Thinking Circular®

Top 10 Circular Materials by mass

– Market study –

Thinking Circular®

Photo by P21

Photo by P21

Photo by P21

Photo by P21

Photo by Ben Kercks from Pixabay

Global Waste Composition:

44 % wet	food and green
38 % dry	metal, paper, cardboard, plastic
18 % mixed	all

Sources: Kaza et. al (2018, p. 29).

Waste culture and concepts are different in the Global North and the Global South:

Global South

Photo by Roxanne Shewchuk from Pexels

Global South:

Waste grows as income per capita does.

Global North:

Goal: Decoupling waste generation from consumption.

Global North

Photo by Pixabay from Pexels

Sources: Kaza et. al (2018, pp. 17–37).

Key Questions Global South

- Where is value from waste, what and how can be collected or recycled?
- How significant are formal numbers?
- How to measure informal numbers?
- How to institutionalize waste management?

Photo by Mumtahina Tanni from Pexels.

Key Questions Global North

- How can specific materials be recycled?
- How can ownership for material streams be captured?
- Do we need an Intergovernmental Panel for Material Flows (according to IPCC) to fill data gaps?
- How can we synchronize waste and chemical legislation?
- How can substances of concern be identified and eliminated?

Photo by Vogt-Plastic GmbH, Germany.

Majority of waste still in open dump or in landfill:

In the industrialized waste sectors incineration makes up for 12-27%.

In mega cities of Global South incineration has grown up to 26% within 5 years and is substituting landfill.

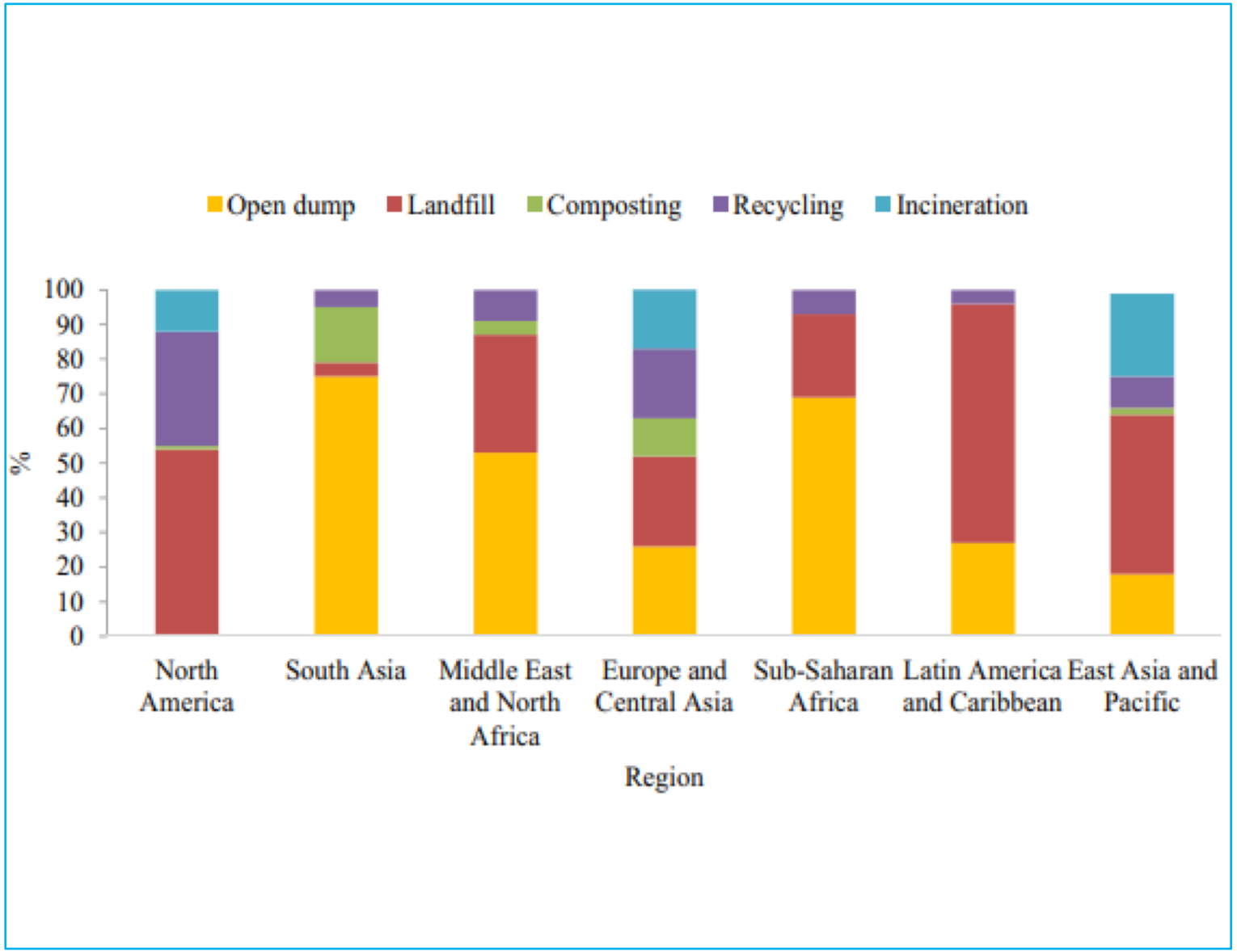


Figure Global, regional waste disposal by method in 2016 (Sabour et. al (2020, p. 2).

Sources: Sabour et. al (2020, p. 2) - Lu et. al (2017, p. 176).

We are looking on 1.5 % of global material flow:

- 100 bill. metric tons are planetary extractions (p.a.)
- 10 bill. tons of all materials are circular (p.a.)
- 1.5 bill. tons of these materials are the TOP 10 circular materials examined in this market study

Circular Material:

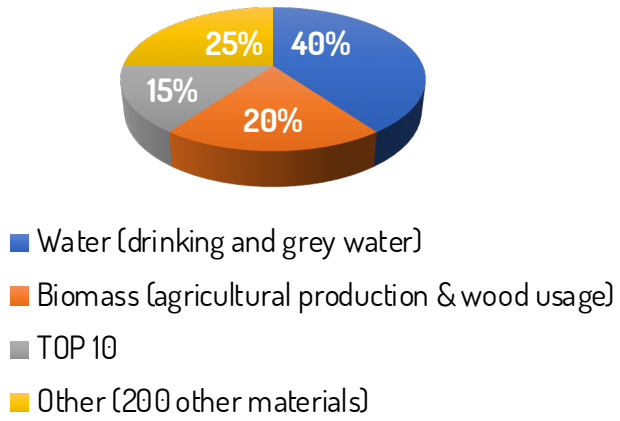


Photo by Sebastian Pichler from Unsplash.

Sources: Hatfield-Dodds et. al (2017, p. 8) - de Wit et. al (2018, p. 6).

Status of the circular economy will be highlighted as rating card in the end of every material chapter:

The rating card is based upon the following criteria (details can be found in the separate methodology document):

Material	Market readiness	Design for CE	Technology	Cognition for CE
Region	• Value Chain (transparent - trust and trace) • Business case according to RESOLVE principle • Marketplace (stock market) • Stock management • Material definition, material passport • Value of material	• Business support schemes • Public procurement & infrastructure • Regulatory Framework • Fiscal frameworks	• Technology available • Visibility as sector technology • Technology affordable • Technology in use	• Awareness, Information, Education • Collaboration platforms

Rating according to expert interview:

Best (green) = 3 points of each category fulfilled.
Good (yellow) = 2 points of each category fulfilled.
Red (fair) = 1 point of each category fulfilled.

Overview of TOP 10 circular materials:

Material	Recycling in million tons (Mt)	Production in Mt	Recycling Rate in % of global average	Liability of data
Steel	600 Mt	1,730 Mt	35%	20%
Asphalt	530 Mt	936 Mt	57%	c.s.*
Paper	221 Mt	420 Mt	53%	5%
Plastics	50 Mt	390 Mt	13%	c.s.*
Aluminum	29 Mt	77 Mt	38%	34%
Glass	27 Mt	130 Mt	21%	33%
Textiles	21 Mt	99 Mt	21%	c.s.*
Rubber	7 Mt	27 Mt	26%	c.s.*
Copper	4 Mt	24 Mt	17%	40%
Cobalt	0.015 Mt	0.117 Mt	13%	30%

Nothing in between copper and cobalt due to low data availability.

*c.s. = case studies

Case studies are selected on basis of the rating card offering valuable clues to best available evaluations. Case studies don't offer solid scientific ground. **Slides will be left blank if data availability is too low.**

1

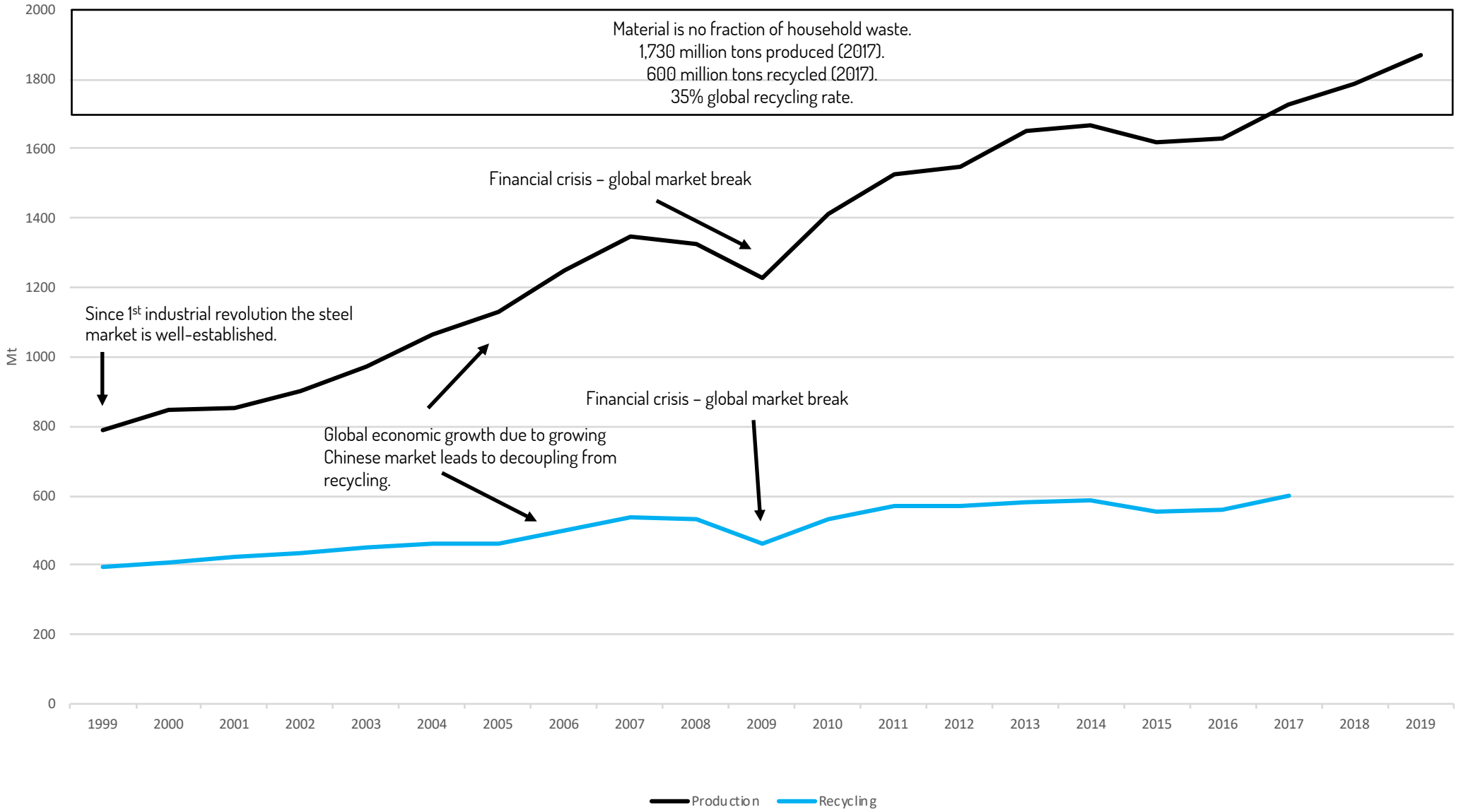
1,730 million tons produced (2017).

600 million tons recycled (2017).

35% global recycling rate.

Photo by Alexas Fotos from Pixabay.

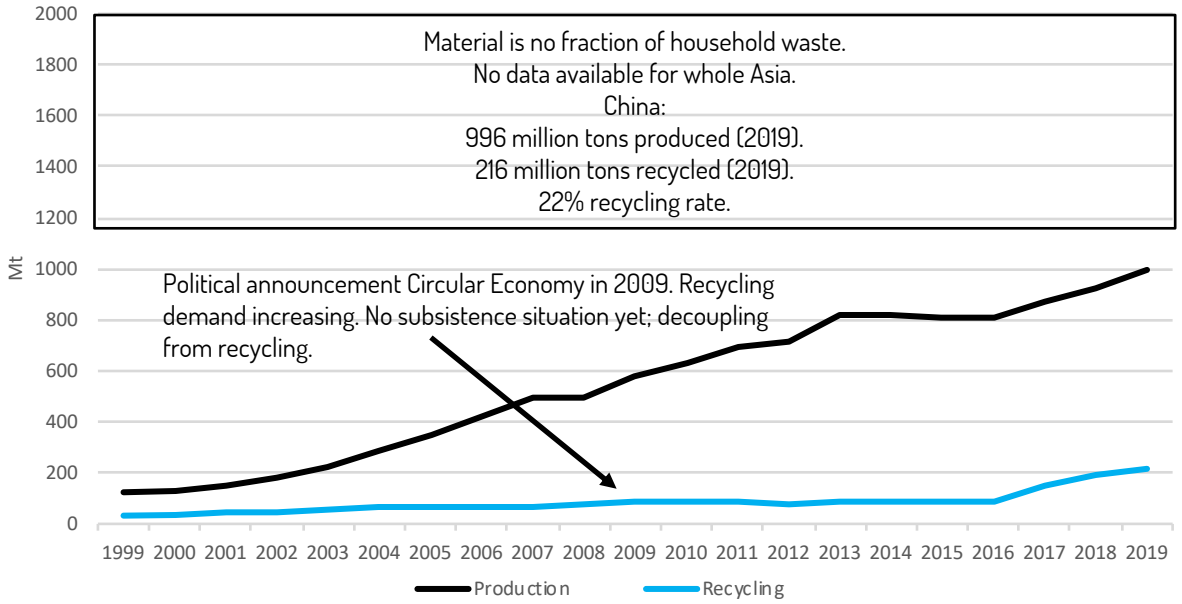
Historic Development of Steel Recycling in the World



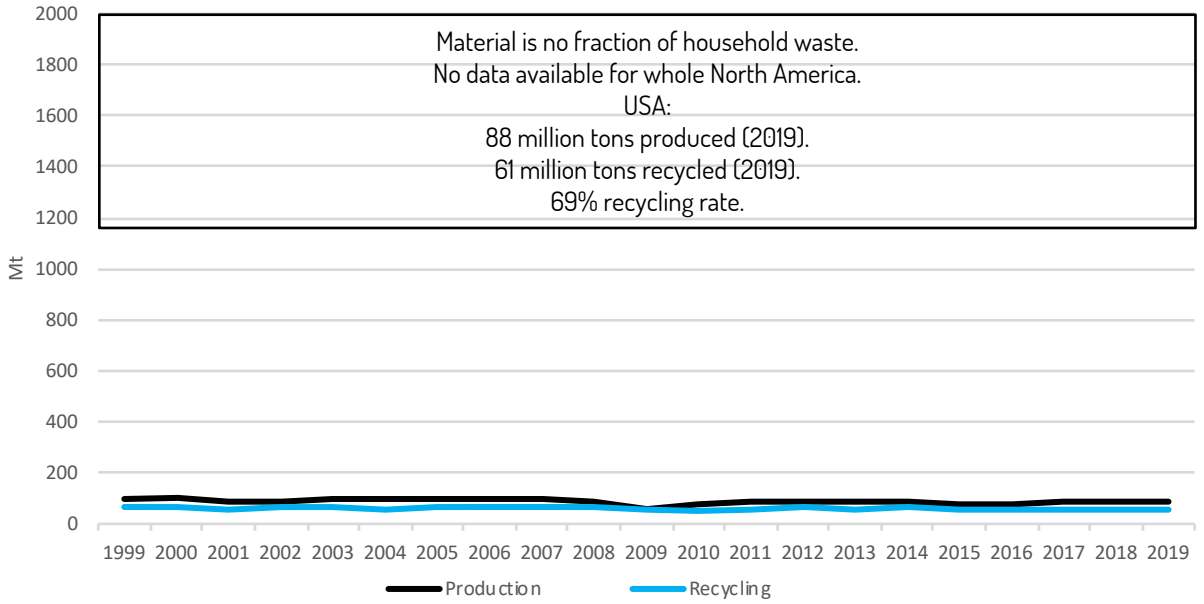
Sources: Bureau of International Recycling – Ferrous Division (2010, p. 8) - Bureau of International Recycling – Ferrous Division (2011, pp. 8-9) - Bureau of International Recycling – Ferrous Division (2013, p. 8, p. 11) - Bureau of International Recycling – Ferrous Division (2017, p. 8, pp. 12-13, pp. 22-23) - Bureau of International Recycling – Ferrous Division (2019, p. 8, p. 13, p. 22) - Bureau of International Recycling – Ferrous Division (2020, p. 8) - International Iron and Steel Institute (1978, p. 49) - International Iron and Steel Institute (2005a, p. 79, p. 90, p. 96, p. 98, p. 116, p. 118) – Söderholm et. al (2008, p. 64) - World Steel Association (2011, p. 4, p. 6, p. 9, p. 26) - World Steel Association (2013, p. 16, p. 27) - World Steel Association (2017, pp. 15-16, p. 22) - World Steel Association (2018, p. 106, p. 108) - World Steel Association (2019, p. 22) - World Steel Association (2020a, p. 1) - World Steel Association (2020b, p. 6, p. 16, p. 22).

