product dimensions.

Retrospective, it can be summed up that some points are still missing in Global North ambitions for a circular economy. Global North is already doing quite well in paper recycling, reaching almost practical maxima. But to address the climate change and extinction crises, additional urgency and transparency are needed to find collaborative solutions at a pace that is sufficient. Corporate leadership potential of circular economy policies in the marketplace is strong, growing, and helping drive change on the ground, but execution and progress on voluntary commitments is lagging in many cases. The circular economy will not make the world a better place if we still don't close loops fully and don't think of systemic consequences like those we can see in Global South.

Sources: chinawaterrisk.org, 2015, 2016; Geng, Yong; Doberstein, 2008, pp. 231-239; Geng, Yong; Sarkis, Joseph; Ulgiati, Sergio; Zhang, 2013; Haggith et al., 2018, p. 3; State Environmental Protection Administration et al., 2008; Mathews & Tan, 2011; Thinking Circular, 2020; Xinhuanews, 2020.

3.3. Paper – Global South

Forests cover around 30% of the earth's land surface. That's around 4 billion hectares. Only ten countries account for 66% of global forest areas. The following map shows the top five countries.



Top ten countries for forest area in % of world forest area, 2020. Own illustration based on FAO. World map by Layerace via Freepik. (Food and Agriculture Organization of the United Nations, 2020, p. 15)

Facts
- missing recycling statistics
- focus lies on raw material exploitation

A fact important to highlight is that, according to World Bank estimates, **forests are a vital source of livelihood for around 1.6 billion people living in extreme poverty worldwide.** For many of the world community's most important problems, such as climate protection, conservation and sustainable use of biological diversity, or poverty reduction, the world's forests are crucial keys to the solution. To achieve this, however, it is necessary to stop the overexploitation and destruction of the forests in many parts of the world.

Just as for ferrous metals, the typical picture of missing recycling statistics appeared, again. Looking at the countries, that are not included in global paper statistics in terms of recycling quantities, correlation to large forest areas becomes clear. Statistics were insufficient for Australia, Indonesia and Russia.

In Global North, it was topic to maximize the use of recycled fiber in the global paper production system by making sure that recycling mills can get the right kinds of recovered fibers, in quantities large enough, for the specific products they are making. For Global South, recycling and collection processes must be initiated and established.

Looking at recycling infrastructures, it becomes obvious, that focus for Global South does not lie on recycling. Whereas Europe accounts for almost 3,000 recycling companies, we only find 99 in Africa, 550 in Japan, 274 in Middle East, and 277 in South America.

Sources: BMEL, 2017, p. 30; ENF Recycling Ltd., n.d.-c; Food and Agriculture Organization of the United Nations, 2020, pp. 14-15; Haggith et al., 2018, p. 20; Thinking Circular, 2020.

For circular theory, we can state that if Global South can't yet contribute to paper recycling, at least paper production is sourced by the Global South. Therefore, it makes sense to look deeper into raw material exploitation: forest management.

The story behind forests:

There has been a progressive decline in the proportion of primary and semi-natural forest in various regions. The reasons for this are complex. Forest losses in Portugal are mainly attributed to the increasing frequency of forest fires. In South America and Asia, main driver is industrial agriculture as well as plantations for palm oil, sugar, rice and natural rubber.

Brazil as largest resource is strongly affected by deforestation with almost 10%. The deforestation area is as large as whole forest areas of Sweden and Finland combined. Anyhow, the German Environmental Institute "Bifa" (Bavarian Institute for Waste) has identified that main source for deforestation is not paper industry alone, but the proceeding industrialization and to satisfy the worldwide demand for meat, for which large forest areas are cleared to create space for cattle farming and grow soy beans for cattle feeding.

Facts

- overexploitation and climate change lead to deforestation
- paper industry is part but no single driver of global forest clearing
- Global South is exploited to be fuel to global industrialization
- protection and circular economy strategies are missing

Deforestation. Photo by Aleksey Kuprikov via Pexels.

Sources: Dr. Wolfram Dietz, Dr. Gert Meinl, René Peche, Dr. Siegfried Kreibe, 2020, pp. 31-32; ENF Recycling Ltd., n.d.-c; Thinking Circular, 2020.

The "Bifa" furthermore constitutes that paper industry is circumstantial for deforestation in many areas in the world, except for Indonesia. For Indonesia, pulp and paper industry is made responsible for becoming one of the areas of conflict in Asia in terms of deforestation.

Paper industry and deforestation relate. The proceeding global industrialization is causing deforestation in order to: use wood as material, e.g., for furniture, create space for plantations, e.g., to cultivate cocoa, palm oil, soy, sugar, rice, rubber, to create space for farming, e.g., for cattle and to get to raw materials lying under the forest, e.g., coal, bituminous sands.

Though paper industry is only part of the whole procedure, demand for wood will continue to rise so that deforestation will continue to be a problem. Fueled by a growing population and expanding economy, demand in Africa could triple by 2050 from the current annual level of 96.2 million cubic meter. Moreover, forests decline due to frequent bushfires which increasingly occur.

Industrialization, deforestation and paper industry are involved in a much more complex network than obvious. The complexity becomes clear when looking to Australia, one of the ten countries with the most forest areas in the world: Industrialization fuels climate change which leads to global warming which leads to bushfires which leads to deforestation which leads to conflicts for paper industry resulting in higher recycling rates for paper as it is a crucial way to protect lasting forest areas. So, it needs to be highlighted that **the chain of cause and effect is long.** And it's not limited to Australia. As mentioned, Portugal is victim of frequent bushfires just as Australia.

Unlike the rest of Global South, Australia is known for its high paper recycling rates reaching 97% putting the production of recovered paper in relation to the production of virgin paper (calculation based on Food and Agriculture Organization of the United Nations, 2019, pp. 292, 300). It therefore makes sense to take a look at the country.

The story behind Australia:

Due to its large forest areas, the pulp and paper industry is one of the key industries for Australia. The climate in Australia is generally hot, dry and prone to drought. Most of Australia is covered by deserts and predominantly arid areas. 40% of the land mass is sand dunes. Little fertile soil exists. Only 6% of the land is arable. Most of the land is used as year-round pasture. 19% are forests and scrubland (of which ¾ is eucalyptus).

About 42 million hectares are used for forestry. Annual clearing of natural vegetation is about 600,000 hectares. Of the original areas, about 43% of all forests have been cleared.

Sources: ACT Government, 2018; Australian Government - Department of Agriculture, 2020; Australian Government - Department of Agriculture, n.d.; Bundesverband Sekundärrohstoffe und Entsorgung e.V., 2019; Commonwealth of Australia, 2018; CSIRO, 2019; Dr. Wolfram Dietz, Dr. Gert Meinl, René Peche, Dr. Siegfried Kreibe, 2020, pp. 31-32; ENF Recycling Ltd., n.d.-c; Grieg-Gran et al., 2015, pp. 19, 22; Honnold, 2009; National Waste Policy Action Plan 2019; Seadon, 2019; Thinking Circular, 2020; Wikipedia, 2007, 2020, 2021a, 2021b; Zhou, 2018.

Of the rainforests, 75% have been cleared. 80 million hectares are protected areas (data: 2004). Flora Reserves and Forest Reserves are representative forest areas. An important goal is to limit large-scale clearing, yet the forest balance is negative: clearing outweighs reforestation. About half of the rainforests are protected; also, 64% of the mangroves and swamp forests are protected, but only 5% of the few remaining southeastern dry forests and woodlands are protected. The State of the Environment Council in 1996 considered that reserves would only be established in economically unimportant areas. This shows that cause and effect of land decline have not been understood.

Bushfires are frequently taking place. As environmental factor, they are intrinsic part of the green movement on the Australian continent. The increased occurrence of human-caused bushfires has allowed fire-resistant plant species to spread, especially eucalypts. With their rapid formation of shoots after fires, woody stem bulges, and fire-resistant seeds, many plants adapted evolutionarily. As of March 3, 2020, an area of 126,000 km² had fallen victim to the ongoing 2019/2020 bushfires in Australia. These bushfires are described as "outstanding and worse than ever before" in various publications. A state of emergency was declared in Sydney as well as in the surrounding state of New South Wales as well as in Victoria. Scientists attribute the unusually severe fires, which occurred early in the fire season, to global warming. The fires were accompanied by prolonged drought and temperatures as high as 46 °C (excluding heat from the fire). In 2011, the Australian Labor Party (ALP) in power at the time, under Julia Gillard, formed the government-funded Climate Commission to study climate change in Australia with reliable and authoritative data. In 2013, the liberal-conservative Liberal Party of Australia became the strongest party. The new government under Prime Minister Tony Abbott cancelled funding for this commission, which then reformed as a non-profit organization under the new name Climate Council. In its 2013 report, the council found a clear link between climate change and increased bushfires.

Already in the 1970s, growing community involvement in recycling started, associated with concerns about the environment and resource conservation. Although recycling in Australia was already extensive by then, there were strong feelings in the community that individuals, industry and governments should do better.

The environmental movement reached a peak in Australia already in the 1980s. Nuclear testing and whaling in the Pacific had a major impact on Australia's social consciousness. There has been pressure on governments to force the pace of recycling, and governments at all levels have been keen to respond in a positive way.

Facts

- strong environmental pressure in Australia
- politicians needed to act delivering a coherent strategy
- high investments in recycling infrastructure
- oligopoly structure

Sources: ACT Government, 2018; Australian Government - Department of Agriculture, 2020; Australian Government - Department of Agriculture, n.d.; Bundesverband Sekundärrohstoffe und Entsorgung e.V., 2019; Commonwealth of Australia, 2018; CSIRO, 2019; ENF Recycling Ltd., n.d.-c; Honnold, 2009; National Waste Policy Action Plan 2019; Seadon, 2019; Thinking Circular, 2020; Wikipedia, 2007, 2020, 2021a, 2021b; Zhou, 2018.

The Australian Labor Party began to campaign with a national conservation and land protection strategy. In July 1989, Bob Hawke delivered a famous "Our Country, Our Future" speech in which he announced that the Australian Labor Party would plant a billion trees to combat soil erosion and declared the 1990s to be the "Decade of Land Conservation". Conclusions in terms of government administration were that Australian Government needs to better inform community about forest conservation and paper recycling, there is a need for greater accountability and clear criteria for the use of the funds contributed by industry to support recycling schemes and that the Government needs to intervene stronger in environmental matters. Moreover, the Government wanted to make the markets work better as well direct incentives to support recycling schemes including recycling targets and assistance for recycling plants. It developed into a clear strategy to foster recycling. However, with the change to the Keating government, the economy became the dominant issue and the government's environmental policy was not a major political issue for over a decade.