Thinking Circular®

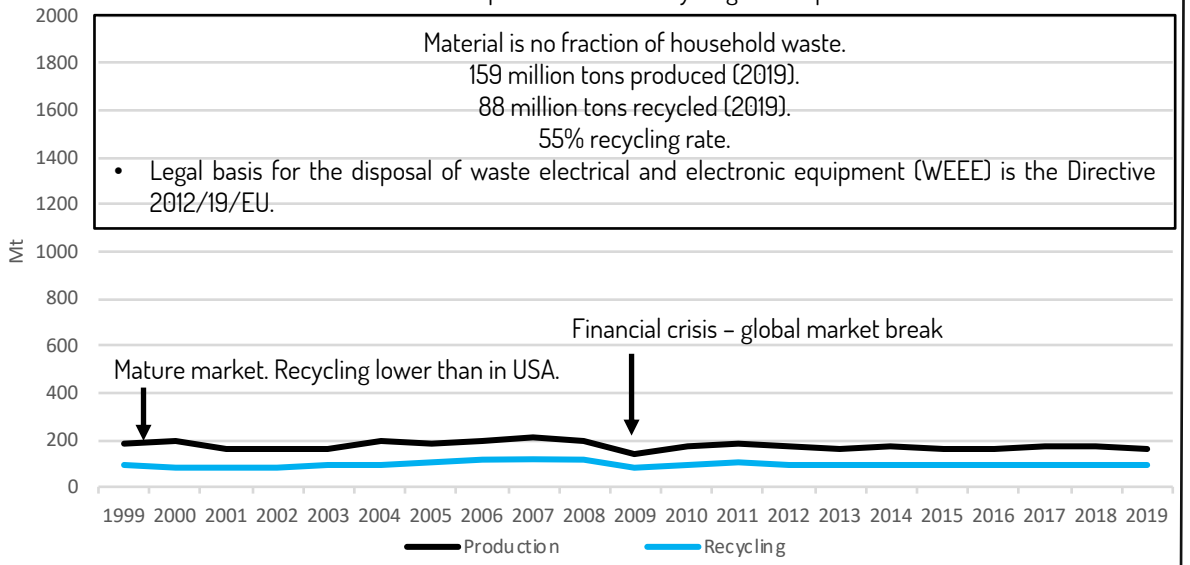
Historic Development of Steel Recycling in China



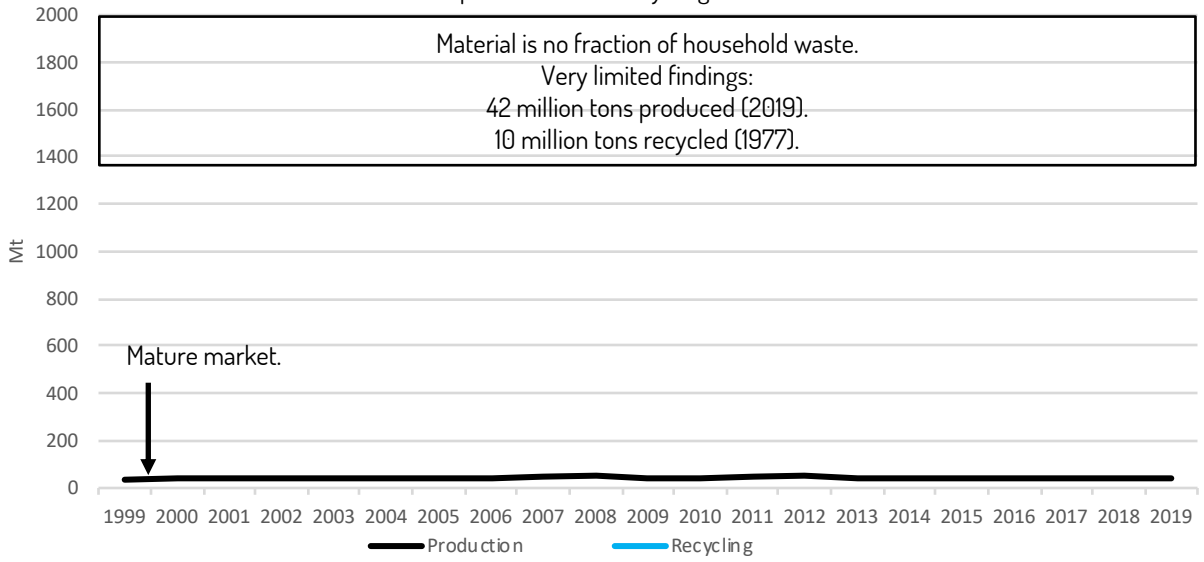
Historic Development of Steel Recycling in USA



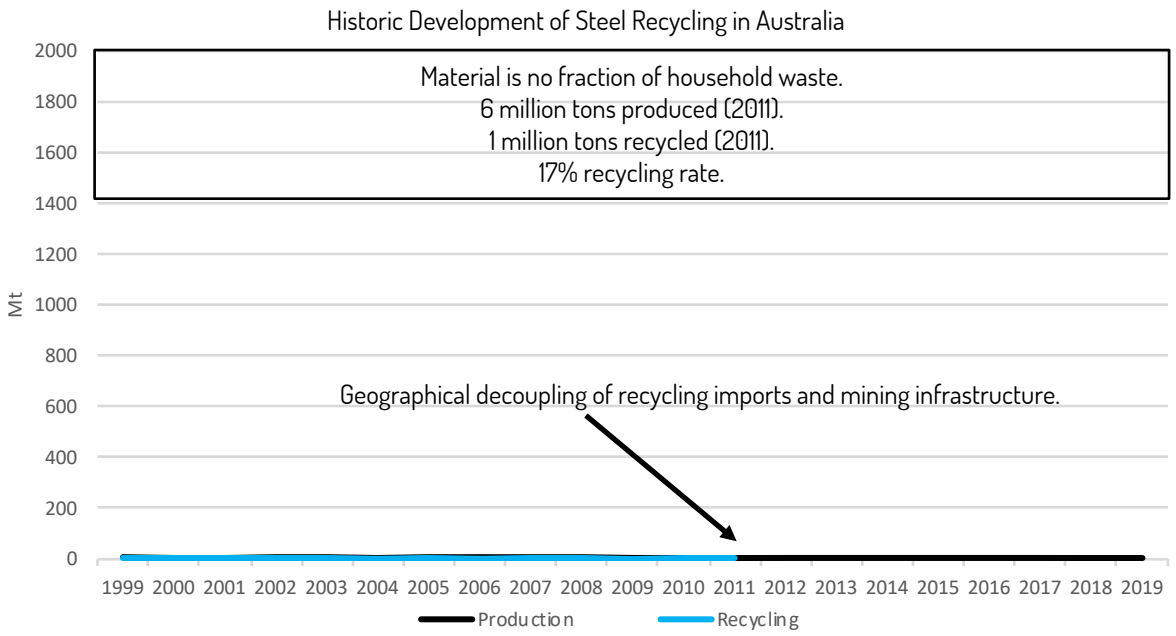
Historic Development of Steel Recycling in Europe



Historic Development of Steel Recycling in South America



Sources: Bureau of International Recycling – Ferrous Division (2010, p. 10, p. 12, p. 15) - Bureau of International Recycling – Ferrous Division (2011, p. 8, pp. 11-12, pp. 14-15) - Bureau of International Recycling – Ferrous Division (2013, p. 8, p. 13, pp. 18-19) - Bureau of International Recycling – Ferrous Division (2014, p. 14, p. 20) - Bureau of International Recycling – Ferrous Division (2017, p. 8, p. 12, p. 23, p. 26) - Bureau of International Recycling – Ferrous Division (2019, p. 8, pp. 12-13) - International Iron and Steel Institute (1978, p. 49) - International Iron and Steel Institute (2000, p. 220) - International Iron and Steel Institute (2002, p. 6, p. 16) - International Iron and Steel Institute (2003, p. 6, p. 16) - International Iron and Steel Institute (2004, p. 6, p. 16) - International Iron and Steel Institute (2005a, pp. 10-12, pp. 77-79, pp. 95-99) - International Iron and Steel Institute (2005b, p. 6, p. 17) - International Iron and Steel Institute (2006, p. 6) - International Iron and Steel Institute (2007, p. 5) - Söderholm et. al (2008, pp. 64-67) - The European Steel Association (EUROFER) (2020) - The European Parliament and the Council of the European Union (2012) - The European Steel Association (EUROFER) (2020, p. 67) - World Steel Association (2008, p. 13) - World Steel Association (2010a, pp. 3-5, pp. 89-90, pp. 115-118) - World Steel Association (2010, p. 13) - World Steel Association (2011, pp. 5-6, p. 9, p. 14, p. 16, p. 26) - World Steel Association (2013, p. 16, p. 27) - World Steel Association (2017, p. 16, p. 22) - World Steel Association (2018, pp. 77-79, pp. 106-108) - World Steel Association (2019, p. 4, p. 10, p. 16, p. 29) - World Steel Association (2020, p. 8, p. 10, p. 16, p. 22).



Best available projections:

- Industry offers considerable potential for resource conservation and is becoming a field for strategic approaches to resource efficiency.
- Lifecycle efficiency at political level as key variable for competitiveness.
- Weight minimization, reparability and recyclability as aspects.
- Search for systemic and cross-material solutions should be given greater attention.
- Under the European Ultra Low CO2 Steelmaking program (ULCOS), technologies for the reduction of CO2 emissions have been investigated, including blast furnace with top-gas recycling, a new smelting reduction process, advanced direct reduction and electrolysis of iron ore.
- Economic and environmental performance of the ULCOS cutting edge technologies shows that the implementation might reduce 80% of CO2 emissions.

Sources: Abdul Quader et. al (2016, p. 537) – Bureau of International Recycling – Ferrous Division (2013, p. 8, p. 19) – Bureau of International Recycling – Ferrous Division (2017, p. 8, p. 26) – Bureau of International Recycling – Ferrous Division (2019, p. 8) – International Iron and Steel Institute (1978, p. 49) – International Iron and Steel Institute (2005, pp. 11-12, pp. 78-79, p. 96, p. 98) – Lemken et. al (2008, p. 26) – World Steel Association (2010, pp. 4-5, pp. 89-90, p. 116, p. 118) – World Steel Association (2011, p. 5, p. 9, p. 26) – World Steel Association (2013, p. 16, p. 27) – World Steel Association (2017, p. 16, p. 22) – World Steel Association (2018, p. 78, ˚p. 106, p. 108) – World Steel Association (2019, p. 5, p. 10, pp. 21-22) – World Steel Association (2020b, p. 8, p. 10, p. 16, p. 22) – Yellishetty et. al (2014, p. 8).

Rating card

Steel	Maturity of market	Design4CE compliance in legislation / jurisdiction	Availability of RE-Tech.	Level of knowledge and cognition for CE
World				
China		Political announcement for Circular Economy.		
USA				
Europe				
South America				
Africa				
Australia				

Steel in a nutshell:

- Steel is a material that has a long economic traditions as it used to be especially important in historic terms for wars.
- Trading with steel is therefore a market tradition that is common practice until today.
- Developments of the material are involved in historic events, e.g. the dissolution of the USSR when Russia was then sitting on huge quantities of steel scrap that needed to be recovered.
- Due to it's historic importance, recycling of steel scrap involves a long tradition as the smelting of steel was needed in unsteady times.
- 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, which is already politically announced. 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 visited Braungart's school.
- It is expected that scrap imports will resume in 2021, as China's steel industry is confronted with economic challenges due to the ban.

2

936 million tons produced (2013).

530 million tons recycled (2013).

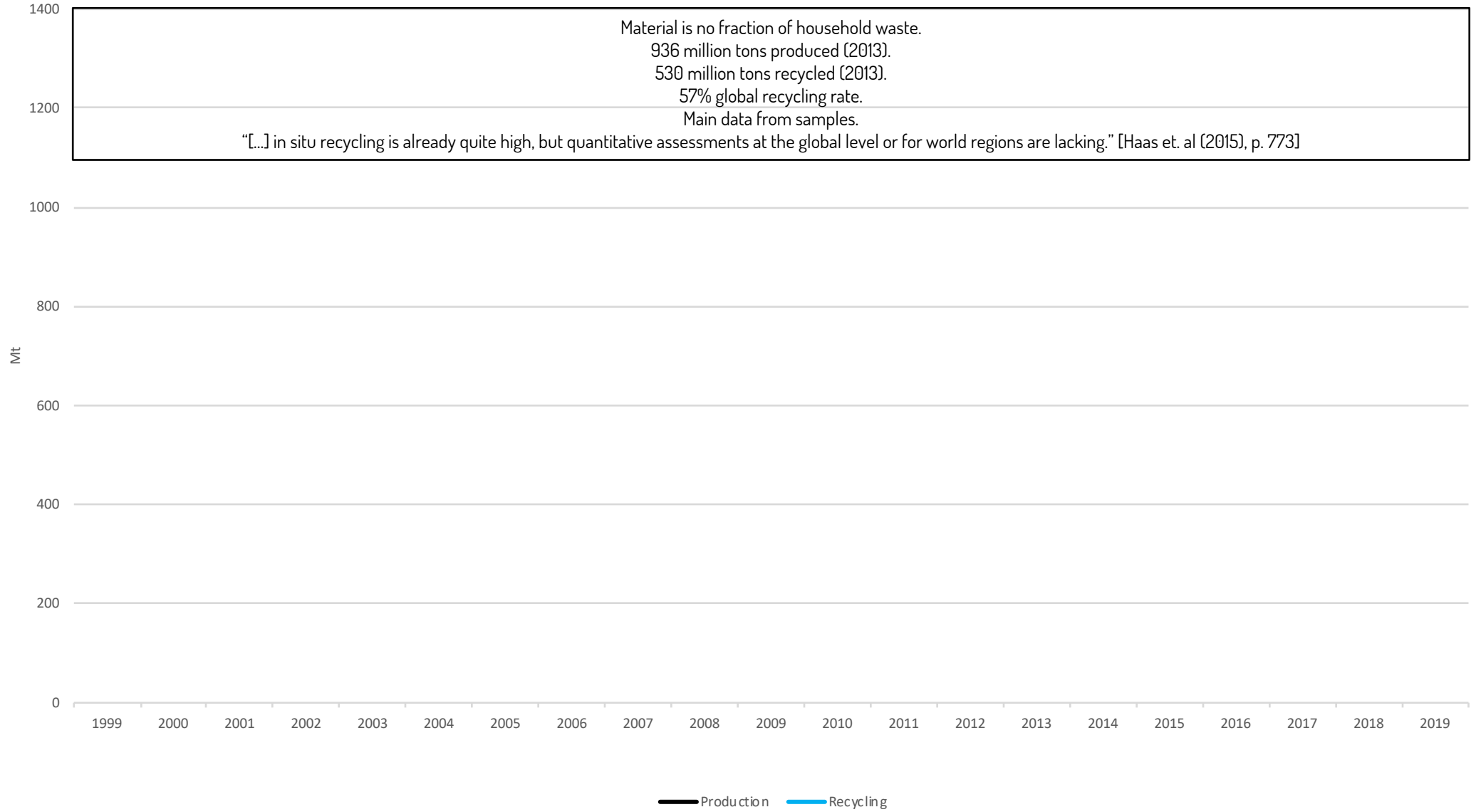
57% global recycling rate.

Main data from case studies.

"[...] in situ recycling is already quite high, but quantitative assessments at the global level or for world regions are lacking." [Haas et. al (2015), p. 773]

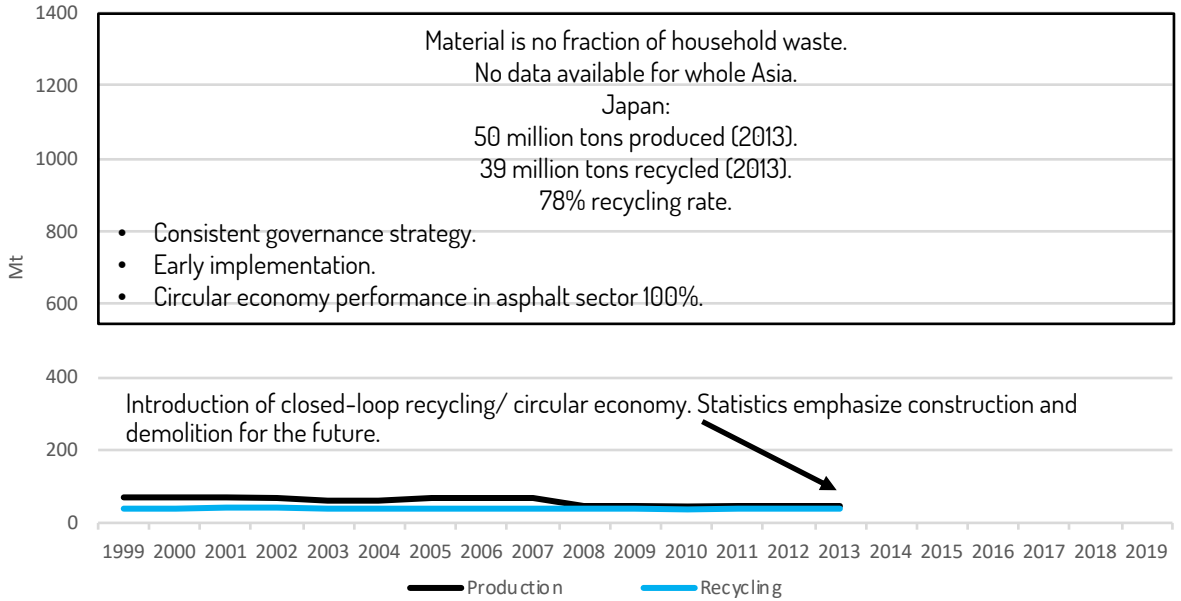
Photo by Wirtgen Group.

Historic Development of Asphalt Recycling in the World

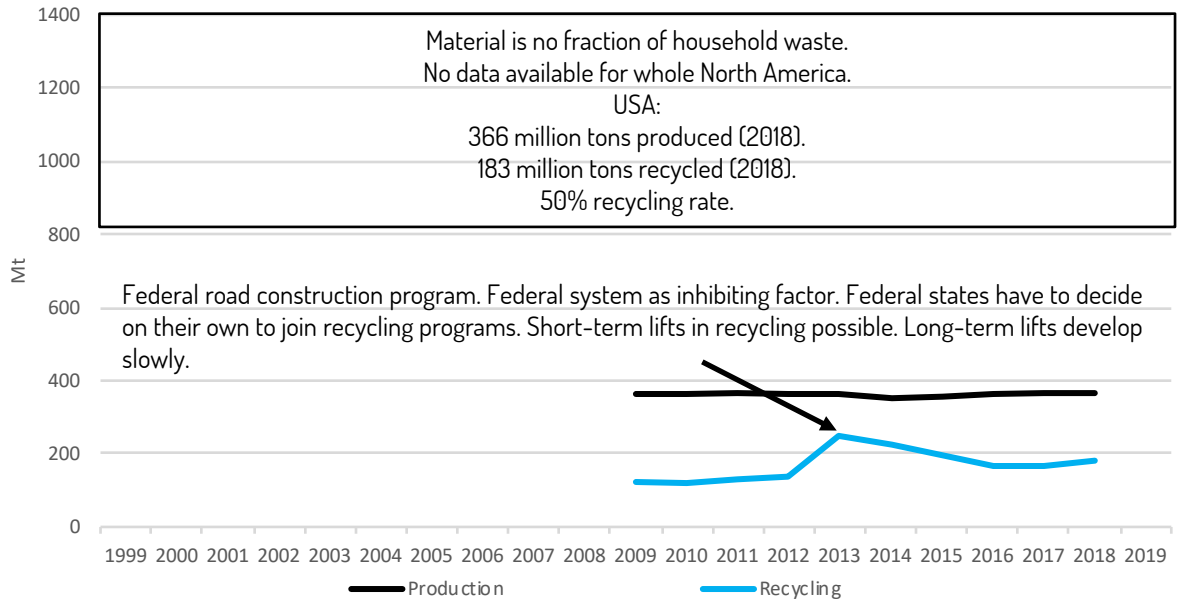


Sources:Haas et. al (2015, p. 773).

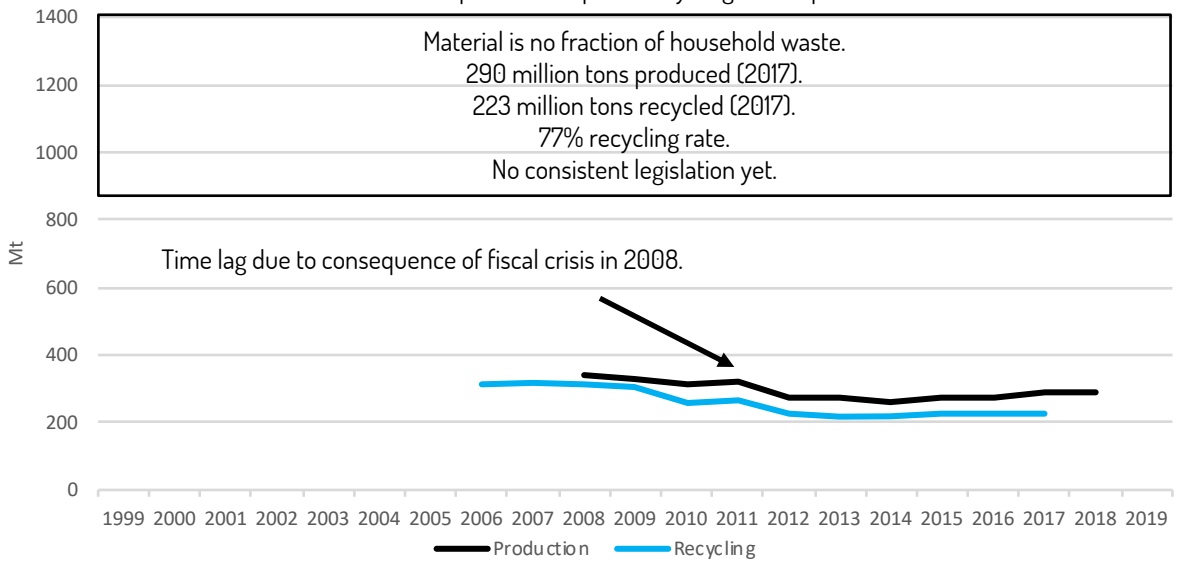
Historic Development of Asphalt Recycling in Japan



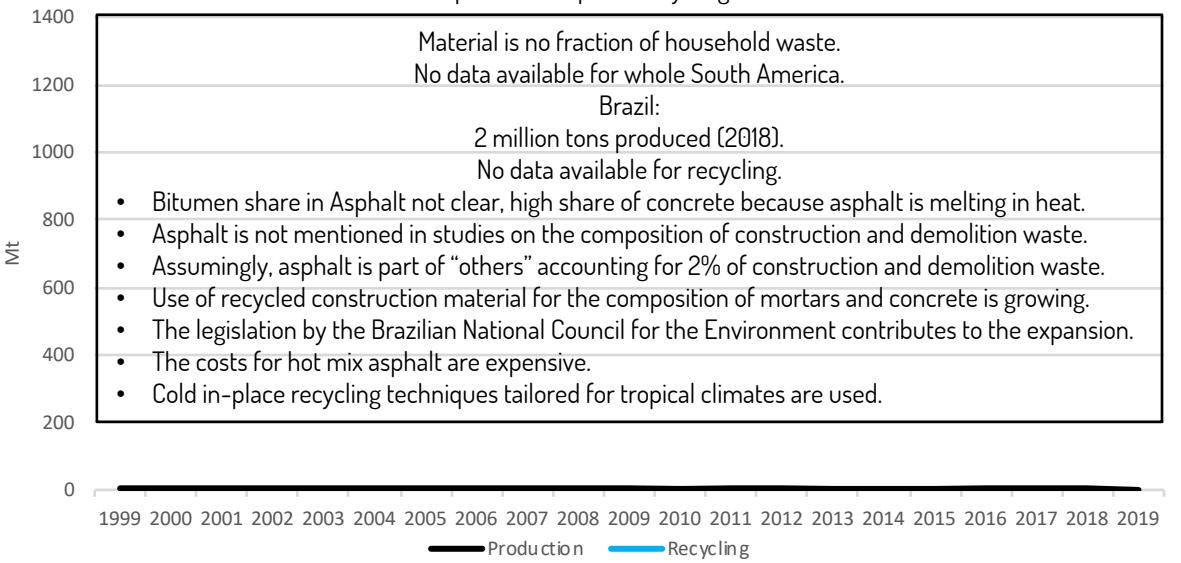
Historic Development of Asphalt Recycling in USA



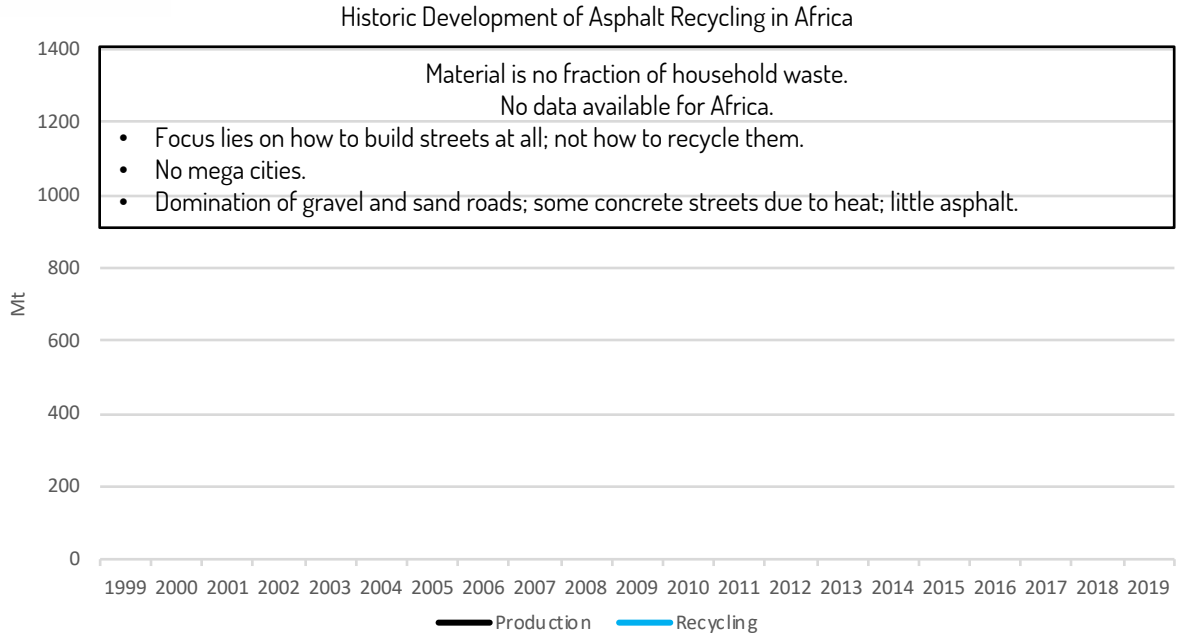
Historic Development of Asphalt Recycling in Europe

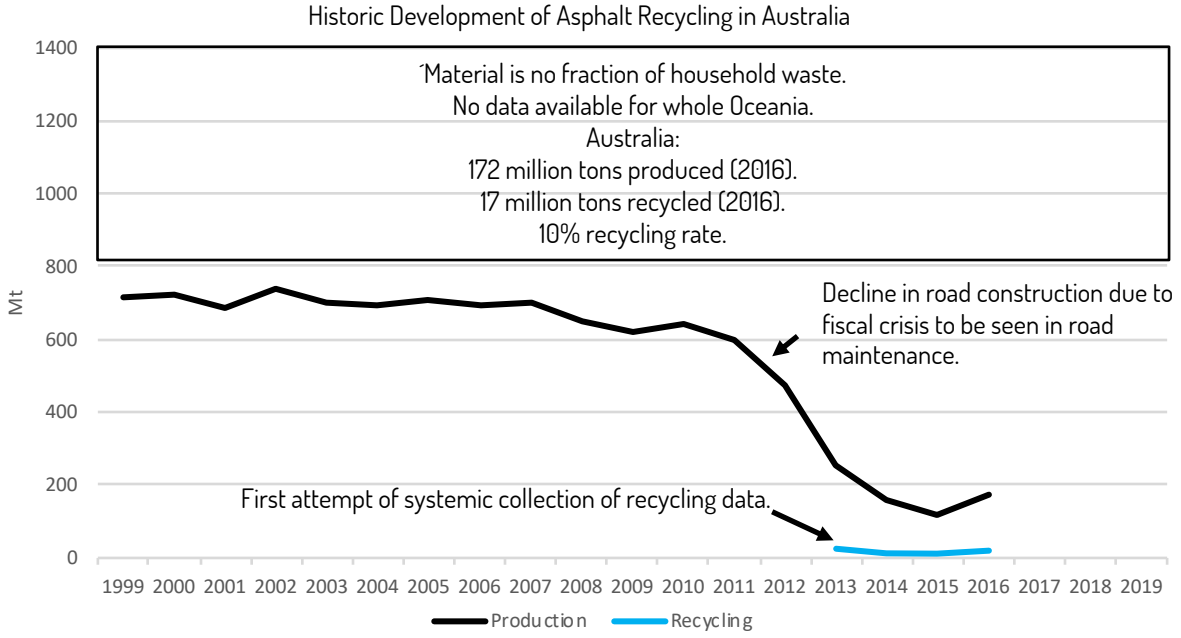


Historic Development of Asphalt Recycling in Brazil



Sources: Contreras et. al (2016, pp. 594-599) - Copeland (2015, p. 3, p. 5, p. 8, pp. 46-47) – European Asphalt Pavement Association (2020, pp. 3-4, p. 6, p. 9) - Hansen et. al (2013, p. 8, p. 12) – Hansen et. al (2015, p. 9, pp. 12-13, p. 17, p. 20) - Hansen et. al (2017, p. 10, p. 12, p. 14, p. 21, pp. 28-29, pp. 37-39) - Kubo (n.d., p. 7) - Kubo (2009, pp. 4-6) – Mantalovas et. al (2019, p. 11, pp. 13-14) – Massara (2018, pp. 410-411) - Ministry of the Environment (2014, p. 25) - Qiu et. al (2016, p. 8) - Transportation Research Board (2014, pp. 60-66) – United Nations Statistics Division (2020) - West et. al (2015, p. 14) - Williams et. al (2018, pp. 6-7, p. 10, p. 13, p. 15, p. 22, pp. 30-31, pp. 40-43) - Williams et. al (2019, p. 12, p. 16, p. 23, p. 31, p. 39, pp. 41-43).





Best available projections:

- No projections available.

Sources: Australian Asphalt Pavement Association (2018, p. 12) - Australian Government - Department of Sustainability, Environment, Water, Population and Communities (2012, p. 13 ff..) - King et. al (2015, p. 3).

Rating card

Asphalt	Maturity of market	Design4CE compliance in legislation / jurisdiction	Availability of RE-Tech.	Level of knowledge and cognition for CE
World				
Japan	○*	○*	○*	○*
USA				
Europe				
Brazil				
Africa				
Australia				

* Circular economy performance in asphalt sector 100%.

Asphalt in a nutshell:

- The development of the material is closely linked to the emerging economy of countries.
- Developed countries use more asphalt as they have a well functioning infrastructure while developing countries fight for building infrastructure and therefore streets at all.
- The development of asphalt also depends on the local (weather) conditions. In countries with high temperatures, asphalt tends to melt which is the reason why more concrete is used for building streets.
- Research revealed that asphalt in Japan is the one and only material in this market study that is used in a closed-loop recycling.
- Thus, Japan is a pioneer in the global recycling industry, consistently working on introducing the circular economy since 30 years.