The commingled yellow bin (including paper) began in the late 90s as a way to cut down on costs, create an economy of scale in recycling and make recycling easier for households. It varies from council to council but, in many Australian neighborhoods, commingled recycling means all the paper, cardboard, glass and hard plastic goes into the same yellow bin together. There are exceptions of course: many provide a blue bin for paper and a green bin for organic waste.

In 2019, the Commonwealth Scientific and Industrial Research Organization (the national science agency) was tasked by the Australian Government to lead the development of a Circular Economy Roadmap. CSIRO is exploring research pathways in support of a circular economy, with an objective of reducing total waste generated in Australia by 10 per cent per person by 2030 and aiming to achieving an 80% average resource recovery rate from all waste stream applying the waste hierarchy by 2030.

Today, Australia's incumbent right-wing conservative government under Scott Morrison refuses to discuss Australia's role in global warming in large parts. This stance pits the government against other groups that believe global warming has significantly increased the risks of bushfires, which is considered uncontroversial in the scientific community. The government relies primarily on the country's large coal reserves for power generation and hopes to generate economic prosperity from coal exports. Australia ranked second in global coal exports in 2017. Prime Minister Morrison of the Liberal Party of Australia is considered a climate skeptic. However, under growing public pressure, he acknowledged that **climate change contributed to the bushfires.**

Sources: ACT Government, 2018; Australian Government - Department of Agriculture, 2020; Australian Government - Department of Agriculture, n.d.; Bundesverband Sekundärrohstoffe und Entsorgung e.V., 2019; Commonwealth of Australia, 2018; CSIRO, 2019; ENF Recycling Ltd., n.d.-c; Honnold, 2009; National Waste Policy Action Plan 2019; Seadon, 2019; Thinking Circular, 2020; Wikipedia, 2007, 2020, 2021a, 2021b; Zhou, 2018.

At the U.N. Climate Change Conference in Madrid in December 2019, Australia joined the U.S. and Brazil in blocking numerous efforts to combat climate change, so the participating nations reached only a minimal consensus.

By mid-2024 the Council of Australian Governments (COAG) mixed paper waste export ban comes into effect. Ahead of the ban coming into effect, Australia will need to build its own recycling capability so that these materials can be recycled within Australia. The Australian Government will subsidize critical recycling infrastructure with state and territory governments and industry. The Government is prepared to co-fund the development of increased paper processing capability. To achieve this, the Australian Government is inviting states and territories to partner with industry (and other states) to submit project proposals for new paper processing facilities that contribute to a national solution. Funding submissions were due by July 31st, 2020.

For paper market, eucalyptus is the main source of raw materials. In 2016, Australia produced about 1.4 million tons of paper; mainly for itself. A small portion is exported. The number of players varies from source to source with figures of 10-700 paper producers. In terms of recycling technology, directories mention 69 recycling companies, six assembly line manufacturers and eight technology manufacturers. Technology for paper recycling is available, though there are not enough recycling plants since China's waste import ban. Technology has no high visibility. Most are hand-sorted and nowhere near sufficient to sort Australia's annual recycling, which is why the country needs to further invest in recycling infrastructure, especially to be prepared when the mixed paper waste export comes into effect.

Sources agree that the Australian paper market is highly concentrated in the Virginia and New South Wales regions, where 75% of the players are located and more than half of the jobs are located. There are many small manufacturers and a few large ones that also offer recycling. So, the market is dominated by a few large manufacturers with a lot of market power.

The waste management and recycling industry is comprised of private firms and government enterprises. Local government, for example, typically manages waste collection and transfer, and may provide landfill facilities. However, in many locations, local government has outsourced these activities to the private sector. Recycling is dominated by the private sector.

The Australian waste management industry in general consists of about 750 companies, but after a period of consolidation, it got dominated by a few large companies. The five leading waste management companies Suez, Cleanaway, Veolia, JJ Richards and Remondis are expected to have a market share of of around 55-60%.

Sources: ACT Government, 2018; Australian Government - Department of Agriculture, 2020; Australian Government - Department of Agriculture, n.d.; Bundesverband Sekundärrohstoffe und Entsorgung e.V., 2019; Commonwealth of Australia, 2018; CSIRO, 2019; ENF Recycling Ltd., n.d.-c; Honnold, 2009; National Waste Policy Action Plan 2019; Seadon, 2019; Thinking Circular, 2020; Wikipedia, 2007, 2020, 2021a, 2021b; Zhou, 2018.

Facts

- closed loop recycling is still missing in Australia
- a lot of paper ends up in landfills
- waste strategy not coherent

In paper and cardboard recycling, Visy, Orora and Norske Skog dominate.

Though high paper recycling rates are impressive, Australia is no best practice example for circular economy because dumping rates are surprisingly just as high. The high recycling rates confuse because they suggest circularity, but instead, circularity is quite lagging behind. Around 50% of the paper is imported and around 25% end up disposed. This again shows the need for improvement in terms of circularity in Global South.

Sources: ACT Government, 2018; Australian Government - Department of Agriculture, 2020; Australian Government - Department of Agriculture, n.d.; Bundesverband Sekundärrohstoffe und Entsorgung e.V., 2019; Commonwealth of Australia, 2018; CSIRO, 2019; ENF Recycling Ltd., n.d.-c; Honnold, 2009; Seadon, 2019; Industry Edge, 2019, p. 4; Thinking Circular, 2020; Wikipedia, 2007, 2020, 2021a, 2021b; Zhou, 2018.

Summary

Paper is a biogenic material with a long tradition. It was and is used as sanitary product, to store knowledge, as payment instrument, as wallpaper i.e. People have understood the value of the material and its collection. The invention of book printing by Johannes Gutenberg in 1450 accelerated its development.

Today, digitization and e-commerce are driving market developments. E-commerce is driving paper markets to grow. North America, Europe and Oceania are having the highest paper consumption per capita.

Recycling technology is available but due to contaminations, the material can't be recycled fully. Global recycling rate is 53%. Deinking must be solved in order to avoid leakages and being digestible for the environment. Paper can be recycled only a definite number of loops before fiber gets too short.

Regulatory framework differs from country to country. In countries of Global North recycling rates are very high. African countries did surprisingly well. Australia is global leader in terms of paper recycling, with recycling rates coming close to 100% resulting out of a strong environmental pressure. Politicians needed to act against climate change and delivered a coherent strategy. Anyhow, Australia is missing closed loop recycling. A lot of paper ends up in landfills. The import ban imposed by China has disrupted the recovered paper market. It represents an immediate challenge for recycling companies recovering paper.

The continuous evolution of paper technology and production processes has become increasingly responsive to environmental concerns. New technologies are in place to make paper lighter, reduce energy consumption and to generate biofuels. European paper market is leading.

Global South is missing recycling statistics because focus lies on raw material exploitation to be fuel to industrialization. Overexploitation and climate change lead to deforestation. The region is still missing protection and circular economy strategies. **Forests are a vital source of livelihood for around 1.6 billion people living in extreme poverty worldwide.** For many of the world community's most important problems, such as climate protection, conservation and sustainable use of biological diversity, or poverty reduction, the world's forests are crucial keys to the solution. To achieve this, however, it is necessary to stop the overexploitation and destruction of the forests in many parts of the world.

The destruction of the natural resource forests is in wide contrast to the claim of freedom of mind. As humans claim freedom, they curtail the freedom of other species. And though paper industries have high recycling figures they are not circular in the sense of the C2C principle. These two aspects make up for rebound effects within the existing paper cycles.

4.1. Glass – Global Overview

The production of window glass or eyeglasses promised and promises transparency, the invention of bottles and glasses for food and beverage promised food security, a healthy life and was as much a symbol for wealth as for freedom of illness. Today modern electronic articles can't be imagined without high tech glasses for tv-screens, mobile phones or even an electric stove. Glass industries have evolved as cultures changed with the technologies used, always promising more efficiency and freedom.

In 2018, there were 130 million tons of glass produced globally of which 27 million tons got recycled. That makes a recycling rate of 21%.

Compared to the rest of the world, recycling rates for glass in Europe are very high with about 70%, especially for container glass with 74%. For Europeans, glass recycling is very present due to the good infrastructure of glass containers for collection.

For North Americans, glass recycling is such an industrially usual process as for Europeans. Recycled glass is cheaper than virgin glass production. Anyhow, the total recycling rate of glass in the US is estimated to be around 35%, also for recycled container glass. Originally, the goal was to achieve a recycling rate of 50 % in 2013. According to the US Glass Packaging Institute (GPI), the number of recycling plants in the US has grown.

Sand scarcity on the agenda:

For other countries, only very little reliable data is available. So far, glass recycling quotes in the Global South have been low. Sand scarcity has not affected virgin glass production which is the reason why it is cheaper than recycled glass. But sand scarcity is now on the agenda. A trend reversal can be observed in many countries: E.g., South Africa now recycles over 41% of its glass and has installed more than 4000 „bottle banks" for glass collection.

In the case of China, it is assumed that the recycling rate is currently still below 20%, even for container glass. Various sources report that recovered glass still has a relatively low financial value in China and the numerous glassworks prefer virgin materials. This may also have something to do with the fact that most recycling lines have been built in the 1950th, which can't process recycled glass as it doesn't meet quality requirements as for virgin material.

Best available projections show that research is conducted to compare the environmental impact of bottles made of PET, R-PET, non-returnable glass and returnable glass in order to understand which is the most environmentally friendly packaging solution. Research reveals that the substitution of plastic with glass does not help to reduce life cycle impact, e.g., global warming potential whereas great improvements can be obtained using bottles made with recycled materials, as R-PET. But glass bottles could contribute to reduce marine litter. It is necessary to disadvantage waste dispersion, giving incentives to returnable packaging and raising people's awareness of eco impacts.

Facts

- technically circular material
- endless recycling potential with almost no quality loss
- ca. 1,350 glassworks with ca. 2,500 glass furnaces worldwide
- fraction of household waste only in a few countries of Global North
- recycling rates differ widely
- 90% recycling rates only for container glass in some regions
- sober recycling rates for other products
- global glass recycling almost not documented
- sand scarcity as major problem

Sources: Butler & Hooper, 2019, pp. 308, 313; Dr. Ing. Harder, 2018; Stefanini et al., 2020, p. 1; Thinking Circular, 2020.

4.2. Glass – Global North

Cross-country initiatives on European level have just been started. Documentation of historic development of production and recycling in quantities shows large data gaps. Whereas production is documented quite well since 2005 on European level, recycling data for glass is missing for many years. Most recycling statistics include container glass only. An overall recycling rate is hard to estimate. In 2019, almost 12 million tons of container glass got recycled in Europe. 35 million tons of glass were produced all in all.

Data for the USA is more sufficient than for Europe. Latest recycling rates mention 35%. On a single-country basis, documentation is often better than for a whole continent. Since 1990, recycling development remained very stable. Production remained just as stable, but decreased a little. (Dr. Ing. Harder, 2018)

Looking to China, documentation gets worse. Statistics include container glass only. Latest figures mention recycling rates below 20%.

A view into glass history enables us to understand the present situation and draw conclusion for the circular economy.

The story behind glass:

It's not clear when people started making glass for the first time. Discoveries in the orient reach back to 5,000 B.C.

In 2,000 B.C., glass production developed independently and simultaneously in Greece, Egypt, China and Europe. For a long time, glass could only be made in combination with ceramics in an invert process. It took until 1,500 B.C. so that glass could be made separately. The first glass containers and bottles were made. They were especially useful due to their good material characteristics: reusable, refillable, heat-resistant, inert and impermeable (making it safe to store food and drinks). It was the most stable of all packaging materials with no risk of harmful chemicals getting into the food or drinks. Moreover, glass is transparent which also had a marketing benefit compared to barrels.

Anyhow, glass production did not reach scalable levels. The process of making it was complicated. Only a few people were able to do so. Glass making became an art. It was not yet possible to blow glass so that it was only possible to make bulky glass products.

In 650 B.C., the Assyrian king Ashurbanipal made a famous record of his glass recipe on a clay tablet: "Take 60 parts sand, 180 parts ash from sea plants, 5 parts lime - and you get glass." Later on, the recipe became popular as "sand, lime, soda and pearl ash". The essential process has remained the same to this day with one major difference: Much more ingredients are used to make glass.

Facts

- part of basic industrial development in Global North
- missing documentation for quantified production and recycling in many regions worldwide
- cultural aspects to understand industrial development
- formed naturally by melting quartz by great heat, e.g., by volcanoes
- doesn't crystallize after having been melted and cooled down
- was already used as cutting tool during Stone Age

Sources: FEVE - The European Container Glass Federation, n.d.-a; FEVE - The European Container Glass Federation, n.d.-c; Heidenreich, 2018; O.Berk, 2016; Thinking Circular, 2020.

About 60% of the approximately 90 elements found on earth are used in the manufacture of glass.

The invention of the blowpipe in Syria around 200 B.C. was a revolution. The innovation enabled to manufacture new shapes and products.

During the Roman Empire, the kilns were improved so that glass quality became better. To make an impression was an important topic to people during that time, so the development of pompous gold-plated and delicate glass ornaments and jars were highly in trend, but reserved for the church and the nobles. With the fall of the Roman Empire around 400 A.D., much of the knowledge was lost.

In the 10th century, Venetian glassware became famous. The recipe was in great demand everywhere, but kept secret. The glassworks moved to Murano, an island off the coast of Venice. The island seemed to be spy-proof and they solved the problem of fire hazard for Venice. However, the secret of Venetian glass art could not be kept a secret for long. Many glassmakers tried their luck beyond the Alps, founded glassworks and continued to work in the Venetian style. The heyday of Venetian glass came to an end.

Anyhow, the first eyeglasses were made in Venice in the 13th century. Manufacturing lenses from the mineral "beryl" was common. The German word "Brille" for glasses arose from this. Whether the lenses really improved visibility is doubtful. The glasses had streaks, inclusions and bubbles. It was not until 1884 that the chemist Otto Schott was able to produce optically perfect glasses, because he questioned old glassmaking recipes. He experimented with new raw materials and was successful.

The story behind European glass industry:

As the industrial revolution took place, glassmaking reached mass production in Europe.

During the 20th century, glass usage developed into quite new applications in Europe. Before, glass was mainly used for mono-material products, like windows, containers, eyeglasses. Then it became component of high-technology, e.g., fiberglass consisting of numerous extremely fine fibers of glass. It has become one of the most important usages of glass today. Products including fiberglass are, i.e., thermal insulation, electrical insulation, sound insulation, high-strength fabrics, automobile bodies, cast for medical purposes and much more.

Another recent innovation in European glass industry was to use glass as compound: Glass-reinforced plastic (GRP) is a fiber reinforced polymer made of a plastic matrix reinforced by fine fibers made of glass.

Sources: FEVE - The European Container Glass Federation, n.d.-a; FEVE - The European Container Glass Federation, n.d.-c; Heidenreich, 2018; Macfarlane & Martin, 2004, pp. 1407-1408; O.Berk, 2016; Thinking Circular, 2020.

As just many other applications, GRP was developed out of a scarcity situation in the UK during the Second World War. It served as a replacement for the molded plywood used in aircraft radomes as it was transparent to microwaves. The first civilian application of GRP was for the building of boats. During the 1950s, it already was widely used for this purpose. Shortly after, it was also used for the automotive and sport equipment sectors as well as for model aircraft. Today, it is also used for hot tubes, pipes for drinking water and sewers as well as for office plant display containers and flat roof systems. As carbon fiber is even lighter, it has become competing material to GRP.

In 1962, the first European Glass Association was founded in Paris, the "Glass Alliance Europe". In 1977, the second European Glass Association was founded in Brussels, known as "FEVE", focusing on glass as packaging material. Both are still important networks of the EU glass industry.

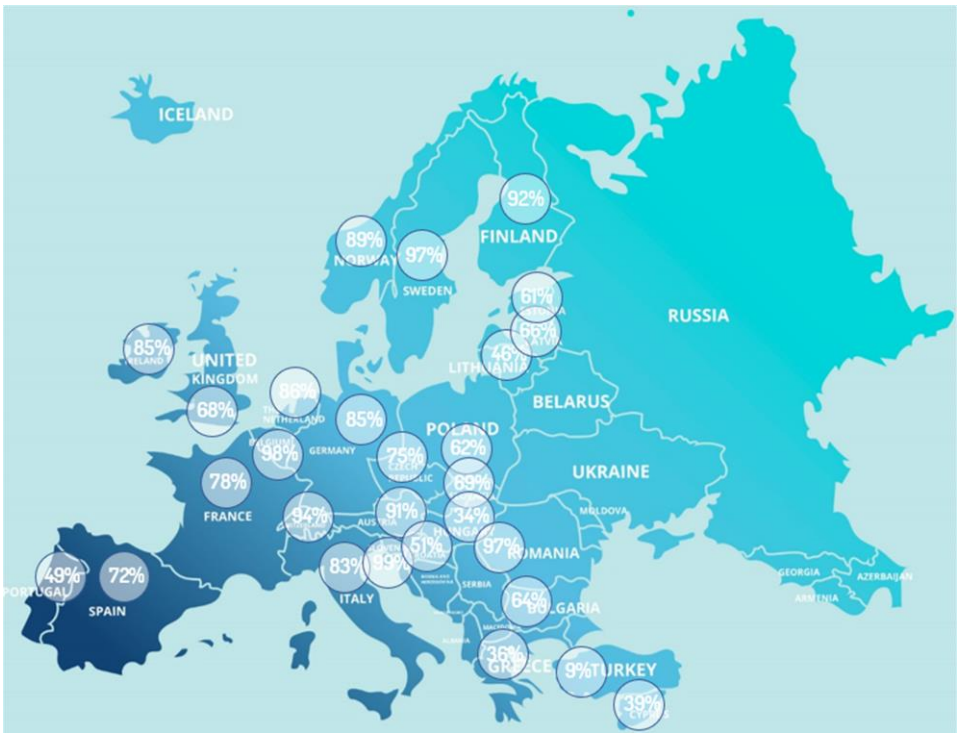
In 2008, the glass industry was hit by the global economic crisis. Between 2016 and 2019, the European glass industry was increasing its production, due to economic growth. However, production levels can be deeply impacted by third countries imports into the EU, Brexit, US policies, Chinese competition, and, of course, the COVID-19 outbreak crisis adding to the EU stringent climate policies (ETS, Decarbonization, Green Deal, REACH, Food Contact, etc.). They will all together impact EU glass sectors. Due to strong competition, especially from China, the global trend indicates steadily increasing imports in all glass sectors.

Today, over 150 production sites are spread across Europe. To prepare for the future, the container glass industry has made significant investments (610€ million per year) in the past decade in upgrading glass plants to be more environmentally friendly. The industry is searching for ways of re-using the CO2 and heat produced to support regional projects. For example, the surplus heat from the factory is piped to a tank to store heat. Glass bottles of today are already 30% lighter than they were two decades ago, without sacrificing product preservation, recyclability or design. The industry reached a cut-off of their CO2 emissions by 70%.

Germany remains the EU's biggest producer of glass with about one fifth of the volume, closely followed by France, Spain, Italy and the UK. Together with China and North America, Europe is one of the largest glass producers in the world with a market share of around one third of global glass production.

Not only for production, but also for recycling, Europe is right in front of other countries. European countries deliver the best statistical data on glass recycling. An own Federation of Glass Recyclers named "FERVER" (an association of private and independent glass recycling companies) was found. The Federation claims that its members process 70% of Europe's recycling volumes.

Sources: Dr. Ing. Harder, 2018; European Commission, n.d.; FEVE - The European Container Glass Alliance Federation, n.d.-a; FEVE - The European Container Glass Federation Europe, n.d.-b; Glass Alliance Europe, n.d.-a; Glass Alliance Europe, n.d.-b; Thinking Circular, 2020; Yeon, 2010.



Overview of recycling rates for container glass in European countries. Own illustration based on BVSE. Map of Europe by City vector via Freepik. (Source: bvse-Fachverband Glasrecycling, 2019)

For container glass, the recycling rates in the EU-28 are the highest and stable at 74%. There is still a large north-south and west-east divide with countries such as Sweden, Belgium and Slovenia, perform best with over 95% recycling rates and countries such as Turkey, Greece, Cyprus and Malta performing worst. Reasons can be found in the collection gap in these countries, lack of government incentives and the general economic framework.

For glass recycling market, Europe is projected to be the fastest-growing region in 2019 to 2026. It is expected that supportive government regulations will create demand as European government has applied strict restrictions on pollution, which are pushing manufacturers to choose recycled glass instead of virgin glass, a driving factor for recycled glass value.