3

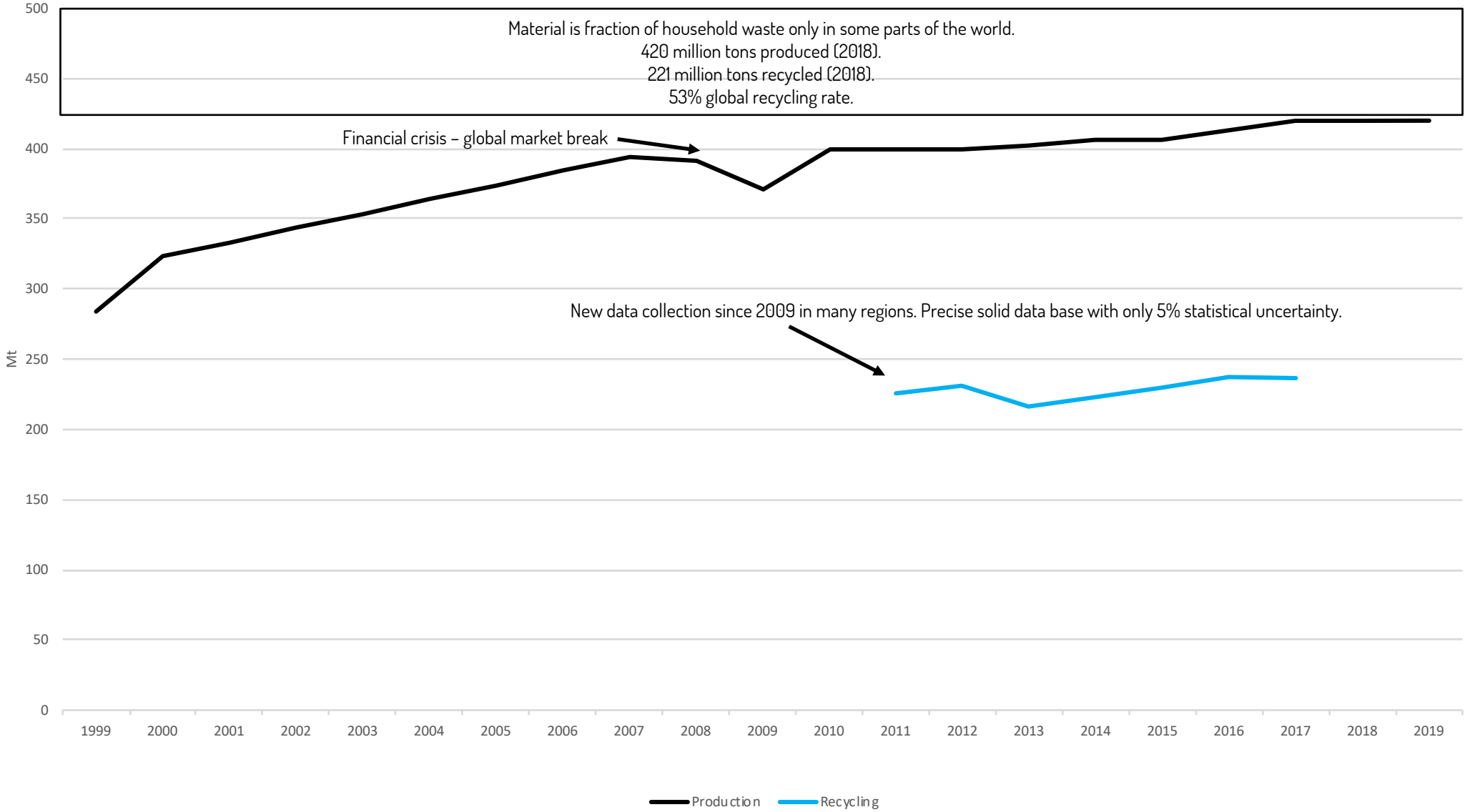
420 million tons produced (2018).

221 million tons recycled (2018).

53% global recycling rate.

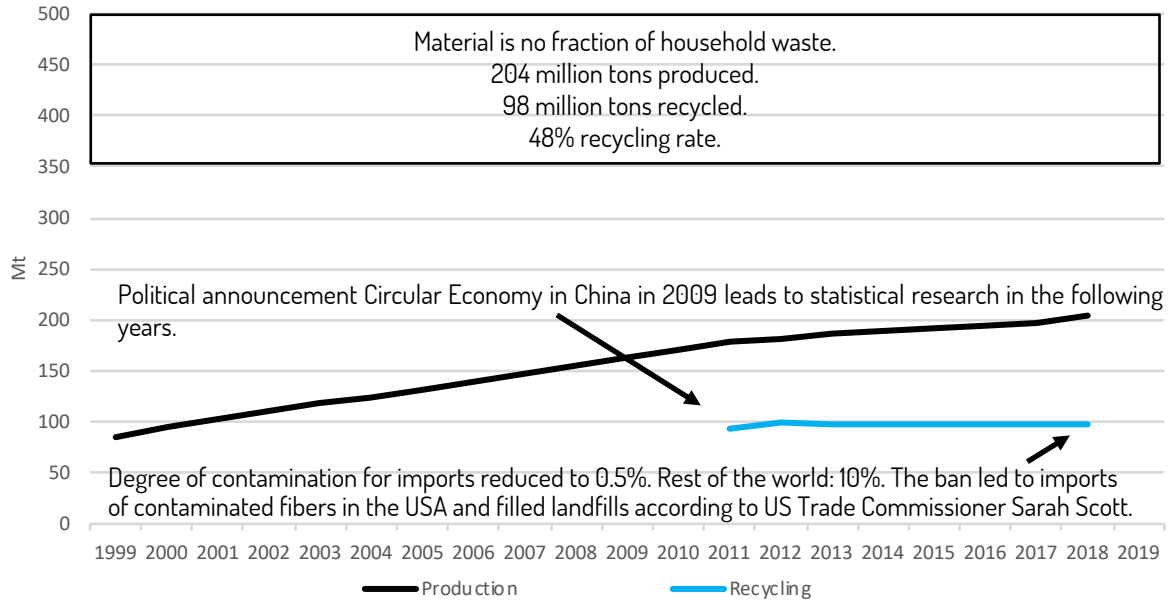
Photo delivered by P21..

Historic Development of Paper Recycling in the World

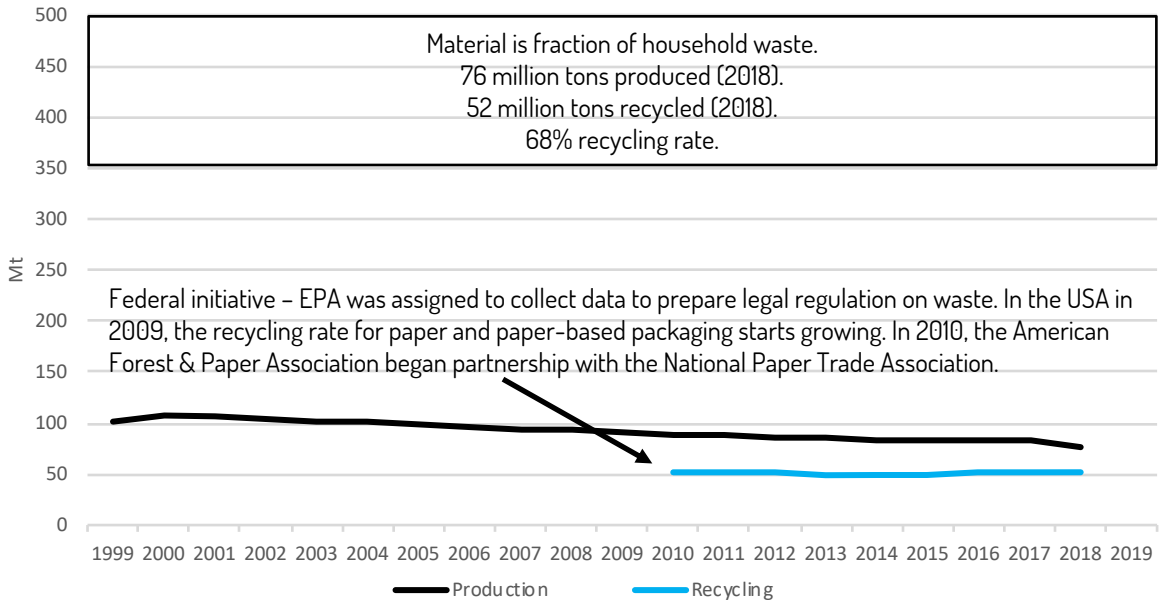


Sources: Bureau of International Recycling – Paper Division (2013, p. 2, p. 10) - Bureau of International Recycling – Paper Division (2014, p. 2, p. 10) - Bureau of International Recycling – Paper Division (2015, p. 2, p. 10) - Bureau of International Recycling – Paper Division (2020, p. 5, p. 15, p. 17, pp. 19-20) - Food and Agriculture Organization of the United Nations (2019, pp. 1-3) - Haggith et. al (2018, pp. 10-12, p. 18, p. 21, pp. 34-35) - Verband Deutscher Papierfabriken e.V. (2019, p. 2).

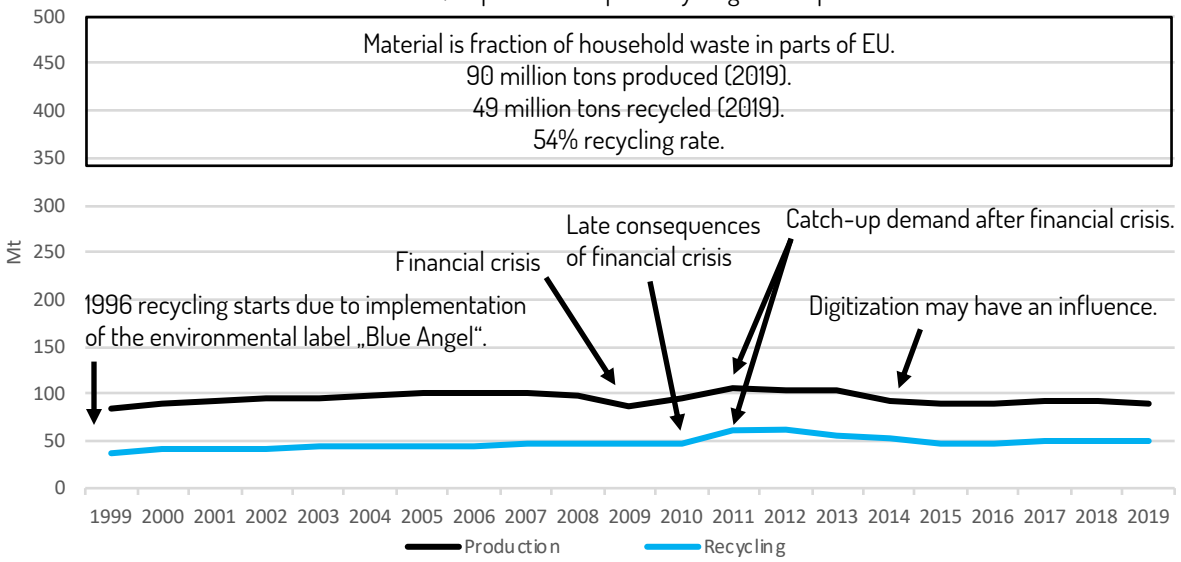
Historic Development of Paper Recycling in Asia



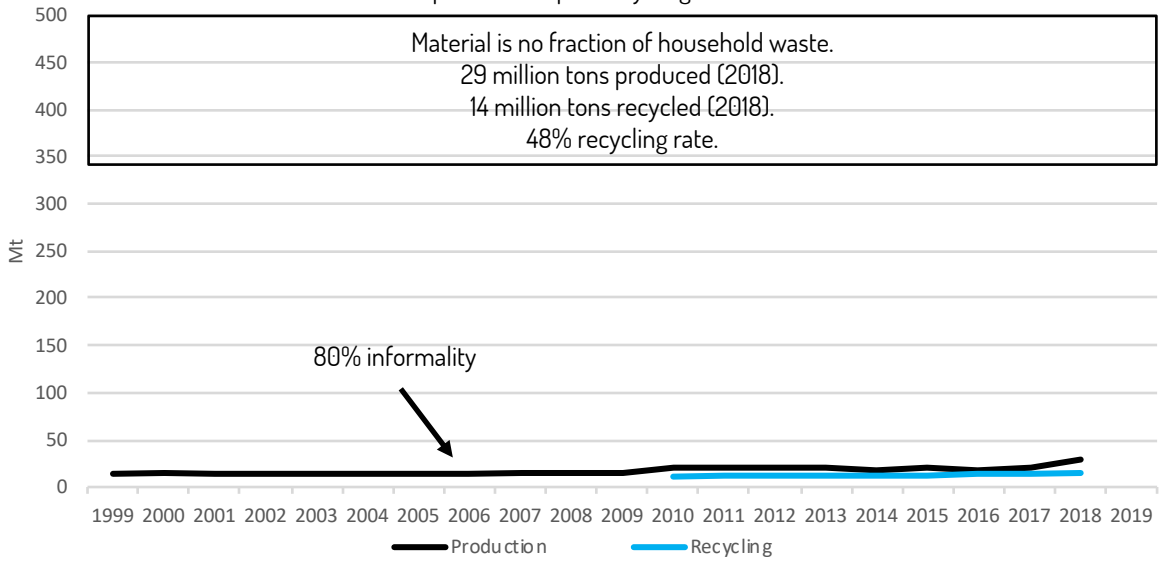
Historic Development of Paper Recycling in North America



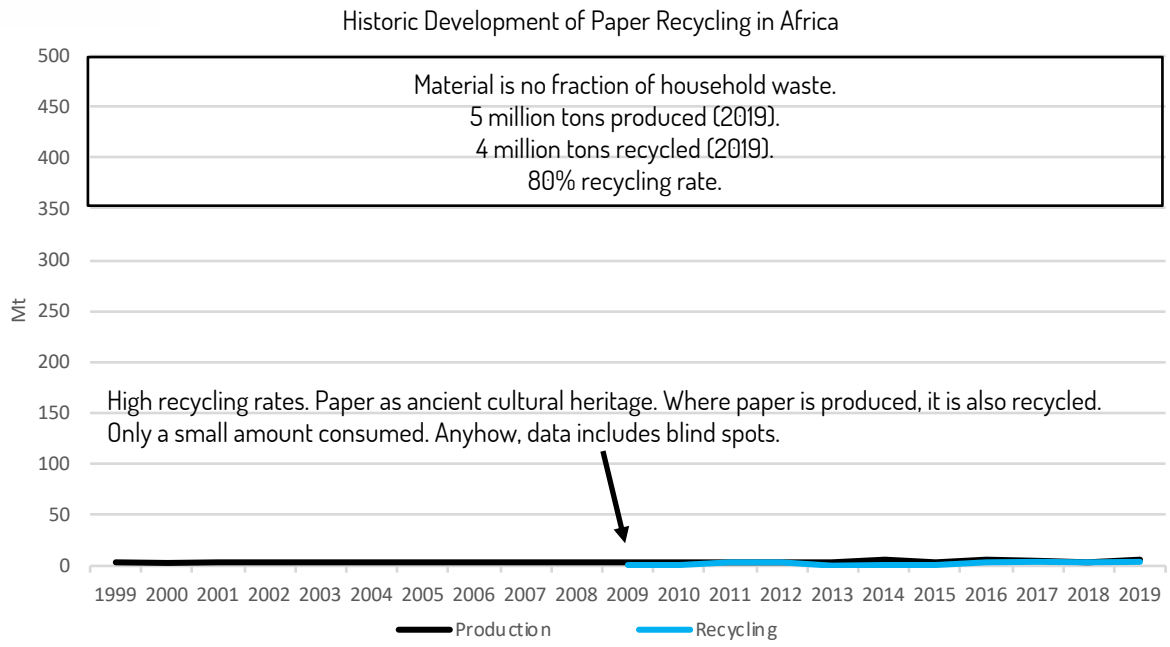
Historic Development of Paper Recycling in Europe

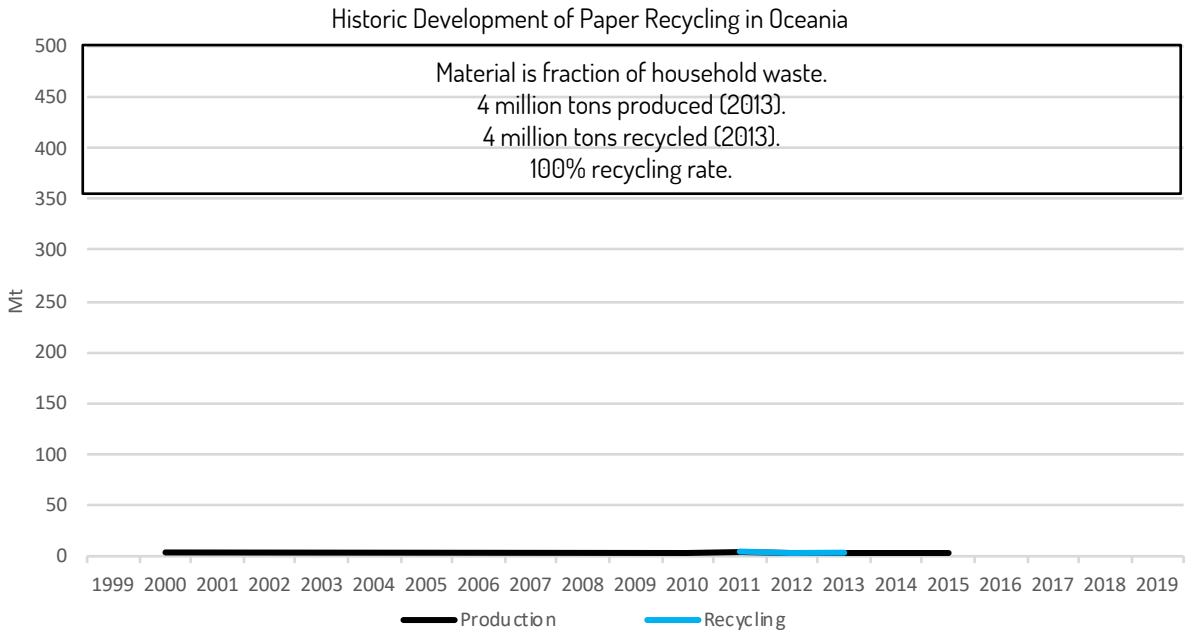


Historic Development of Paper Recycling in South America



Sources: Berg et. al (2019, pp. 2-3, p. 5) - Bureau of International Recycling – Paper Division (2013, pp. 2-4, p. 7, p. 10, pp. 12-13) - Bureau of International Recycling – Paper Division (2014, pp. 2-3, p. 7, p. 10, pp. 12-13) - Bureau of International Recycling – Paper Division (2015, pp. 2-3, p. 7, p. 10, pp. 12-12) - Bureau of International Recycling – Paper Division (2020, pp. 5-13, pp. 15-21) - CONFEDERATION OF EUROPEAN PAPER INDUSTRIES (2020b, p. 5, pp. 16-17, pp. 23-24) - Eurostat (2020) - Food and Agriculture Organization of the United Nations (2009, p. 66, p. 135) - Haggith et. al (2018, pp. 3-4, pp. 9-11, p. 18, pp. 20-21) - Lu et. al (2017, p. 7) - Verband Deutscher Papierfabriken e.V. (2019, p. 2).