The story behind United States' glass industry:

In the USA, glass has a very long tradition as well, but only reaching back until the early 17th century. Glassmaking was America's first industry. In 1608, the first glass shop was established in Virginia. Unfortunately, heavy weather events and unfavorable economic conditions forced the shop to close. It took 100 years that America gave glass a second chance when colonists brought glass products.

Facts

- Europe is leader in global glass recycling, especially for container glass
- Sweden, Slovenia and Belgium are outperforming countries with recycling rates higher than 95%
- they have efficient separate collection systems for container glass
- countries like Turkey, Greece, Cyprus and Malta are performing low pulling the overall recycling rate down
- they miss collection systems

Sources: bvse-Fachverband Glasrecycling, 2019; Dr. Ing. Harder, 2018; Global Recycling Magazine, 2020; The Corning Museum of Glass - One Museum Way, n.d.-a; The Corning Museum of Glass - One Museum Way, n.d.-b; The Corning Museum of Glass - One Museum Way, n.d.-d; The Corning Museum of Glass - One Museum Way, n.d.-e; The Corning Museum of Glass - One Museum Way, n.d.-f; Thinking Circular, 2020.

In 1739, the first glass company, the "Wistar Factory", was founded in New Jersey producing windows and bottles. The factory was a huge success. It soon developed into the first mass production factory, producing 15,000 bottles each year. The production formula was coming from Northern Europe, where it was already used since the Middle Ages. The Wistars made it possible to convert glass in such a way that products were so similar to those coming from Europe that differences could not be identified and threatened imports. In the following decades, glass industry started to rise.

One year after the American Revolution ended in 1776, John Amelung opened a large glass factory in Maryland. He was one of the major investors of the glass industry though he remained in business for only 11 years. During these 11 years, he invested more money in glassmaking than anyone in America before him.

Another major player and investor of early American glass industry was Albert Gallatin, who was actually from Switzerland. He financed the move of the glass industry from East Coast to new regions. Thanks to him, in 1797, the first glasshouse west of the Alleghenies was built in Pennsylvania. Gallatin owned large properties in the western part of the state and was a member of the U.S. House of Representatives. Later, he served as Secretary of the Treasury under President Thomas Jefferson and as minister to France and to Great Britain.

With Gallatin marking a beginning, settlers moved west to the Alleghenies and created new markets for glassware. Glass was difficult to ship overland, so Pittsburgh was an ideal location for manufacturing as it had river transportation to the entire western frontier and nearby coal deposits as a ready source for fuel. Benjamin Bakewell operated the largest glass factory in Pittsburgh for many years. It was famous for its fine tableware. Even President Monroe ordered cut glass from Bakewell's for the White House in 1817. Although his factory was known to have made engraved glass, relatively few of such pieces can be attributed to it. One of them is this bowl:

Footed bowl with engraved decoration of Bakewell. (The Corning Museum of Glass - One Museum Way, n.d.-c)

Sources: The Corning Museum of Glass - One Museum Way, n.d.-a; The Corning Museum of Glass - One Museum Way, n.d.-b; The Corning Museum of Glass - One Museum Way, n.d.-c; The Corning Museum of Glass - One Museum Way, n.d.-d; The Corning Museum of Glass - One Museum Way, n.d.-e; The Corning Museum of Glass - One Museum Way, n.d.-f; Thinking Circular, 2020.

Since then, a rapid development of the industry could be observed. New inventions made glass products affordable to middle class, e.g., the innovation of pressing to produce glass tableware in the 1820s.

Today, the USA enlists over 2,000 glass manufacturing companies. Recycling rates are low compared to many European countries, reaching only 35%. Anyhow, glass ranks top three in the most recycled household materials in the USA. Though technical know-how is available and consumers prefer recycled glass, the shortfall of glass recycling has to do with comingled collection. Comingled collection is inefficient for US glassmakers as it makes the whole sorting process more complicated and cost-intensive.

The story behind China's glass industry:

China is one of the biggest producers of glass. When looking for information on glass recycling in China, there is not much found. Glass is not really recycled in China because recycling entities are not technically equipped for it.

History of ancient Chinese glass manufacturing is controversially discussed. Some say that glass was brought to China from the West via trade along the silk road only as early as the 3rd century. Others discuss findings of small glass objects in China dating from as early as 206 B.C. Newest publications including recent findings claim that glass was made already in 770 B.C. or even before. Whatever comes close to reality, it was no doubt that glass was a useful and cheap substitute for jade and therefore interesting for Chinese tradespeople. Nevertheless, typical Chinese glass objects are not known to be before the 17th century, so about the same time that glass reached the USA. It is likely that glassmaking through glassblowing technologies was in fact introduced in this period when, through the Jesuits, China became vividly aware of Western culture.

During the reign of emperor Kangxi, Chinese glassmaking underwent a profound change, starting with the establishment of an imperial glass workshop at the palace in Beijing in 1689. Under the direction of a Jesuit missionary, Kilian Stumpf, he was able to deliver know-how on how to set up the workshop. By 1696, the workshop delivered lenses for telescopes for imperial observatory. In the early 1700s, the workshop also produced bottles and other products.

In the late 17th century, glassworks also settled in other parts of the country. But in comparison with the works of the imperial glassmakers, glass products from other workshops were not held in high reputation as quality was not as good. "Beijing glass" was an expression that made its way. As a result, the regions tried to find their own USP by specializing in a field of product they became well known for. Today, information about how glass industry is currently organized including how many players, could not be found.

Facts

- besides Europe, glass recycling in the rest of the world is lagging behind

Sources: Charleston, 2018; Curtis, 2008, p. 6; Fuxi, 2021; Glass Packaging Institute, 2020; Industry Select, 2020; Jacoby, 2019; The Corning Museum of Glass - One Museum Way, n.d.-a; The Corning Museum of Glass - One Museum Way, n.d.-b; The Corning Museum of Glass - One Museum Way, n.d.-d; The Corning Museum of Glass - One Museum Way, n.d.-e; The Corning Museum of Glass - One Museum Way, n.d.-f; Thinking Circular, 2020; Whitehouse, 2012, p. 60.

Only one glass association is known. For recycling, directories mention only 2 material recovery facilities in whole China and 7 recycling plants. Flat glass is the mostly produced product in quantity in China. (For comparison: 1,122 material recovery facilities for glass in Europe and 67 recycling plants are mentioned by directories.)

What is analyzed quite well is China's glass industry's market after the global economic crisis in 2008. Due to the economic crisis, the 2009 report "Through China's Looking Glass" was published by the Economic Policy Institute. The report describes China's glass industry's situation before and after the crisis as follows:

From 1987 to 2007, China's glass output increased, on average, by 18% per year. Since 2000, production capacity increased more than threefold and since 2003, production capacity and overall glass production more than doubled. Main reason for this development were government subsidies of over $30 billion which supported the industry between 2004 and 2008. The subsidies spanned heavy oil, coal, electricity, and soda ash and have been growing steadily in this period. It has to be mentioned that in an official statement, the Chinese government revised this information as not being true. Glass industry had sheerly developed from higher demand in architecture and automotive industry.

Facts

- China is catching up on cultural and industrial development for glass

The same development could be observed for exports to the USA, tripling between 2000 and 2008. Though the industry was then affected by the global crisis, in 2008, China contributed over 31% of global glass production. In 2009, China was globally the largest producer of glass and glass products, having the greatest number of glass producing enterprises in 29 of 32 provinces and the largest number of flat glass production entities. Moreover, it had become the largest exporter of flat glass and glass fiber in the world despite competitive pressures.

China's glass market mainly developed into an export market due to declines in the real-estate and automobile sectors, combined with enormous excess capacity. Anyhow, concerning consumption, China is not staying behind. Contrariwise, China is the largest consumer of glass in the world.

From 2017 to 2019, China's glass industry's sustained trend of increasing continued. In 2019, official statements at the annual glass exhibition in Beijing described China's present glass industry facing new growth and economic vitality. Several policies are expected to stimulate its growth, e.g., the "13th Five-Year Plan", the "Made in China 2025 strategy", the "Belt and Road Initiative", the "Coordinated Development for the Beijing-Tianjin- Hebei Region", as well as the "Development strategy of Yangtze River economic belt including enhance technological innovation in manufacturing". Consumption is mentioned as another factor upgrading Chinese domestic market.

Sources: Beijing Zhonggui Exhibition Co., 2019; "China's Statement in Response to Questions about China's Glass Industry," 2010; ENF Recycling Ltd., n.d.-a, n.d.-b; Haley, 2009; Thinking Circular, 2020.

Of course, the outbreak of Covid-19 has had a significant impact on industry and technical glass manufacturing in China. In the first quarter of 2020, domestic factories had to stop production and sales were greatly negatively affected. With Government control of the epidemic during the year, the industrial and technical glass manufacturing gradually returned to normal levels. However, foreign businesses are still greatly affected by the epidemic which is also affecting China's export business. Nevertheless, it is projected that China will recover soon from COVID-19. Besides China, other Asian economies such as South Korea, Taiwan, Singapore, India, Vietnam, Myanmar, Indonesia, and Malaysia are also predicted to recover quickly compared to European and North America economies. As a result, the growth of glass manufacturing market in Asia Pacific is expected.

The circular economy will not make the world a better place if we still don't close loops fully and don't think of systemic consequences like those we can see in Global South.

Sources: Beijing Zhonggui Exhibition Co., 2019; Grand View Research, 2020; Thinking Circular, 2020.

4.3. Glass – Global South

Just as for the other materials, the pattern of resource exploitation in Global South and consumption and recycling in Global North replicated. Therefore, it makes sense to again look at mining activities. For producing glass, sand is mined resource. Sand mining is more or less a geographical and topographical question. Sand deposits can be found either terrestrial or offshore. As offshore dredging needs more technology and specific environmental permits, it is most commonly placed in countries of Global North whereas terrestrial mining is a topic of Global South. The leading producers of sand until 2015 were China (being widely ahead of other countries with 2,400 million metric tons production) and India (with ca. 300 million metric tons production). More sand reserves can be found in other countries of the Global South.

In Global South, sand mines are mainly located in environmentally valuable areas like mountain and river valleys. The Yangtze River in China is mentioned as globally biggest sand mine. Though the mentioned countries are leading in terms of production, they are not leading in terms of sand exports or imports. Both, sand exportation and especially importation actually involve again mostly countries of Global North and economically emerging countries. For exportation, the USA, Germany, the Netherlands and China are leading countries. For importation, Singapore, Luxembourg, Canada, Japan and the Netherlands are leading countries.

It is noticeable that the Netherlands, but also Germany and China are among the top exporters as well as among the top importers of sand. This may cause confusion but is easy to explain as countries need different types of sand for different purposes. Whereas China and developing countries need sand for urbanization and economic growth, developed countries rather use sand for glass, electronics or other industries. The exports and imports of sand have changed since 1995 with countries of Global North having absorbed the sand of the past and still continuously absorbing more, and countries of Global South coming into play with rising demand after global economic crisis.

Of course, illegal mining activities are not part of the statistics. In underdeveloped and developing countries, governments often lack the capacity to establish and enforce environmental regulations. Therefore, they are usually confronted with illegal sand mining operation, leading to a series of environmental issues and threats. Reducing, reusing and recycling of glass would relieve environmental impacts of sand mining. Anyhow, recycling is not yet an answer in Global South, especially not on continental level. So, continental statistics are also almost not available. Even for individual countries, glass recycling statistics are hard to get. Neither for South America, nor for Oceania reliable and comparable data could be found. For Africa, South Africa makes a difference reaching around 40% glass recycling rate.

Facts

Some direct consequences of sand mining:

- Depletion of groundwater
- Lesser availability of water for different purposes, like industry, agriculture and drinking
- Destruction of agricultural land
- Loss of employment to farm workers
- Threat to livelihoods
- Violation to human rights
- Damage to roads and bridges

Sources: Dan Gavriletea, 2017, pp. 3-7, 11-12; M. Naveen Saviour, 2012, pp. 125-133; Thinking Circular, 2020.

Sand mining is a topic where research is still conducted and summarizing reports about global sand mines are just as rare as sand itself. Therefore, in difference to "Aluminum – Global South", this chapter won't give a global overview categorized into countries due to missing data. Instead, the story behind sand mining in general will be described, underlined with regional examples.

The specific glass recycling situation in South Africa will be described as well as it can be mentioned as best practice example for glass recycling in Global South.

The story behind sand mining in Global South:

Sand is one of the most important resources for the stabilization of current systems. In volume, sand and gravel are mentioned to be the second most consumed material on earth, after water. Today, life without sand would just not be possible in the way it is. Sand is not only raw material for glass, but also for many industrial applications, like in the construction sector for concrete and cement, or in water filtration. Modern civilization is dependent on sand. At the same time, global sand market is facing major challenges: illegal mining, environmental damage and scarcity as it already exceeds its natural renewability rate. At the same time, the saying "like sand on the beach" illustrates that sand scarcity is still difficult to imagine as sand is so present in daily life. One can easily think that sand is infinite as about 20% of the earth's surface is covered by deserts. Anyhow, not every type of sand is suitable for industrial demand, only specific ones which are even rarer.

Sand is just as important for human civilization as for the environment. Sand is indispensable for working ecosystems and keeps our planet in balance. It is part of the fragile symbiogenesis that people call life. Destroying these habitats for higher, faster, further not only means running out of an important resource, but digging planetary foundation. This is not only limited to sand mining, but mining in general disturbs ecosystems and leaves behind environmental impact.

In the past years, environmental issues linked to sand mining has received rising attention. Demand for sand is further increasing due to growing construction and industry activities, especially in developing countries. Water pollution is one evidence becoming quite obvious when water in rivers of mining areas changes color. Toxic heavy metals are just one parameter for water degradation in these areas. Land degradation is, of course, one of the major environmental damages caused by mining spawning other damages, e.g., topographical disorder and ecological imbalance. Unfortunately, sand reserves are often found below forests, which is why sand mining frequently involves deforestation. Another point is air quality which is affected through high concentrations of dust which are, furthermore, hazard to health, leading to asthma and other health issues.

Sources: Dan Gavriletea, 2017, pp. 1-3; M. Naveen Saviour, 2012, pp. 125-133; Peduzzi, 2014, p. 215; Thinking Circular, 2020.

For soil, opencast mining is having the greatest effect. Soil is not only deteriorated by contamination and erosion but also endangered as topsoil is scarce. Of course, indigenous biodiversity is also reduced.

Above that, also noise and vibration are an issue which are no superficial problems as mining normally endures 24 hours a day, widely fluctuates and noise levels are normally not controlled. It is a question of good life for all to also include these reasons in the overall discussion about sand mining.

The following table shows the environmental impacts of different types of mining:

Type	Method	Primary Resource Extracted	Environmental Impacts
Mountaintop Removal	Uses explosives to blast off entire tops of mountains in order to access veins of coal.	Coal	Deforestation, disruption to ecosystems, exposure of toxic metals and radioactive elements to weathering, filling in and destroying thousands of streams, leveling of mountains, loss of biodiversity, poisoning water for local communities, soil erosion.
Open-pit Mining	Involves digging in order to reach the desired resource.	Coal, copper, diamonds, gold, iron	Acid mine drainage (from the exposure of sulfur to oxygen and water to form sulfuric acid, H2S04), complete ecosystem destruction, toxic wastewater.
Placer Mining	Uses water to separate the heavier minerals from lighter silt and clay.	Gems, gold	Erosion of seam banks, loss of habitats, pollution of streams, toxic wastewater.
Subsurface Mining	Create shafts deep underground to extract resources from pockets or seams of minerals.	Coal, copper, gold, lead, nickel, salt, uranium, zinc, and other metals	Acid mine drainage, air pollution, health hazards to miners and local communities, toxic wastewater.
Surface Mining	Removes the soil and rock that cover mineral deposits.	Coal, gravel, oil sands, sand	Acid mine drainage, deforestation, loss of biodiversity, soil erosion.

Types of mining and their environmental impact. Own illustration based on (Healing Earth, n.d.)

Sources: Healing Earth, n.d.; M. Naveen Saviour, 2012, pp. 125-133; Thinking Circular, 2020.

In Tamil Nadu, India, a campaign for the protection of water resources and the impact of sand mining on the region has been started. For the campaign, they identified 15 direct consequences of sand mining, e.g., depletion of groundwater, water scarcity or the destruction of agricultural land.

13 of 28 districts of the state were victim to those consequences. India itself has adopted a strategy to tackle such environmental issues. Before starting mining projects, it is therefore mandatory to draft an environmental management plan to prevent environmental hazards.

Anyhow, weak governance and corruption are a threat to any strategy imposed. Laws and monitoring are lagging behind. Of course, the socio-economic relevance of mining to these regions also has to be taken into consideration.

Though sand mining is not limited to Global South, this case shows that special attention has to be paid to underdeveloped and developing countries because exploitation there involves different problems. Illegal sand mining is an important topic. A long list provides an overview of the countries which are confronted with this phenomenon, among them Bangladesh, India, Nepal, Puerto Rico, South Africa, Sri Lanka and others.

Another problem to these countries is that cost-intensive technologies are needed to mine sand cleanly to avoid negative environmental effects. Furthermore, resulting environmental damage is much more difficult to renature because it is cost-intensive as well and needs specialists like biologists, engineers or scientists which are rare in those countries. Last but not least, a cognitive element also comes into play: Environmental protection is not understood as information about consequences are lagging behind which may be one reason why environmental regulation is not enforced. Other reasons are corruption and that environmental regulation needs to be accompanied by monitoring tools which implementation is, again, too costly for underdeveloped countries.

For recycling industry, similar reasons can be applied. It needs a clear and coherent strategy in developing countries to foster recycling after understanding its benefits. South Africa may be mentioned as best practice example.

The story behind glass recycling in South Africa:

South Africa consumes more than 3 million tons of glass per year. Glass accounts for 4.5% of all waste in South Africa. 2 million tons are reusable and can be diverted from landfills. Though South Africa does not have punitive mandatory legislation in place which makes separation of recyclables at the source, the country is experiencing a trend shift in glass recycling since over 10 years. Over the past 12 years, glass recycling amounts have increased by 18%.

Sources: Consol Glass, n.d.; Dan Gavriletea, 2017, p. 17; Dr. Ing. Harder, 2018; FoodReview - South African Journal for Food and Beverage Manufacturers, 2018; Jacobs, 2020; M. Naveen Saviour, 2012, pp. 125-133; National Recycling Forum, n.d; the Glass Recycling Company, 2021; the Glass Recycling Company, n.d.-a; the Glass Recycling Company, n.d.-b; the Glass Recycling Company, n.d.-c; the Glass Recycling Company, n.d.-d; the Glass Recycling Company, n.d.-e; the Glass Recycling Company, n.d.-f; Thinking Circular, 2020; Vivier, 2018.

The development is spearheaded by glass manufacturers through extended producer responsibility (EPR). The Glass Recycling Company is the official South African organization dedicated to raising awareness on glass recycling. According to South African statement, today it has one of the most sophisticated returnable systems in the world, owing to the efforts of a number of brand owners and the retail sector. The efficiency of the system is evidenced by 2.5 million tons of filled glass packaging consumed annually in South Africa. Because of this, only 900,000 tons of new glass is produced per year. More than 4,000 bottle banks have been installed for glass collection, reaching recycling rates of over 40% now and enabling to achieve effective environmental benefits.

80% of South African glass waste has been diverted from landfill. Landfill is a scarcity topic in South Africa. There are more than 1 200 landfill sites in South Africa which receive approximately 90% of all solid waste. The government has a target of reducing the weight of industrial waste sent to landfill by 20% and domestic waste by 60% until 2025. The recycling efforts of citizens and businesses are helping to achieve these targets. Recycling of glass shall be fostered to relieve dumping sites to save scarce landfill space and keep South Africa clean and beautiful. Manufactured bottles and jars contain at least 40% recycled content. In South Africa, that is one of the highest percentages reached for packaging. For packaging overall, recycling rate in South Africa is 51%. Manufacturers of glass are supporting the development and have invested in recycling equipment and processes.

To support participation in recycling, South African glass recycling companies are trying to motivate inhabitants through gamification and refunds. For instance, competing events between schools are linked to win prices monthly and annually. The competition is to collect more glass bottles and jars than other schools in the same district. To do so, glass banks have been installed at schools so that parents, pupils and teachers can bring their glass containers to school. All schools which want to participate can apply for the installation of glass banks. Not only schools, but also individuals can request a glass bank for their community.