Best available projections:

- 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.
- The removal of inks is the key problem 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.
- 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 LCAs and validate their green claims within the Green Deal context.

Sources: Bureau of International Recycling – Paper Division (2013, pp. 2-3, p. 7, p. 10) - Bureau of International Recycling – Paper Division (2014, pp. 2-3, p. 7, p. 10) - Bureau of International Recycling – Paper Division (2015, pp. 2-3, p. 7, p. 10) - Bureau of International Recycling – Paper Division (2020, p. 7, p. 9, p. 12, pp. 15-16, p. 18, pp. 20-21) - CONFEDERATION OF EUROPEAN PAPER INDUSTRIES (n.d.) - CONFEDERATION OF EUROPEAN PAPER INDUSTRIES (2020a) - Haggith et. al (2018, p. 3, pp. 9-11, p. 18, p. 21) - Sardjeva et. al (2015, p. 24).

Rating card

Paper	Maturity of market	Design4CE compliance in legislation / jurisdiction	Availability of RE-Tech.	Level of knowledge and cognition for CE
World				
China / Asia				
USA / North America				
Europe				
South America				
Africa				
Oceania				

Paper in a nutshell:

- Paper is a very old, traditional material that has a long economic history.
- Due to its sound economic standing, the collection and recycling of the material is not a new topic, especially not for Europe.
- Anyhow, due to the growing interest in ecological questions because of climate change and resource scarcity (and deforestation as consequence) , recycling is becoming more important.
- Moreover, the financial crisis had an impact on the stronger interest in the collection of data after 2009.
- Both incidents show that crisis are reasons for new research and data collection.
- The most important development of the past years is the contamination/ import ban in China.
- Whereas the degree of contamination of fibers is allowed up to 10% in most countries in the world, China decided to lower the degree to 0.5%. This strategy belongs to China's first major campaign to enforce stringent waste quality legislation "Operation Green Fence".
- The Green Fence is causing chaos on global recycling markets as countries have to reallocate waste exports.

4

390 million tons produced (2018).

50 million tons recycled (2018).

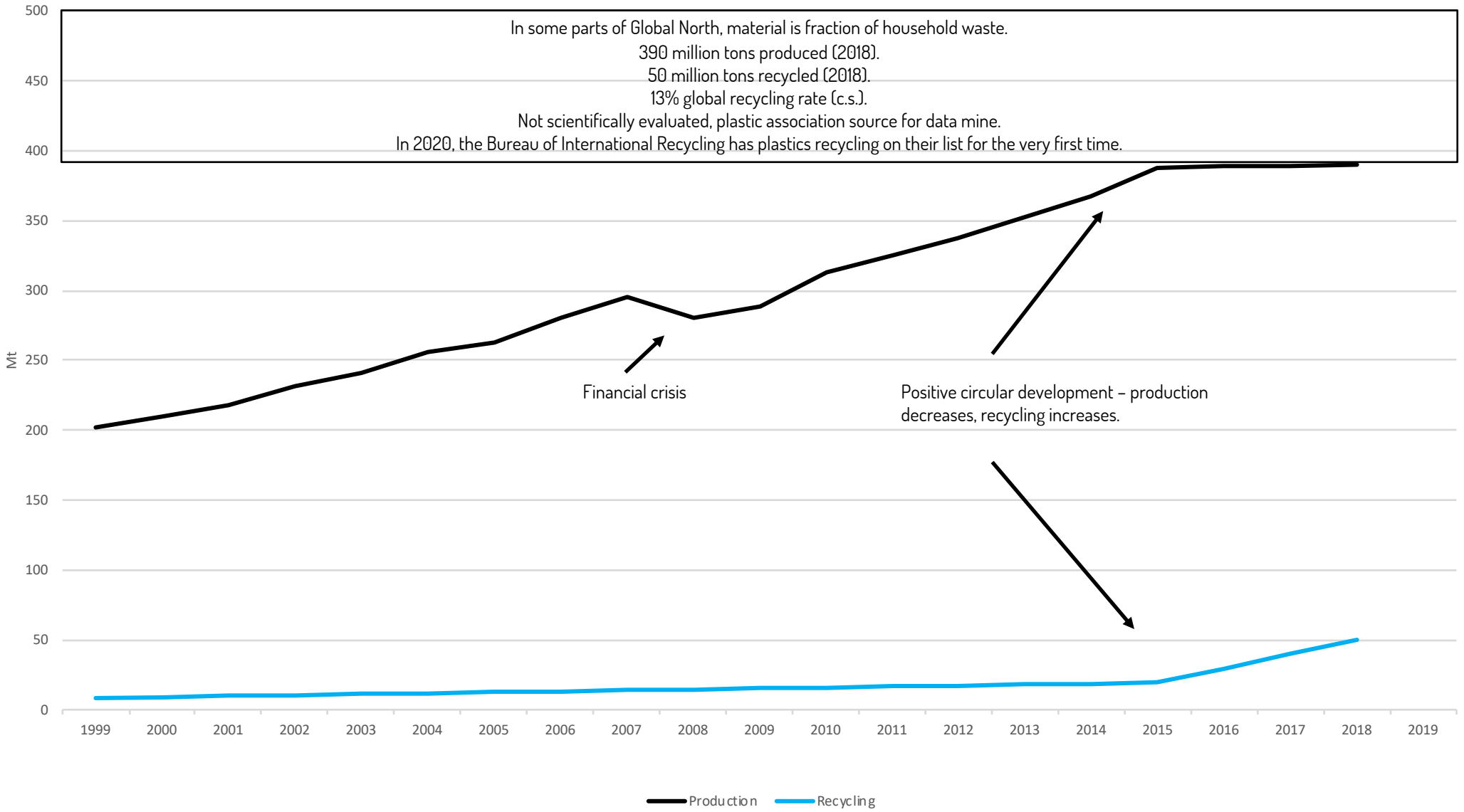
13% global recycling rate (c.s.).

Not scientifically evaluated, plastic association source for data mine.

In 2020 the Bureau of International Recycling has plastics recycling on their list for the very first time.

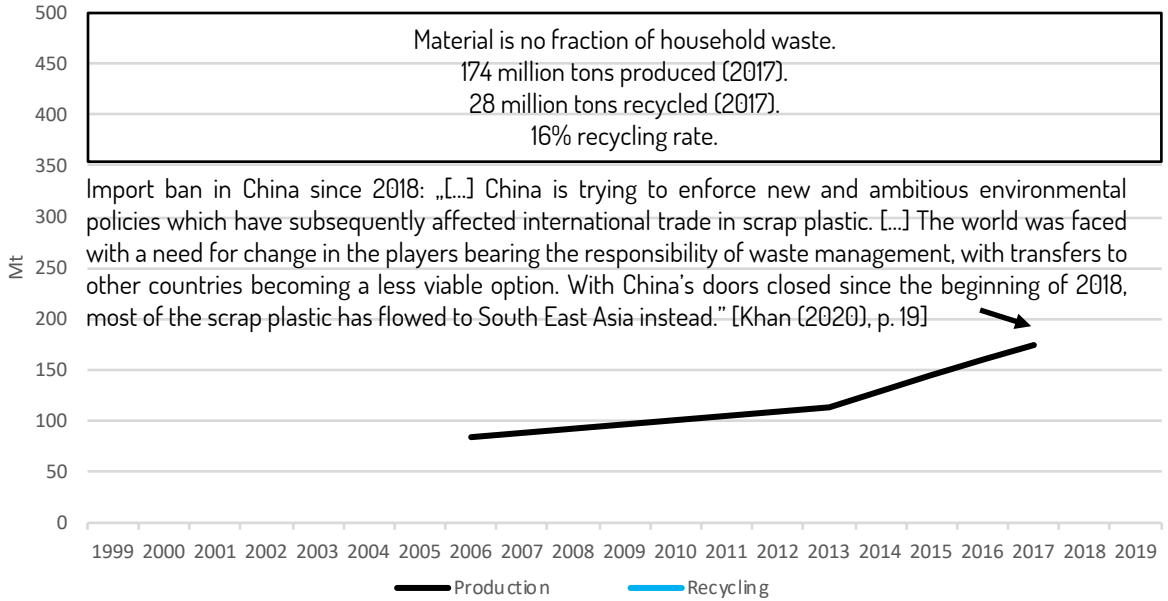
Photo by Brian Yurasits from Unsplash.

Historic Development of Plastics Recycling in the World

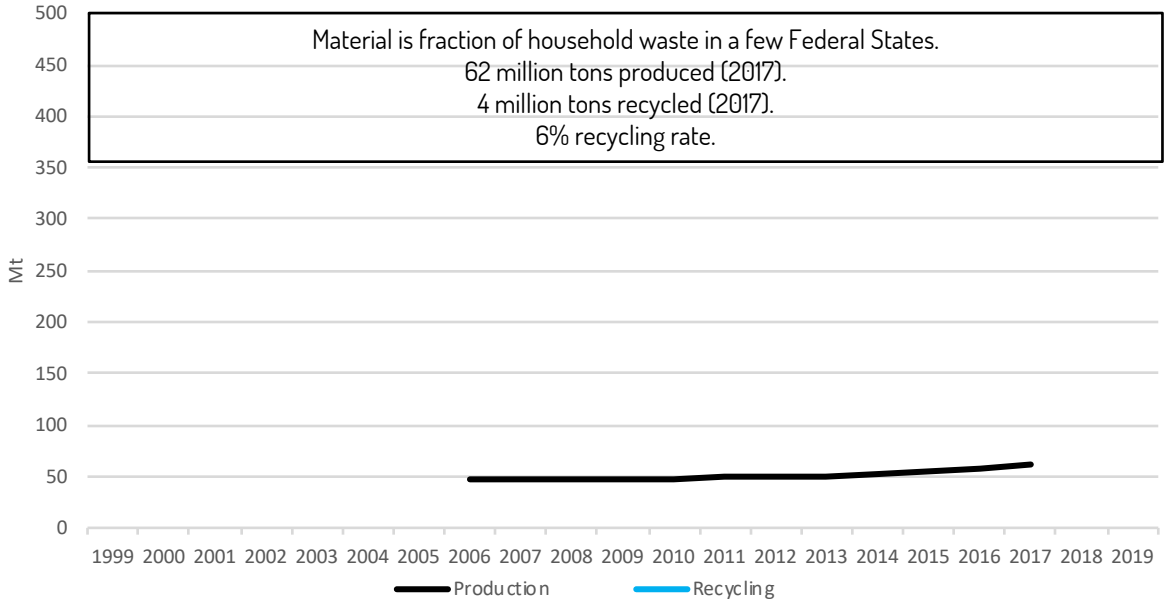


Sources: Conversio Market & Strategy GmbH (2019, pp. 8-10, p. 16) – Khan (2020) - PlasticsEurope - Association of Plastics Manufacturers (2015, pp. 1-2, p. 8) - Ritchie et. al (2018) - Ryberg et. al (2018, pp. 28-29, p. 93).

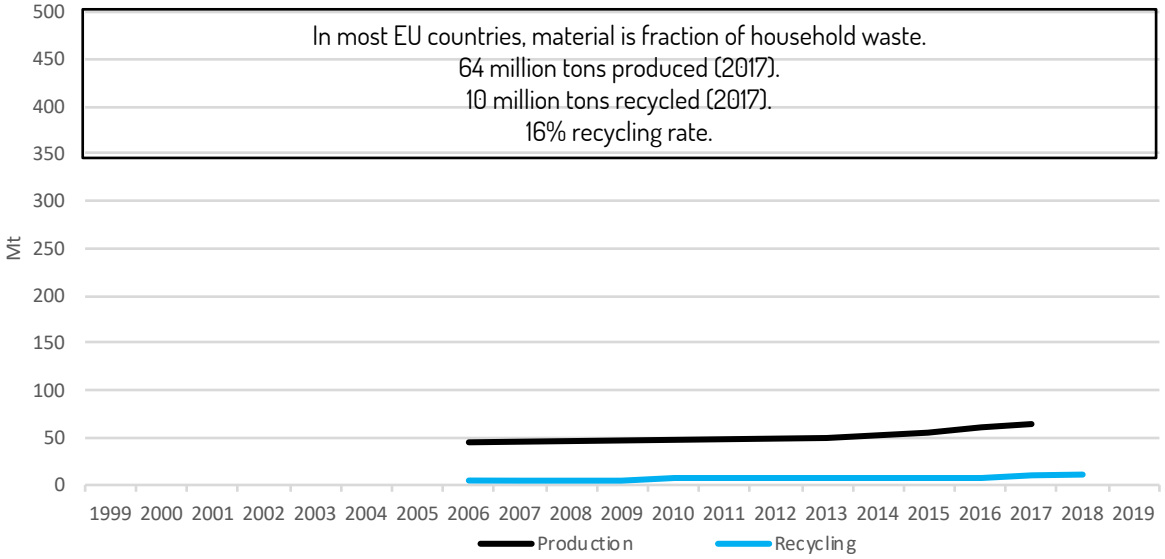
Historic Development of Plastics Recycling in Asia



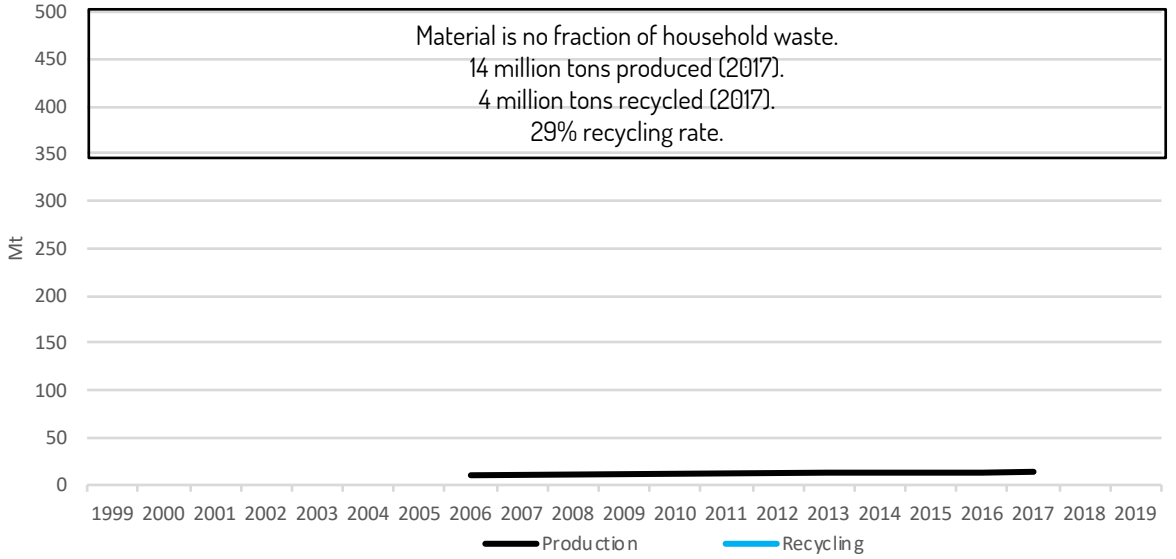
Historic Development of Plastics Recycling in North America