People are motivated through refunds. The majority of beer, wine and spirits producers in the country make use of returnable glass bottles. People can collect them and sell back glass to buy-back-centers. For unemployed people, this way is even promoted as an opportunity to earn a source of income. Approximately 50,000 South Africans earn an informal source of income from collecting waste glass and selling this valuable packaging to entrepreneurial buy-back centers. Furthermore, supermarkets, liquor outlets and retailers have installed deposit-return-systems where people can return glass bottles for a refund.

Sources: Consol Glass, n.d.; Dr. Ing. Harder, 2018; FoodReview - South African Journal for Food and Beverage Manufacturers, 2018; Jacobs, 2020; National Recycling Forum, n.d; the Glass Recycling Company, 2021; the Glass Recycling Company, n.d.-a; the Glass Recycling Company, n.d.-b; the Glass Recycling Company, n.d.-c; the Glass Recycling Company, n.d.-d; the Glass Recycling Company, n.d.-e; the Glass Recycling Company, n.d.-f; Thinking Circular, 2020; Vivier, 2018.

Beside school campaigns, education for kids on glass recycling is further supported by other gamification, e.g., fun games and puzzles created by glass recycling companies, like the following:

"Fun with recycling"-game of the Glass Recycling Company for kids. (the Glass Recycling Company, 2014)

As a consequence of all these measures, South Africans are becoming increasingly environmentally conscious and responsible. The demand for recycling points has increased. Over 3,000 glass entrepreneurs have been trained to support the upcoming trend.

Further glass banks have been installed at service stations, shopping centers or municipal refuse drop-off sites. Platforms have been initiated to locate nearby glass banks as well as other ways. Like the following picture of glass lifecycle shows, people can send an SMS with the word "GLASS" and their belonging number of suburb to glass recycling companies to get an answer directly to their phone (though sending the SMS is not for free but includes normal SMS fees). Unlike in Europe, in South Africa, it is not necessary to place different colored glass into separate banks. Waste glass is collected by local, independent registered waste collection agencies and sold back to the glass packaging industry.

Sources: Consol Glass, n.d.; Dr. Ing. Harder, 2018; FoodReview - South African Journal for Food and Beverage Manufacturers, 2018; Jacobs, 2020; National Recycling Forum, n.d; the Glass Recycling Company, 2014; the Glass Recycling Company, 2021; the Glass Recycling Company, n.d.-a; the Glass Recycling Company, n.d.-b; the Glass Recycling Company, n.d.-c; the Glass Recycling Company, n.d.-d; the Glass Recycling Company, n.d.-e; the Glass Recycling Company, n.d.-f; Vivier, 2018; Thinking Circular, 2020.

Summary

Glass is a material that has endless recycling potential. Recycling rates differ widely. The material is fraction of household waste only in a few countries. Global glass recycling is almost not documented. Global recycling rate is about 21%. Glass recycling statistics for Global South are missing, except for South Africa, which is best practice example for glass recycling in Global South with 41% due to educational campaigns.

Recycling rates for glass in Europe are very high with about 70%. Sweden, Slovenia and Belgium are outperforming countries with recycling rates higher than 95% due to efficient separate collection systems for container glass.

Venice in Europe has been accelerating place for global glass production in 10th century. Between 14th and 18th century, Europe was cradle to many important human civilization steps: From the Renaissance to the scientific and industrial revolutions. Glass played a major role as it was important for providing new scientific instruments, like microscopes or telescopes. This development enabled important discoveries of, e.g., Copernicus and Galileo. During industrial revolution, glass reached mass production in Europe and was spread into the world. Markets in the U.S. and other parts of the world developed.

The total recycling rate of glass in the US is estimated to be around 35%. That has to do with comingled collection. Comingled collection is inefficient as it makes the whole sorting process more complicated and cost-intensive.

In the case of China, it is assumed that the recycling rate is currently still below 20%, even for container glass. Various sources report that recovered glass still has a relatively low financial value in China and the numerous glassworks prefer virgin materials. This may also have something to do with the fact that most recycling lines have been built in the 1950th, which can't process recycled glass as it doesn't meet quality requirements as for virgin material.

Major problem to glass industry is sand scarcity. Sand mining is causing environmental problems in Global South. Some of the direct consequences of sand mining on Global Southern countries are: depletion of groundwater, lesser availability of water for different purposes, like industry, agriculture and drinking, destruction of agricultural land, loss of employment to farm workers, threat to livelihoods, violation to human rights, damage to roads and bridges.

The paradigms of transparency, health security and technology have driven glass production. But sensitive biotopes are endangered by sand exploitation and glass resources have reached planetary boundaries. Driving recycling infrastructure will deliver higher numbers but without ending linear structures we will not be able to prevent systemic consequences by the destruction of natural resources especially in the Global South.

5. Asphalt – Upcoming Hope

With the evolvement of industrial systems, the wish and necessity for mobility rose. Good infrastructure serves the needs to move around fast and safe and offer resonance to markets. It opens up new geographic areas for companies and people. The intention to drive infrastructure is always clear, the attention often lacks resources. The circular perspectives offer more than stories about public transportation systems, which by far are most effective. As asphalt is one of the Big Five material, we have identified a small but industrial country that drew a lot of attention to circularity and can be referred as best case to others.

Whereas documentation of asphalt production and recycling in Europe and the US reaches back until global economic crisis or shortly before, documentation in Japan is very consistent and reaching back centuries. Looking at the statistics, it becomes clear that Japan performed clearly through the years: Whereas production of asphalt went down, recycling went up just as long as the quantity recycled almost equaled the quantity produced. In 2013, suddenly the statistics broke up. Digging deeper into Japan's asphalt history, a coherent circular economy strategy appears. The development of asphalt management in Japan therefore differs a lot to applied strategies in other countries of Global North, not to mention Global South where research and development often does not focus on how to recycle streets but how to build streets at all. Nevertheless, the story of material banking of asphalt in Japan is upcoming hope and worth to have a deeper look.

In Europe, asphalt recycling developed quite differently and unfortunately not in a good direction though recycling volumes stayed near production volumes. Before 2008, recycling quantities slowly were rising but then crashed after global economic crisis. Since then, both, production and recycling of asphalt went down. In 2008, recycling rate was 91% whereas in 2017, it was 77%. Since 2016, it seems that asphalt markets are recovering though recycling has slowed down.

Documentation of asphalt history in the US started shortly after the global economic crisis. Production remained at almost the same level since then, always around 360 million tons produced. Recycling experienced a leap frog in 2013. Before 2014, recycling volumes slightly grew from 120 million to 140 million. Suddenly, numbers went up to 250 million, drastically boosting recycling rate from 34% in 2009 to 69% in 2013 but then surprisingly went down again from year to year until 170 million in 2016. After that break-down, recycling slowly recovered. Such short-term lifts in recycling are possible fostered by Federal Road Construction Programs. Anyhow, long-term lifts only develop slowly as federal systems are an inhibiting factor. Federal states have to decide on their own to join recycling programs.

The story behind asphalt management in Japan:

The overall story about Japan's success in asphalt recycling is quite short: System has evolved. Technical cycle is working. Asphalt recycling has reached circularity.

Facts

- asphalt has a long life up to 40 years
- repair and refurbishment every 15 years
- after end of life, asphalt streets can fully get recycled
- 1.4 billion tons produced globally in 2015
- no documentation on quantitative global asphalt recycling
- quantitative details on production and recycling could be found for Japan, the USA and Europe
- Japan is success story and upcoming hope for circular economy

Sources: Copeland, 2015; Giani et al., 2015; Hashimoto et al., 2007; Hashimoto et al., 2009; Kubo, n.d; Ministry of the Environment, 2014; Thinking Circular, 2020; Transportation Research Board, 2014; West & Copeland, 2015.

Nevertheless, the way to reach current state was long and stony. Japan has one of the largest road networks in the world (1.22 million km; 791.189 miles). It has only 4% of the land area of the USA, but 50% of the road kilometer length of the USA. The infrastructure has industrial character: 80 out of 126 million people use the roads. The country has a very high population density: 347.07 inhabitants are living per square kilometer. That makes Japan ranking the 13th place in the world's ranking for population density.

The story of asphalt recycling in Japan reaches back 50 years already. In 1970, the development of recycling technology for pavement waste was started. The invention of digitized close-the-loop technology to recycle streets just in place was quite rocket science back then and a goal far-to-reach. The early need for recycling technology to endure product durability was and is in the public interest due to cost savings. Asphalt has become indispensable for infrastructure but highly threatened with earthquakes. The recycling process technology was developed by a scientific network that had a clear job solving the problem that roads needed to be paved permanently new due to earthquakes and natural erosions. The result were overloaded landfills within a country with limited space being in an island position. On 17th January 1995, one of the most severe earthquakes of Japan's history shattered the island. Japan realized its dependence from imports. Resources were limited: Virgin aggregate came from Russia, oil was imported. To become resilient, recycled asphalt pavement (RAP) needed to become resource. Research and investigation on how to solve the problem developed into a coherent asphalt recycling strategy and resulted in a close-the-loop system with recycling material being as cheap as virgin material.

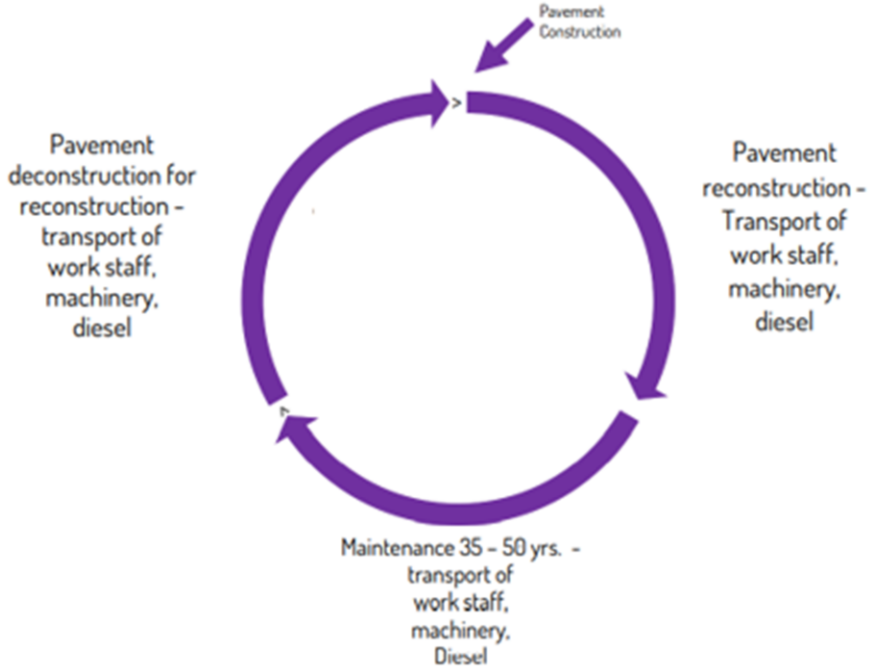


Illustration of asphalt lifecycle in Japan. Own illustration.

Sources: Copeland, 2015; Giani et al., 2015; Hashimoto et al., 2007; Hashimoto et al., 2009; Kubo, n.d; Ministry of the Environment, 2014; Thinking Circular, 2020; Transportation Research Board, 2014; West & Copeland, 2015.

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As the illustration of the lifecycle shows, roads pavement is directly transferred into a reconstruction period after its end-of-life. Between reconstruction and deconstruction, pavement needs only maintenance. Road maintenance endures 30-50 years in Japan. The arrows between maintenance period and deconstruction period as well as between deconstruction and reconstruction indicate the question of diversity management. Today, almost every product consists of mixed materials instead of mono materials. So does asphalt which is a product made out of bitumen (natural source is crude oil). The question after how to handle this material mix in recycling is often key question and decides about the success of a material loop. The shown material loop of asphalt identifies that, between these phases, material complexity is reduced in order to handle the recycling process.

Asphalt recycling developed into a mature market situation in Japan. The successful implementation of such a system involves a network of players that make the system manageable. In Japan, the system is oligopolistic and state managed. Japan consists of 5 regions which are subdivided into 47 prefectures and one national contracting authority. Each authority oversees an average of 22 road construction companies, 9 "raw material extraction" companies and 1,150 road construction companies. The industry is represented by strong associations (Japan Asphalt Mixture Association JAMA, Public Institute for Land + Infrastructure Management, Public Works Research Institute). A workers' union apparently doesn't exist.

The development of the system was fostered by specific policies:

- Public Cleansing Law No 137 of 1970
- Basic Environmental Law 1993 & 2014 for Measures
- Procurement Eco Friendly Goods + Services by State and other institutions 2000
- Partition of Road Standards EN 15804

Furthermore, life cycle assessments are conducted and standards are defined by ISO norms. A "Handbook of Recycling Technology of Pavement Waste" gives insides into lessons learned and was published already in 1984. Further handbooks followed like the "Handbook of In-Situ Surface Recycling" in 1986, the "Handbook of In-Situ Basecourse Recycling" in 1987, as well as the "Handbook of Plant Recycling of Pavement" in 1992.

In the same year of 1992, a government mandate defined that RAP mixtures are as good as virgin mixes. Two years later, first material flow analysis started. In 2004, another "Handbook of Pavement Recycling" was published. Through the load of publications, Japan fostered industrial knowledge about pavement recycling and supported closed-loop development.

Sources: Copeland, 2015; Giani et al., 2015; Hashimoto et al., 2007; Hashimoto et al., 2009; Kubo, n.d; Ministry of the Environment, 2014; Thinking Circular, 2020; Transportation Research Board, 2014; West & Copeland, 2015.

During the year of 2004, Japan also reached a major milestone: Almost all streets were paved with recycled asphalt. In 2005, the country reached the point that the whole infrastructural system needed to be maintained only.

As the graph about the documented history of asphalt recycling shows, research and development didn't stop back then. In 2009, contractors engage in extensive research laboratories. Trust between industry and agencies have reached high levels for empirical emphasis, performance-based specifications and warranties. In 2013, statistics for documentation of asphalt recycling came to an end as since then, research and development is focused on other sectors for construction and demolition material. Anyhow, asphalt recycling industry is still trying to do better, driving tests to compare material specifications. For instance, in 2016, tests were done to compare Bitumen foam and Mortar foam (from car tires) to show that asphalt with mortar has an even longer life span.

Due to the sinking price level of asphalt, of course the development also resulted into pushbacks from road builders. In 2018, they actually needed to face a record ¥60-billion-fine for forming a cartel. Their aim was to fix asphalt prices.

Looking at strengths and weaknesses of the system, there are clear points that need to be mentioned on both sides. On the one hand, Japan managed to develop a closed-loop-system for asphalt which is quite an achievement as comparison to other countries (Global North and Global South) shows. The country hereby implements Cradle-to-Cradle principles through managing the material in a delimited technical cycle. Compliance for circular economy is followed through coherent policies and strategies. The established scientific program was an enabling factor enhancing recycling capabilities through training. Users are highly satisfied with the quality of the recycled asphalt.

On the other hand, stakeholder criticize the substitution of fossil bitumen is still not perfect and critical materials still exist.

Anyhow, the image of recycled asphalt grows. Facing external threats like earth quakes, floods and climate change erosions, it is quite an economic opportunity for Japan saving money through cost-efficient technologies like asphalt recycling. Moreover, the extended maintenance of infrastructure offers market opportunities for players to join. The first in the field sets the standard.

Forecast says, that - due to population and infrastructure growth and continuing threats through earthquakes - recycled asphalt demand is about to rise.

Asphalt management in Japan shows clearly that the circular economy will only make the world a better place if we close loops fully to prevent systemic consequences in other parts of the world.

Sources: Copeland, 2015; Giani et al., 2015; Hashimoto et al., 2007; Hashimoto et al., 2009; Kubo, n.d; Ministry of the Environment, 2014; Thinking Circular, 2020; Transportation Research Board, 2014; West & Copeland, 2015.

Summary

There is little known about the global quantitative production of asphalt and its recycling.

Asphalt has a long life up to 40 years. Repair and refurbishment need to take place every 15 years. After 40 years, asphalt streets can fully get recycled.

Japan is success story and upcoming hope for circular economy. Documentation in Japan is very consistent and reaching back centuries. Looking at the statistics, it becomes clear that Japan performed clearly through the years: Whereas production of asphalt went down, recycling went up just as long as the quantity recycled almost equaled the quantity produced. In 2013, suddenly the statistics broke up. Digging deeper into Japan's asphalt history, a coherent circular economy strategy appears. The development of asphalt management in Japan therefore differs a lot to applied strategies in other countries of Global North, not to mention Global South where research and development often does not focus on how to recycle streets but how to build streets at all.

The story of asphalt recycling in Japan reaches back 50 years already. In 1970, the development of recycling technology for pavement waste was started. The invention of digitized close-the-loop technology to recycle streets just in place was quite rocket science back then and a goal far-to-reach. The early need for recycling technology to endure product durability was and is in the public interest due to cost savings. Asphalt has become indispensable for infrastructure but highly threatened with earthquakes. The recycling process technology was developed by a scientific network that had a clear job solving the problem that roads needed to be paved permanently new due to earthquakes and natural erosions. The result were overloaded landfills within a country with limited space being in an island position. On 17th January 1995, one of the most severe earthquakes of Japan's history shattered the island. Japan realized its dependence from imports. Resources were limited: Virgin aggregate came from Russia, oil was imported. To become resilient, recycled asphalt pavement (RAP) needed to become resource. Research and investigation on how to solve the problem developed into a coherent asphalt recycling strategy and resulted in a close-the-loop system with recycling material being as cheap as virgin material.

Asphalt management in Japan shows clearly that the circular economy will only make the world a better place if we close loops fully within the local systems we live in to prevent systemic consequences in other parts of the world.

6. Final summary - results

What we have found is a huge gap in the overall understanding of the circular economy. Indeed, the big five globally largest material flows by mass are successfully recycled in many parts of Global North. Even closed-loop systems could be identified for specific materials. But the most material systems are lacking circular comprehensiveness. Circularity is not thought through in a global context. The lifecycle of material starts with exploiting activities in Global South and ends with exported waste in Global South again. The story behind the system evolvement shows that growth of industries and mankind's striving for freedom is accompanied by rebound effects.

Intention and attention are an interplay that defines the outcome. Unintended effects show themselves as rebound effects. This interplay is summed up in the following table, one table each material, to give an overview of the big five global circular materials' evolvement and its effects:

1. **Ferrous metals – Intentions and rebound effects:**

Material	Paradigm	Rebound	Source
Ferrous metals	• freeing mankind from hard manual labor through division of labor (industrial mass production) • efficiency paradigm	• efficiency rebounds = exponential growth and use of resources and energy in total • e-waste and shipbreaking in the Global South • metal waste from the linear systems of the Global North still ends up in the Global South • growth of interdependencies	• Alcaidea et. al (2016) • Chowdhury (2020) • Cotta (2020) • Garside (2020) • Hossain et. al (2015) • International Monetary Fund (2021) • Kaza et. al (2018) • Lemken et. al (2008) • Lovrinovic et. al (2019) • Nakajima et. al (2018) • Pinto (2019) • Preuss (2006) • Rousmaniere et. al (2007) • Sabour et. al (2020) • Sarraf et. al (2010) • Söderholm et. al (2008) • Taylor (2020) • The European Steel Association (2020) • Thinking Circular (2020) • UN Environmental International Resource Panel (2015) • Yong (2007)

2. Aluminum – Intentions and rebound effects:

Material	Paradigm	Rebound	Source
Aluminum	• paradigm of freedom above the skies, even out into space	• efficiency rebounds = exponential growth and use of resources and energy in total • Covid 19 questioned the paradigm of unlimited transports in the sky or in space • growing dependencies by global businesses and sources	• António et. al (2013) • Bray (2018) • Bray (2020) • Bray (2021) • Devezas et. al (2017) • Devezas (2020) • European Aluminium Association (2020) • Hatayama et. al (2012) • International Aluminium Institute et. al (2018) • International Aluminium Institute (2020a; 2020b; 2020c; 2020d) • Kiessling (1933) • OECD Environment Directorate (2010) • Plunkert (2000) • Sheller (2019) • The Aluminum Association (2020) • Thinking Circular (2020) • United States Geological Survey (n.d.)