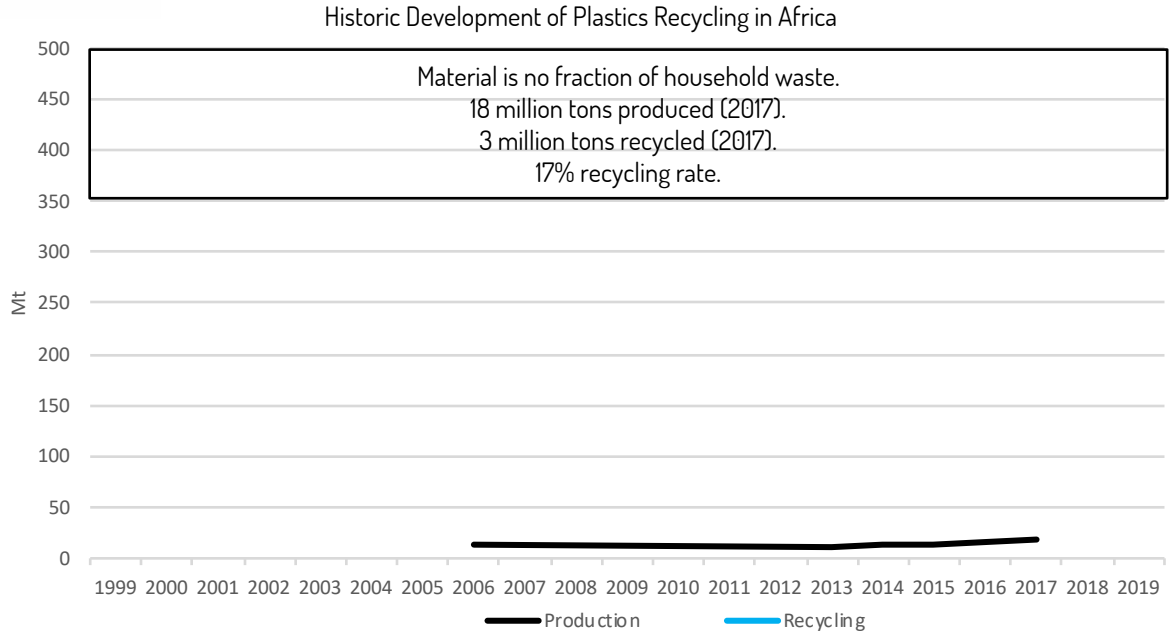
Historic Development of Plastics Recycling in Europe

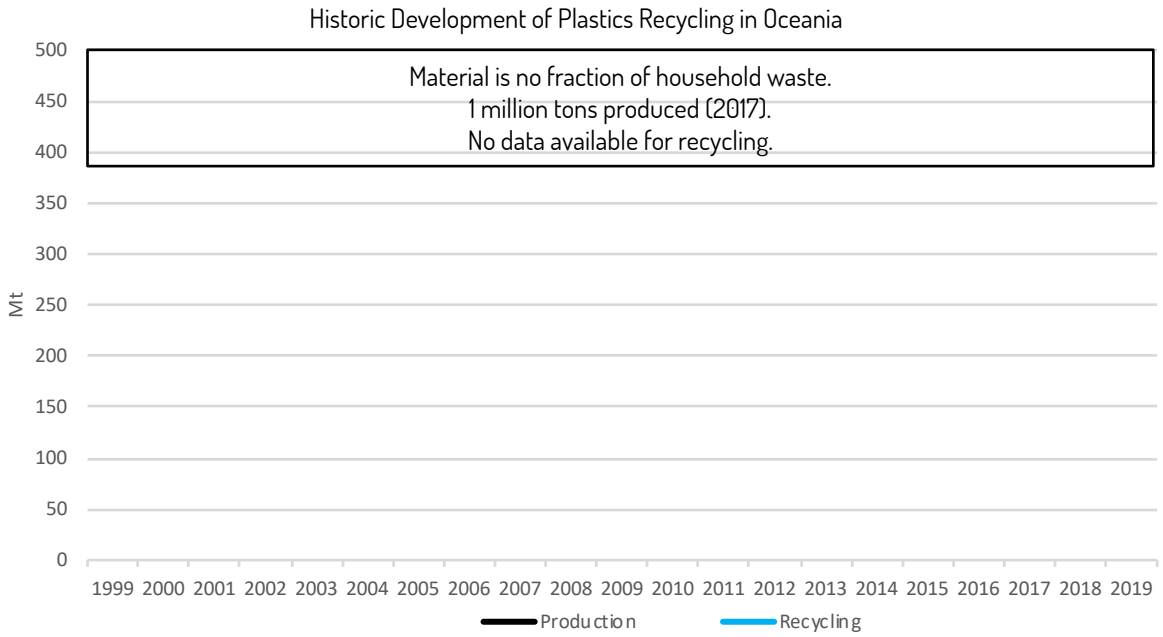


Historic Development of Asphalt Recycling in South America



Sources: Conversio Market & Strategy GmbH (2019, pp. 11-12, p. 15) - Khan (2020, p. 19) - PlasticsEurope - Association of Plastics Manufacturers (2015, p. 2, pp. 7-8) - PlasticsEurope - Association of Plastics Manufacturers (2018, p. 13, pp. 18-19) - Ryberg et. al (2018, p. 11, p. 28, p. 30, p. 34, p. 39, p. 52, p. 93)..





Best available projections:

- Studies focus on the environmental impact of plastics.
- In a Business-As-Usual (BAU) scenario, annual flows of plastic into the ocean could nearly triple by 2040.
- In a BAU scenario where all current industry and government commitments are met, annual flows of plastic into the ocean could be reduced by 7%.
- In a scenario where the world applies and robustly invests in all the technologies, management practices, and policy approaches currently available—including reduction, recycling, and plastic substitution—annual flows of plastic into the ocean could be reduced by 80%.
- Unless the value chain is transformed, the risks for marine species and ecosystems, the climate, the economy, and the communities will become unmanageable.
- There are unique opportunities for governments, businesses, and innovators ready to lead the transition with circular business models.

Sources: Conversio Market & Strategy GmbH (2019, pp. 11-12) - PlasticsEurope - Association of Plastics Manufacturers (2015, p. 2) - Ryberg et. al (2018, p. 30, p. 34, p. 39, p. 52, p. 93) - The Pew Charitable Trusts and SYSTEMIQ (2020, p. 4, p. 48).

Rating card

Plastics	Maturity of market	Design4CE compliance in legislation / jurisdiction	Availability of RE-Tech.	Level of knowledge and cognition for CE
World				
China / Asia				
USA / North America				
Europe				
South America				
Africa				
Australia / Oceania				

Plastics in a nutshell:

- Plastics - just as metals and paper – is affected by China's Green Fence strategy as part of its environmental reform movement to deal with it's growing waste problems.
- And not only China is discussing on how to deal with plastics waste. Many other countries in the world are posing bans and restriction, especially in terms of plastic bags.
- The movement is clearly correlated to the research that was conducted in the past few years to study the ecological impact of plastics. Major topics of interest are microplastics and marine litter.
- Still, recycling data is lacking in most regions of the world, except Europe. It is expected, that data collection will become more important in the next years as pressure is rising.
- How to deal with plastics is not only a political topic but a topic that absorbs media in questions of ecological impact and health impact.
- Today, plastics comes into focus for many people as it has become an emotional debate on systemic implications of economic decisions.

5

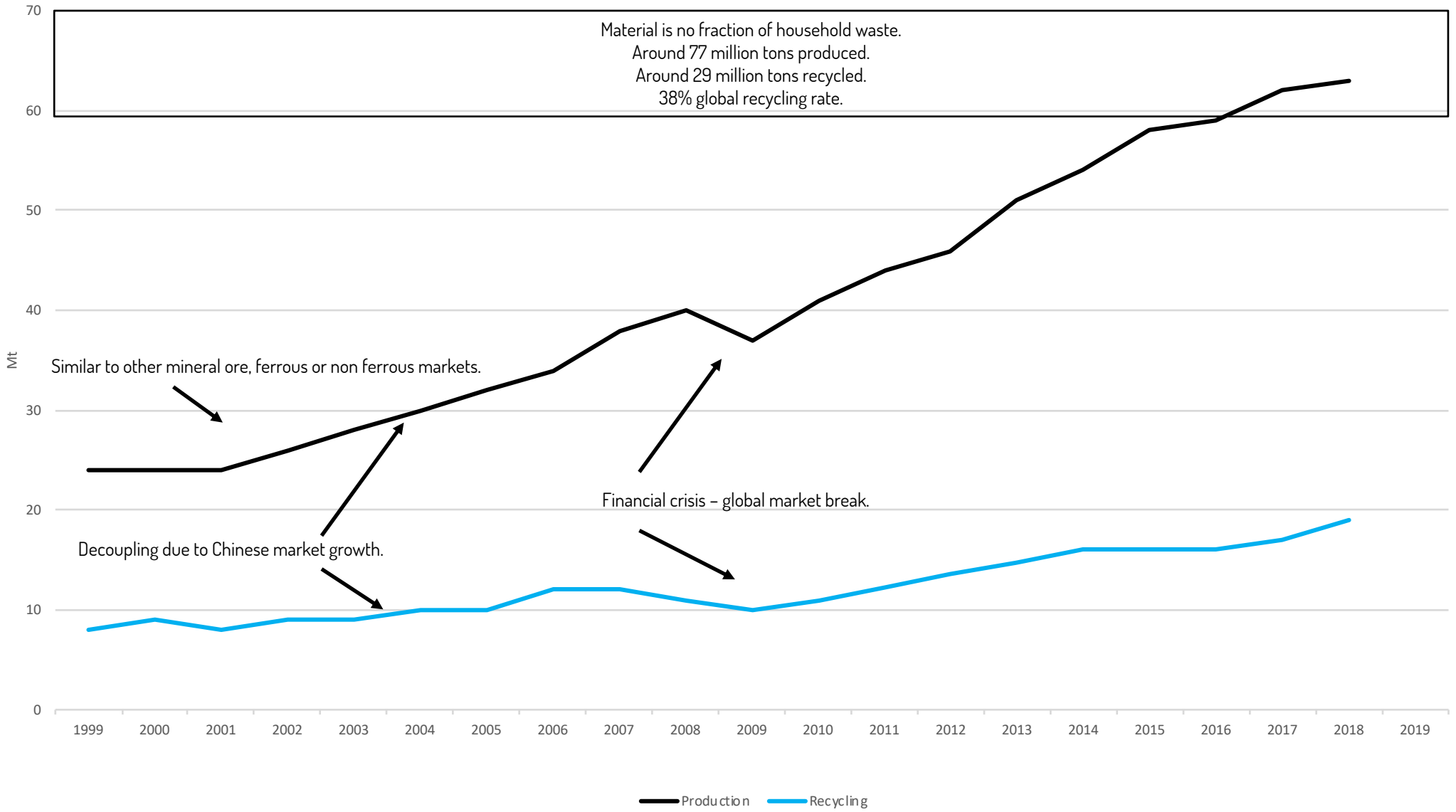
Around 77 million tons produced.

Around 29 million tons recycled.

38% global recycling rate.

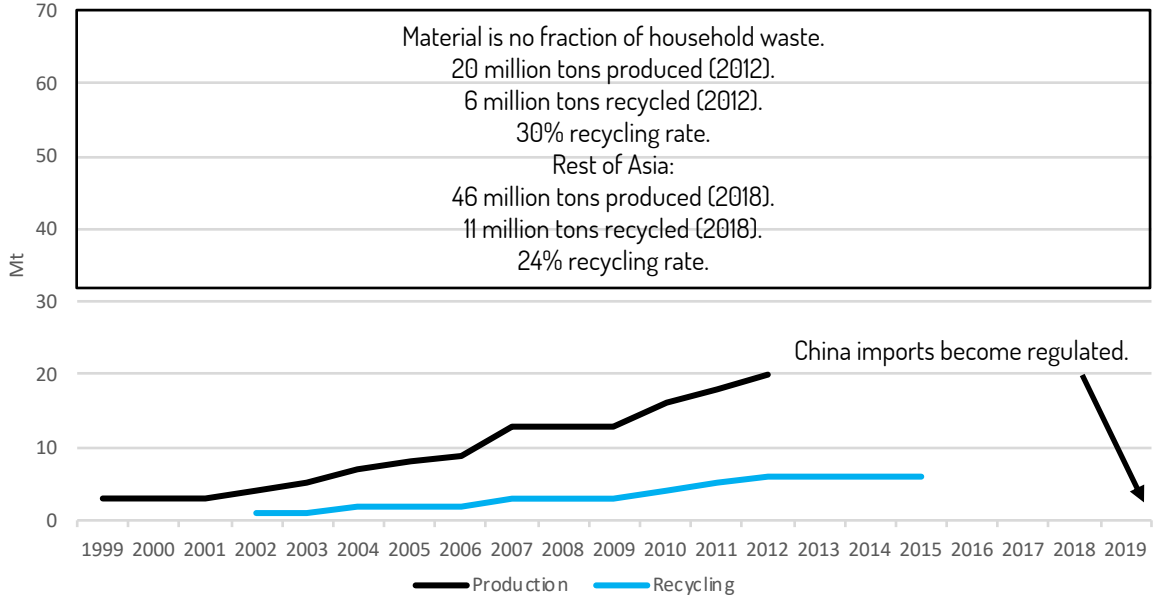
Photo by Alexas Fotos from Pixabay.

Historic Development of Aluminum Recycling in the World

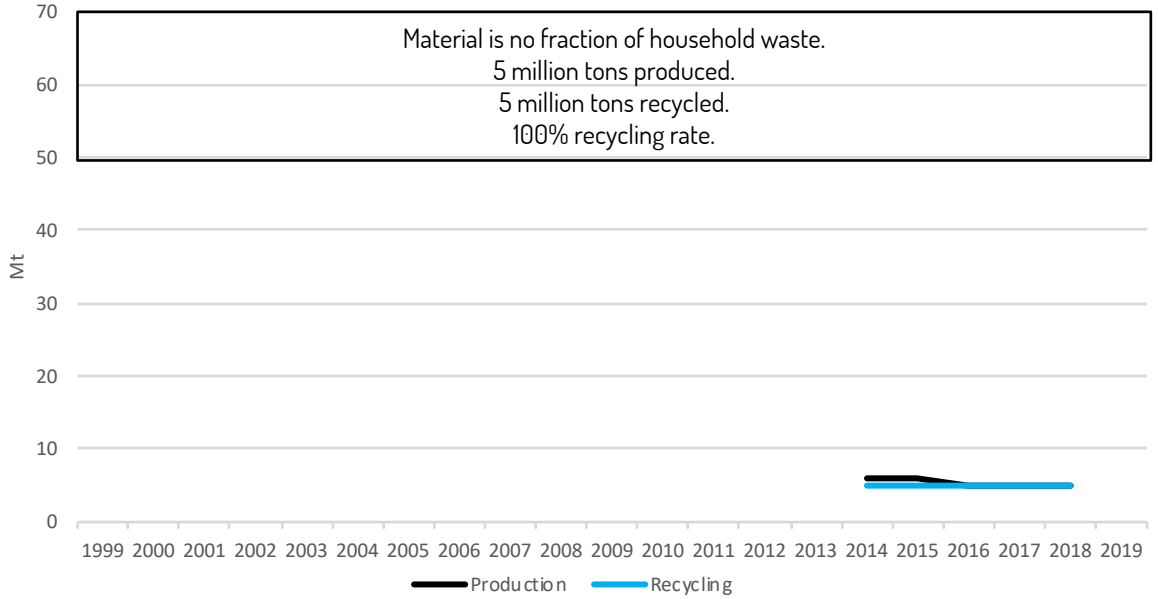


Sources: Barry et. al (2013, Table 4) - Gesamtverband der Aluminiumindustrie e.V. (2019) - Impol Group (2005, p. 22) - Impol Group (2006, pp. 20-21) - Impol Group (2007, pp. 18-19) - Impol Group (2008, p. 16) - Impol Group (2009, pp. 23-24) - Impol Group (2010b, p. 23) - Impol Group (2010b, pp. 23-24) - Impol Group (2012, p. 23) - Impol Group (2013, p. 25) - Impol Group (2014, pp. 27-28) - U.S. Geological Survey (2015).