3. Paper – Intentions and rebound effects:

Material	Paradigm	Rebound	Source
Paper	• paradigm of freedom through (mass) distribution of knowledge • paradigm of freedom from diseases through sanitary products involving the step moving up the species hierarchy, making a difference to being an animal after the thinking of being an	• conservation and regeneration of forests is lagging behind • deforestation is becoming even more severe through overexploitation and climate change • bio-diversity loss of important land and species, e.g., rain forests • endangering the livelihood of around 1.6 billion people to which forests are a vital	• ACT Government (2018) • American Forest & Paper Association (n.d.; 2019) • Australian Government – Department of Agriculture (n.d.; 2020) • Berg et. al (2019) • BMEL (2017) • Bundesverband Sekundärrohstoffe und Entsorgung e.V. (2019) • Bureau of International Recycling – Paper Division (2020) • chinawaterrisk.org

Material	Paradigm	Rebound	Source
Paper	animal means being dirty and uncivilized • paradigm of mankind as homo deus in two terms: being less "uncivilized" like animals, being above/ better than animals, being smart enough to gain control over diseases and therefore natural selection • paradigm of freedom argued by growth paradigm • paradigm of economic and trade freedom by paper money, a globally normed instrument of payment that allowed mankind to do business all around the world to get international goods for the freedom of choice	source • circular rebounds: though biogenic material, it can't be handled in a biological cycle because of contaminations through inks • dependence on the material for e-commerce, household, monetary systems and much more • dependence on Global South for exploitation	(2015; 2016) • Commonwealth of Australia (2018) • Confederation of European Paper Industries (n.d.-a; n.d.-b; 2018; 2020; 2020a) • CSIRO (2019) • Dr. Wolfram Dietz et. al (2020) • East China University of Science and Technology (2019) • ENF Recycling Ltd. (n.d.-c) • EUWID GmbH (2019) • Food and Agriculture Organization of the United Nations (2020) • Geng et. al (2008) • Geng et. al (2013) • Grieg-Gran et. al (2015) • Haggith etl a. (2018) • Honnold (2009) • International Labour Organization (n.d.) • Matthews et. al (2011) • Meinl et. al (2016) • National Waste Policy Action Plan (2019) • Paper Industry Technical Association (2015) • PG Paper Company Ltd. (2018) • Sardjeva et. al (2015) • Seadon (2019) • State Environmental Protection et. al (2008) • Statista (2019a; 2019b; 2020a; 2021) • The Seattle Times (2018) • Umweltbundesamt (2014) • Thinking Circular (2020) • Two Sides (2016) • Wikipedia (2007; 2020; 2021a; 2021b) • Xinhuanews (2020) • Zhou (2018)

4. Glass – Intentions and rebound effects:

Material	Paradigm	Rebound	Source
Glass	• paradigm of economic and trade freedom by glass bottles, which were suitable for global transportation and enabled mankind to share exclusive food and drinks for the freedom of choice • paradigm of freedom of illness by implementation of food security (glass containers)	• missing collection systems in many parts of the world • environmental rebounds through sand scarcity • mining rebounds in Global South: depletion of groundwater, lesser availability of water, destruction of agricultural land, loss of employment to farmers, threat to livelihoods, violation of human rights, damage to roads and bridges • dependence on the material for food and drinks, container packaging, construction, glass fibers and much more– still freedom? • dependence on Global South for mining	• Beijing Zhonggui Exhibition Co. (2019) • Butler et. al (2019) • BVSE (2019) • Charleston (2018) • Consol Glass (n.d.) • Curtis (2008) • Dan Gavriletea (2017) • Dr. Ing. Harder (2018) • ENF Recycling Ltd. (n.d.-a; n.d.-b) • EU Commission (n.d.) • FEVE (n.d.-a; n.d.-c) • FoodReview (2018) • Fuxi (2021) • Glass Alliance Europe (n.d.-a; n.d.-b) • Glass Packaging Institute (2020) • Global Recycling Magazine (2020) • Grand View Research (2020) • Haley (2009) • Healing Earth (n.d.) • Heidenreich (2018) • Industry Select (2020) • Jacobs (2020) • Jacoby (2019) • Macfarlane (2004) • M. Naveen Saviour (2012) • National Recycling Forum (n.d.) • O.Berk (2016) • Peduzzi (2014) • Stefanini et. al (2020) • The Corning Museum of Glass (n.d.-a; n.d.-b; n.d.-c; n.d.-e; n.d.-f) • the Glass Recycling Company (n.d.-a; n.d.-b; n.d.-c; n.d.-d; n.d.e; n.d.-f; 2021) • Thinking Circular (2020) • Vivier (2018) • Whitehouse (2012) • Yeon (2010)

5. Asphalt – Intentions and rebound effects:

Material	Paradigm	Rebound	Source
Asphalt	• mobility as an expression of the paradigm of freedom and interconnection between villages, cities, regions, countries serving the growth paradigm	• environmental rebounds, e.g., peak oil, and health issues, e.g., through leakages into the environment and human uptake • financial rebounds for communities • new infrastructure causes more mobility, which drives climate change • new dependencies	• Copeland (2015) • Giani et. al (2015) • Hashimoto et. al (2007) • Hashimoto et. al (2009) • Kubo (n.d.) • Ministry of the Environment (2014) • Thinking Circular (2020) • Transportation Research Board (2014) • West et. al (2015)

For ferrous metals, e-Waste and shipbreaking in the Global South make clear, how metal waste from the linear systems of the Global North still ends up in the Global South. It illustrates part of the global waste rebounds that we must overcome to develop a pure circular system.

For aluminum, the story about the flying paradigm was not connected to linear or circular questions. But climate change now questions the paradigm of an unlimited transports in the sky or in space, but a paradigm for freedom, overcoming physical dimensions flying and entering space might explain why environmental aspects - not being in the focus - led to a climate rebound. No light has been shed on the flying paradigm before, but climate change forces the industry to reflect developments.

For paper, the destruction of the natural resource forests is in wide contrast to the claim of freedom of mind. As humans claim freedom, they curtail the freedom of other species. And though paper industries have high recycling figures they are not circular in the sense of the C2C principle. These two aspects make up for rebound effects within the existing paper cycles.

For glass, the paradigms of transparency, health security and technology have driven glass production. But sensitive biotopes are endangered by sand exploitation and glass resources have reached planetary boundaries. Driving recycling infrastructure will deliver higher numbers but without ending linear structures we will not be able to prevent systemic consequences by the destruction of natural resources especially in the Global South.

Asphalt management in Japan shows clearly that the circular economy will only make the world a better place if we close loops fully within the local systems we live in to prevent systemic consequences in other parts of the world.

7. Methodology

The aim of this study was to identify the drivers of the big five globally largest material flows by mass from a circular economic perspective to understand their story behind.

This required to make use of tools for system thinkers. Systems thinking requires a shift in the perception of the world around us. In order to understand how systems evolve, dynamics and interconnectedness of the systems needed to be discovered. Methodological approach was therefore a systems mapping. Systems mapping enables to provide an exploration of the system, communicate understanding, and allow for the identification of knowledge gaps, intervention points, and insights. So - what have we done exactly? Generally speaking, systems mapping is the creation of visual depictions of a system, such as its relationships and loops, actors and trends. Systems mapping is intended to provide a simplified conceptual understanding of a complex system.

To understand the story behind the big five material streams, we first needed to make a deep dive into quantified mass flows. A preceding study was conducted which can be found under Thinking Circular® publications. The preceding study builds the basis for this study. The methodology of the preceding study is explained in the above linked documentation. The study gave insights into regional recycling infrastructures. It became clear that globally, there are large circularity gaps, especially in Global South. Nevertheless, the biggest five material streams are showing circular characteristics especially successfully implemented in Global North. We were asking, why implementation was successful in many parts of Global North and in which way Global South is missing circularity and how both ends are interconnected.

Therefore, we made a deep dive into history for each material. Focus lied on the question how people could adapt a cognitive understanding for handling the material over time. Which industry trends, which historic events, which crises, which political intentions, which civic attentions led to the development? Scientific papers and industry reports have been analyzed to create an overall picture.

For conducting the literature research in order to answer the above shown questions, first a regional selection needed to decided. The preceding study again has built the basis for this decision. The results of the proceeded study showed that most of the data was available for Europe, the USA and China. Regional selection for Global North therefore concentrated on these three regions. For Global South, missing data didn't give a clue on how to search for better information. From a systemic point of view, it made sense to look for data in countries, where resources get exploited to fully understand the way of the material stream and its underlying consequences.

Most of the literature chosen were scientific papers. Anyhow, scope of scientific papers is often underlying complex causalities. In contrast to these papers, this study is purposely written in storytelling format because focus lies on delivering a holistic picture. The study is intended to be easy and quickly to understand with a clear message.

The story behind the big five globally largest material flows is therefore not only supported by scientific papers but also by knowledge of circular economy experts with over 30 years' experience within the industry. As "real-world laboratory", our experts are delivering know-how directly out of practice. External expertise was included through the analysis of industry reports and other expert publications.

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9. About Thinking Circular®

About the multiverse of Thinking Circular

At Thinking Circular, we're creating a multiverse for green progress by helping green innovation to prosper. We use the concept of a circular economy and the Cradle-to-Cradle (C2C) design principle to support business, science and politics on the path to a more sustainable society. Consultancy, networking, partners, political positioning, events, expert advice, influencers, speakers – Thinking Circular offers all of this and much more. This is where ideas for securing the future are forged: We develop green innovations and make them a reality.

Eveline Lemke

As Minister O.D., Eveline Lemke is the linchpin and the face of Thinking Circular. She brings her networks and expertise to the table and builds gateways and bridges between the different dimensions of the circular economy. Thanks to her extensive experience of over 30 years in the field of circular economy, she has a keen understanding not only of the political necessities in this field but also the needs of business and society. Together with her competent team of circular economy experts, she helps to make change happen. This is how we are paving the way for an economy that allows everyone to live well and sustainably.

About the author

Charléne L. Nessel

As Project Manager at Thinking Circular®, the commitment to a green transformation in business and society for our grandchildren's future is a matter of course for the young economist. After studying International Economics and Trade in Hangzhou, China, and at the University of Applied Sciences and Arts Hannover, Germany, she earned her Master's degree in Strategic Business Development. For her, the Circular Economy is a model to practically implement sustainability.

What we mean by circular economy

Thinking Circular operates on the basis of a broad, holistic understanding of the circular economy. Thinking Circular is a global endeavor.

The cultural understanding of the circular economy in central European societies is often limited to waste management. However, waste as we define and produce it in our societies does not occur naturally in the environment. This means that the more consciously and harmoniously we interact with nature, the less waste will be produced. Waste as a product of excess and unfair distribution is attributable to the mismanagement of our economic systems. As long as we fail to produce and consume goods in such a way that they are compatible with and cause no harm to humans and the natural environment, we will need to use green technologies to compensate for the flaws in our system. Treating and decontaminating our air, water and soil will remain a necessity until the green transformation is brought to a successful conclusion. Until then, we need to aim to 'close the loop' by making materials and products flow in cycles so that they can be reused to the greatest possible extent. There is much ground left to cover and every step of the way is a learning experience.