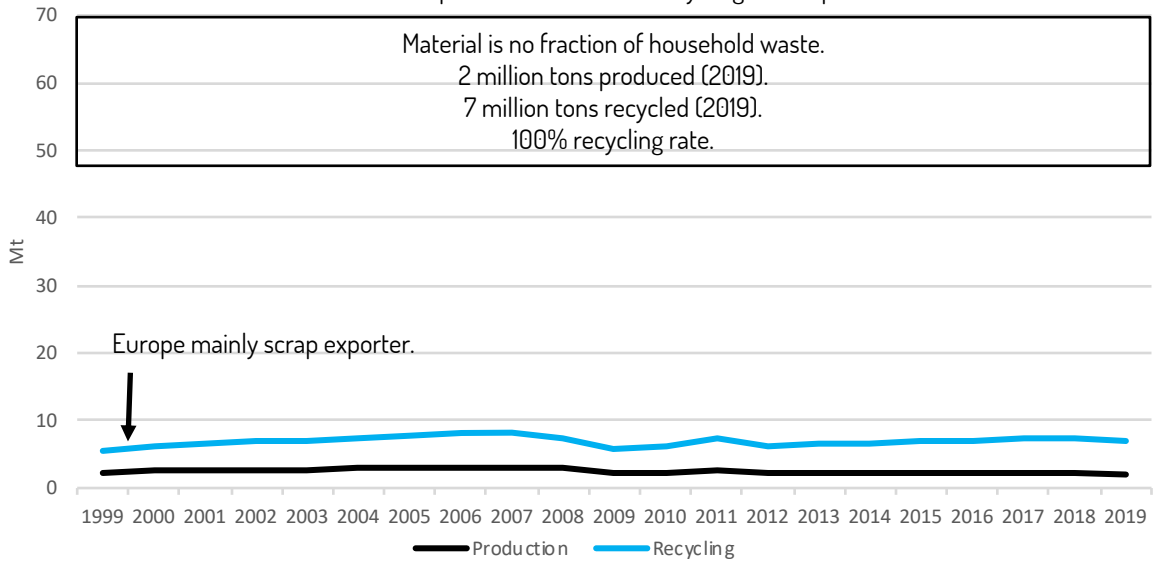
Historic Development of Aluminum Recycling in China



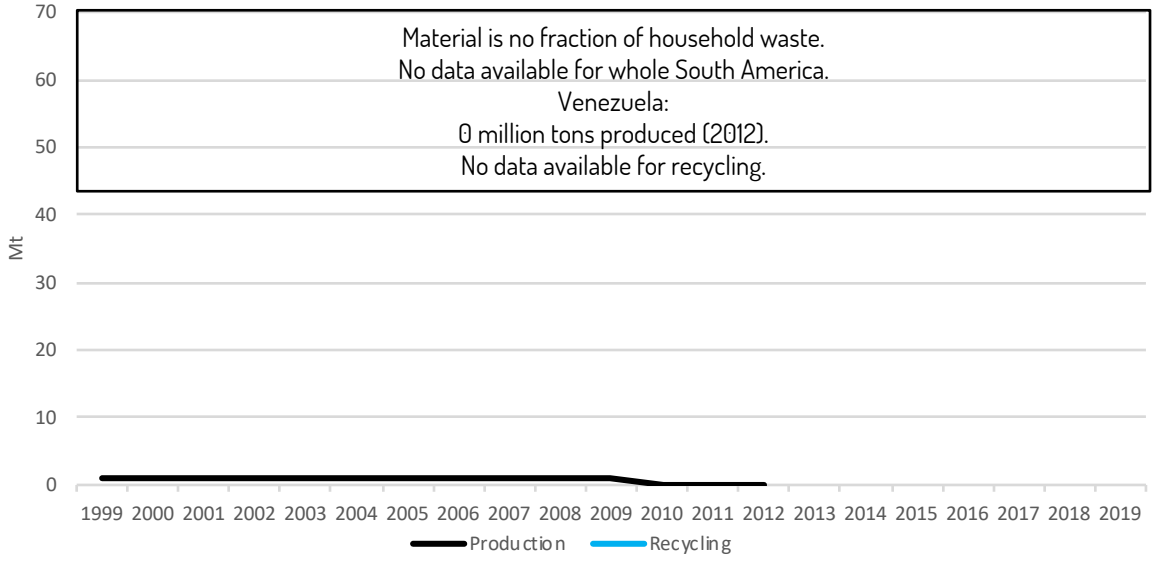
Historic Development of Aluminum Recycling in North America



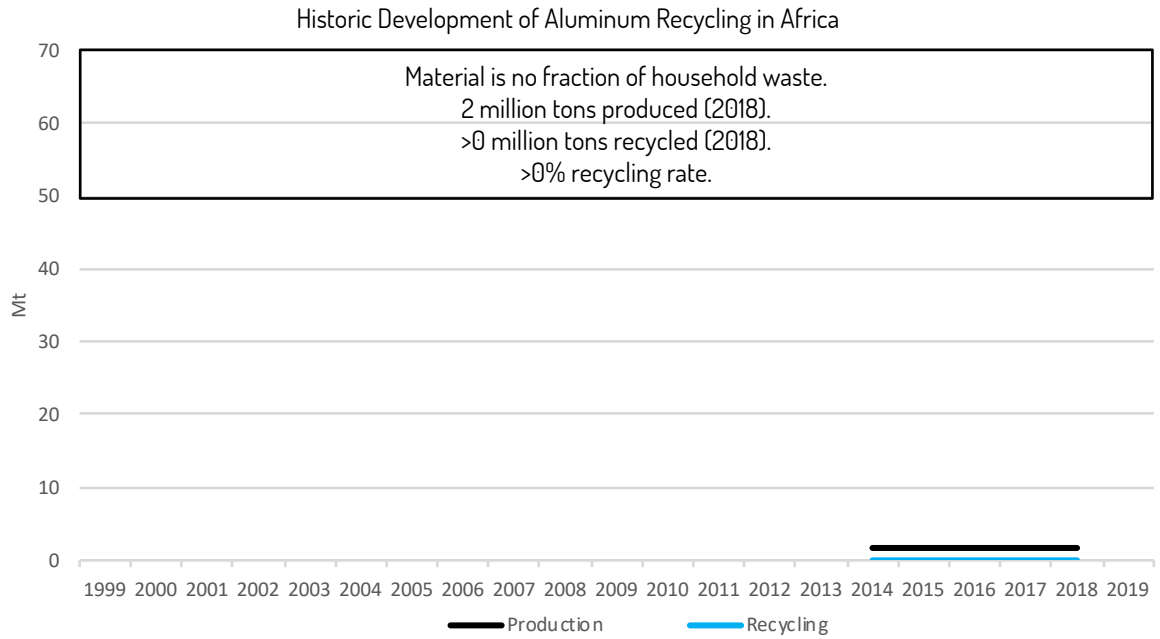
Historic Development of Aluminum Recycling in Europe

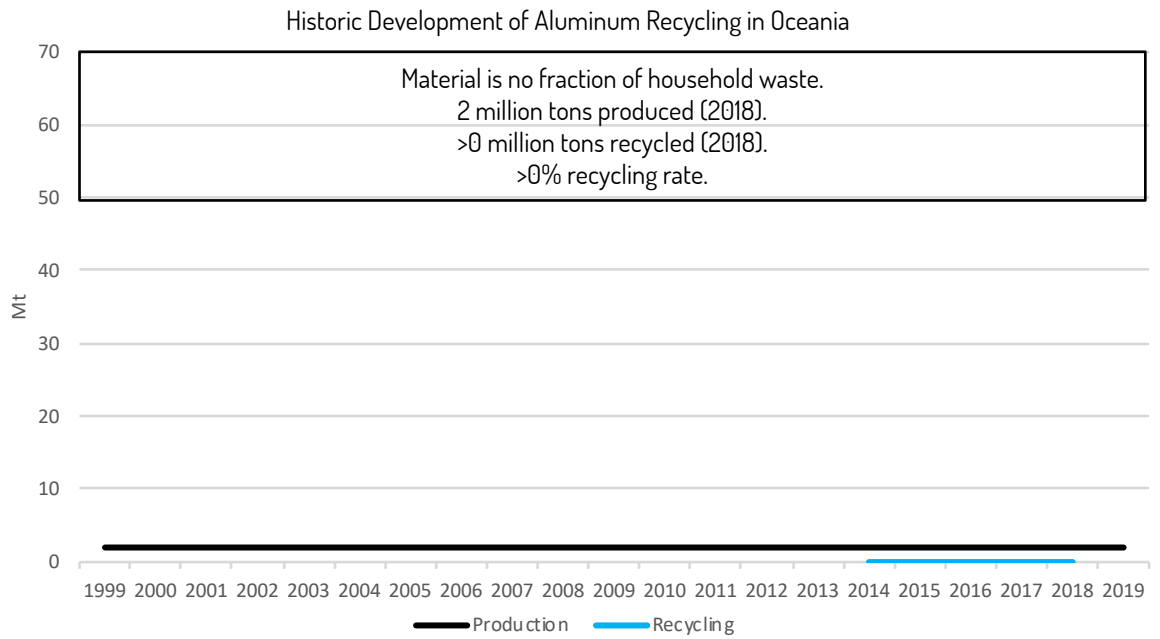


Historic Development of Aluminum Recycling in Venezuela



Sources: Barry et. al (2013, Table 4) - European Aluminum Association (2020a, pp. 8-9) - European Aluminium Association (2020b) - Gesamtverband der Aluminiumindustrie e.V. (2019) - Hatayama et. al (2009, p. 654-656) - U.S. Geological Survey (2015) - Wei (2015, p. 3, pp. 14-15, p. 17).





Best available projections:

- The growth in aluminum usage in transportation, the decline in beverage can recycling, and the increasing reliance of the domestic fabrication industry on secondary aluminum have created new needs in materials design and processing.
- The importance of mixed scrap streams in the makeup of secondary aluminum increases.
- Maximizing the cost-effectiveness and efficiency of recycling processes should lead to extended life-cycle advantages of aluminum alloys.
- The usefulness of directly recycled alloys and the amount of metal that is directly reused without the addition of primary metal would increase.
- In scenario analysis for aviation, aluminum will be the dominant material for short range operation aircraft and composites for long haul.
- Looking at a long-term perspective, scenarios lead to composites as the dominant material.
- Aluminum-alloying technology has almost reached the ceiling of its technological maturity, while composites is yet probably at half the way.

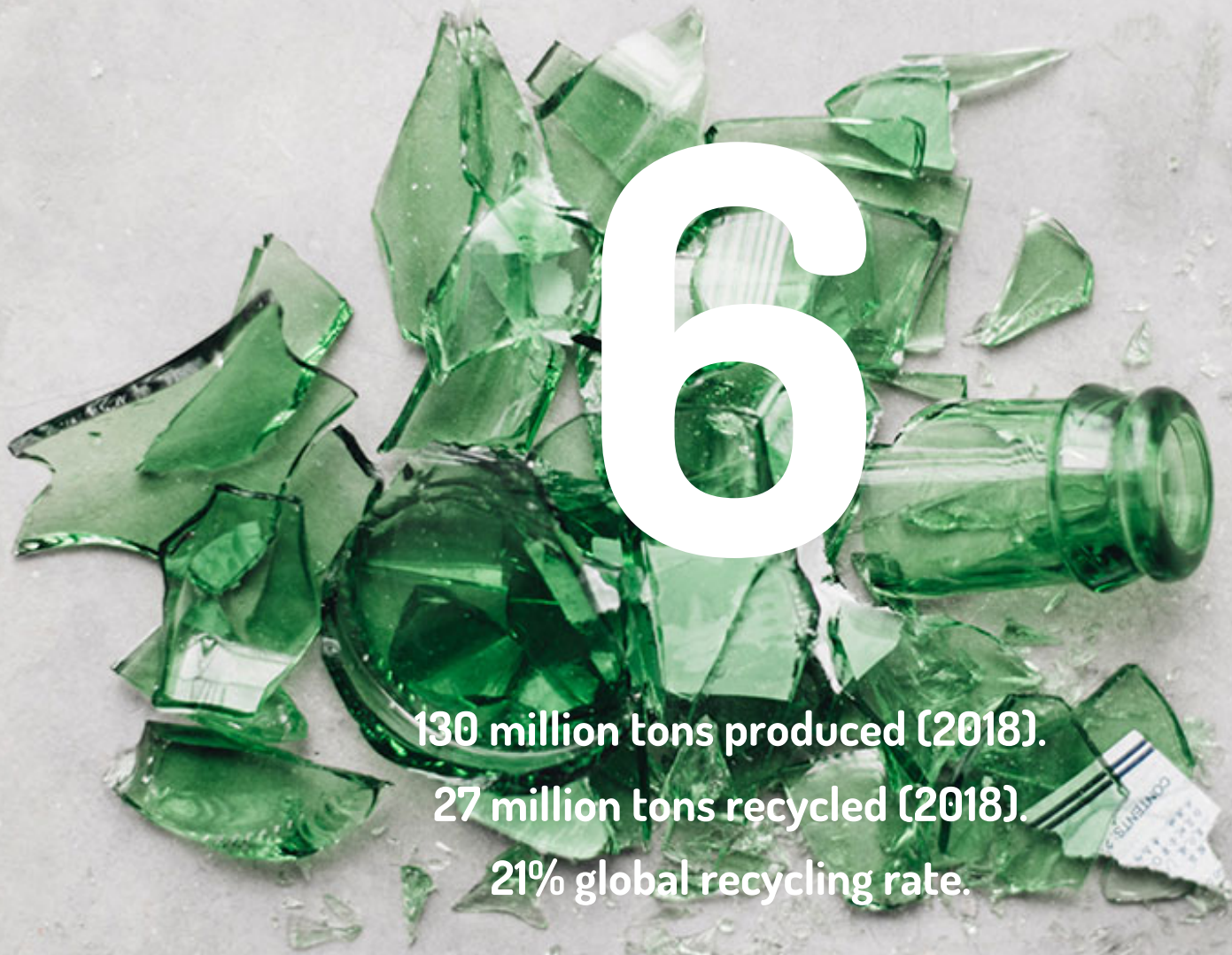
Sources: Bundesanstalt für Geowissenschaften und Rohstoffe (2013, p. 2) - Das (2006, p. 1, p. 5) - Devezas (2020, pp. 8-9) - Gesamtverband der Aluminiumindustrie e.V. (2019) – Shu et. al (2011) - U.S. Geological Survey (2015).

Rating card

Aluminium	Maturity of market	Design4CE compliance in legislation / jurisdiction	Availability of RE-Tech.	Level of knowledge and cognition for CE
World				
China / Asia		Political announcement for Circular Economy.		
USA / North America				
Europe				
Venezuela / South America				
Africa				
Australia / Oceania				

Aluminum in a nutshell:

- Aluminum has a similar background to steel.
- In Europe, the recycling of aluminum is a common practice.
- Due to it's high recyclability, aluminum becomes more and more important for eco-concerns as it is lighter than glass (reducing CO2-emissions during transportation) and doesn't involve such strong ecological and health impacts like plastics.
- Since a few years, aluminum competes with composites due to the flexible composition of the material.
- In terms of recycling, mono-materials like aluminum are to be preferred.
- China's ferrous import ban also means imports of aluminum scrap.



6

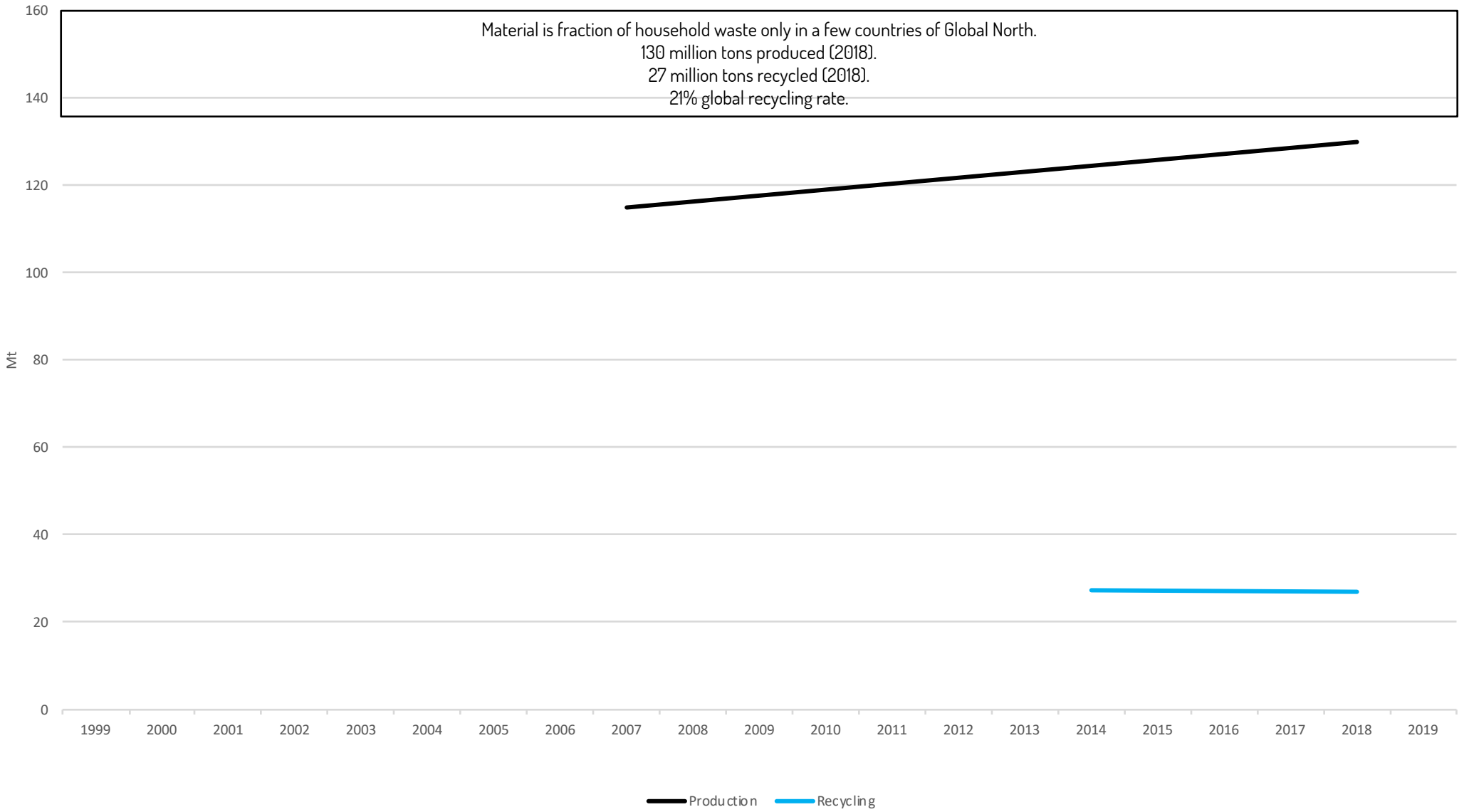
130 million tons produced (2018).

27 million tons recycled (2018).

21% global recycling rate.

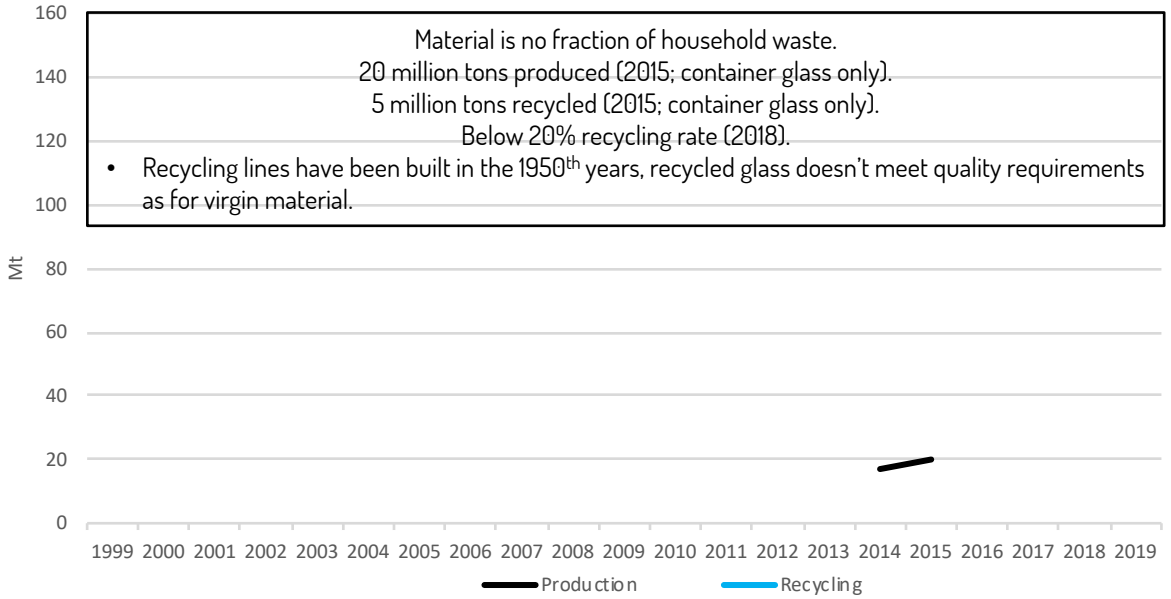
Photo by Chuttersnap from Unsplash

Historic Development of Glass Recycling in the World

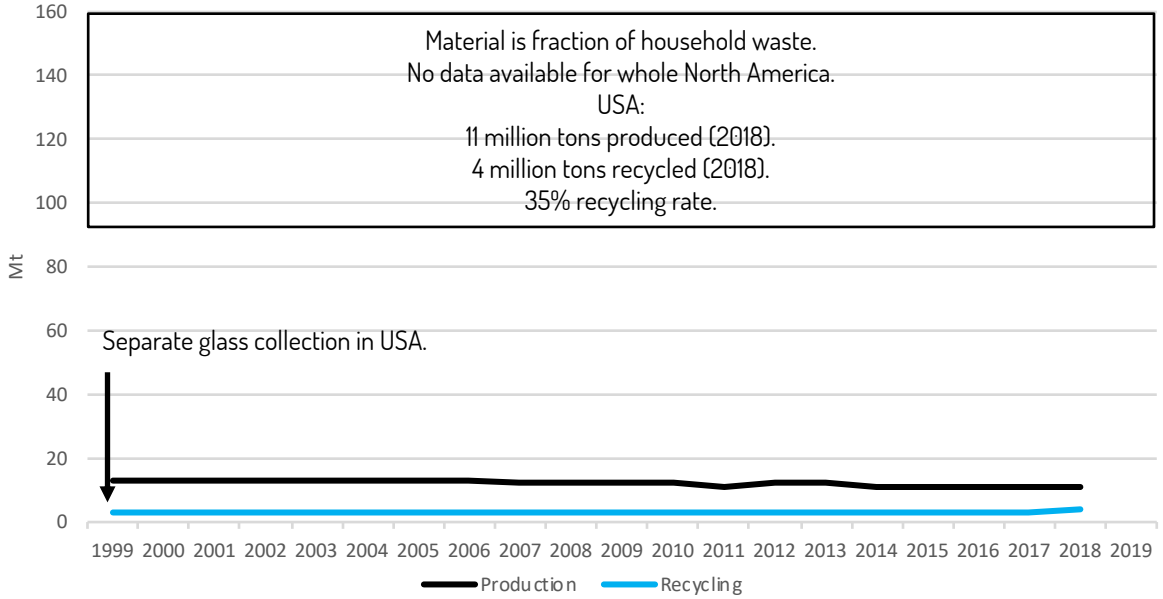


Sources: Butler et. al (2019, p. 308, p. 313) - Kaza et. al (2018, p. 25, p. 29) - Wintour (2015, p. 1).

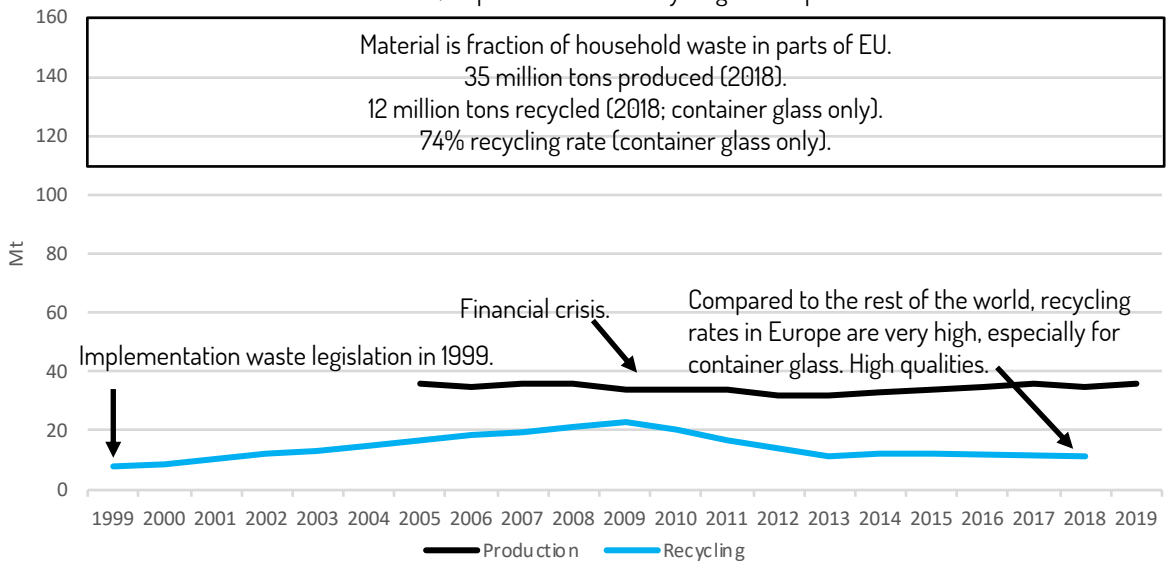
Historic Development of Glass Recycling in China



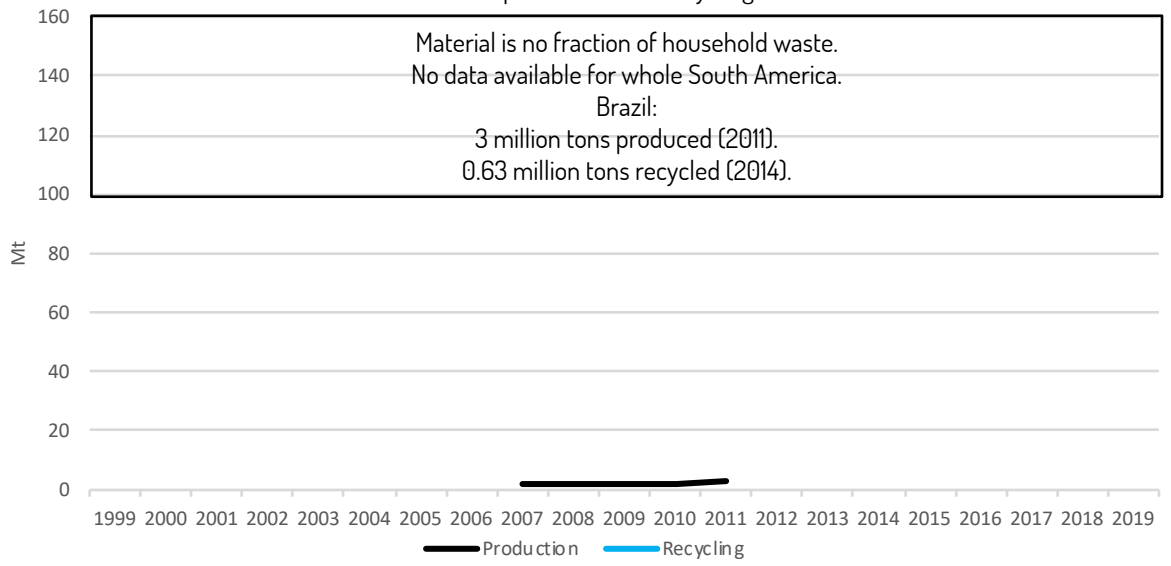
Historic Development of Glass Recycling in the USA



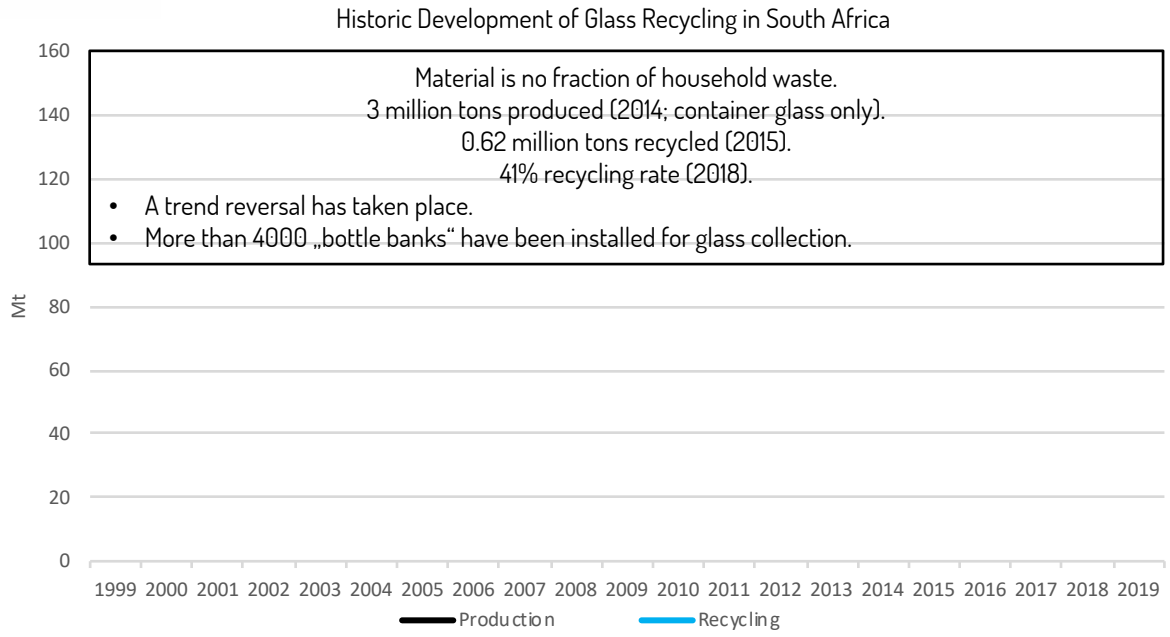
Historic Development of Glass Recycling in Europe

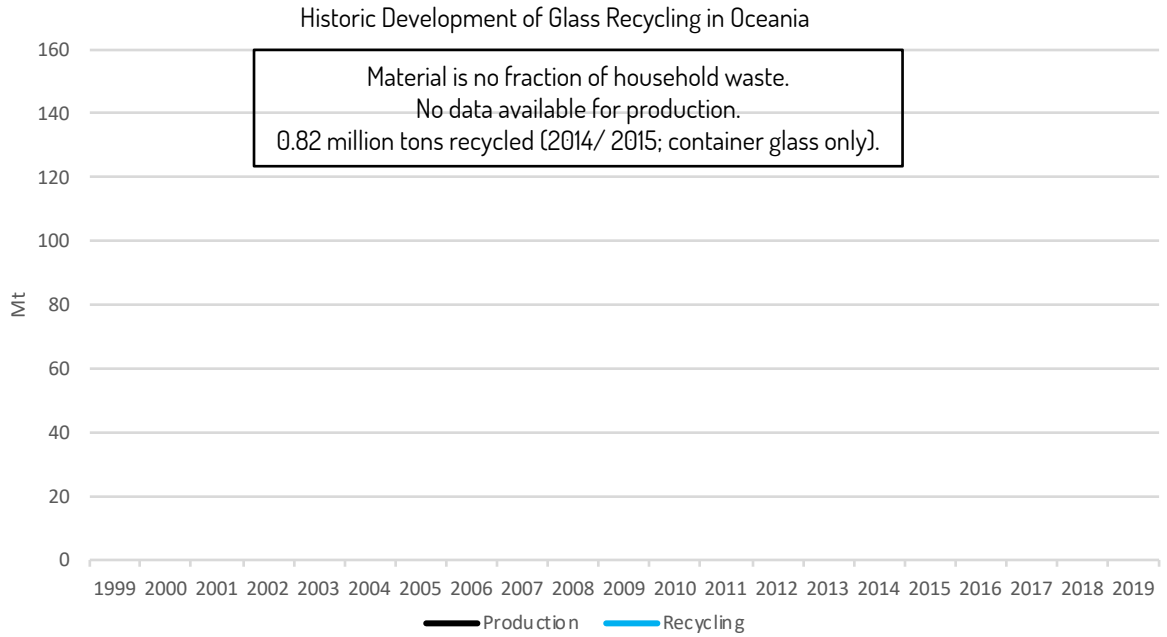


Historic Development of Glass Recycling in Brazil



Sources: Association of Cities and Regions for Recycling and Sustainable Resource Management et. al (2012, p. 26) - Bundesverband Sekundärrohstoffe und Entsorgung e.V., Fachverband Glasrecycling (2016) - Bundesverband Sekundärrohstoffe und Entsorgung e.V., Fachverband Glasrecycling (2018) - Butler et. al (2019, p. 308, p. 316) - Gonzáles-Torre (2002, p. 3) - Hohmann (2020) - United States Environmental Protection Agency (2014, pp. 1-2) - United States Environmental Protection Agency (2016, pp. 1-2) - United States Environmental Protection Agency (2020) - Wintour (2015, p. 10).





Best available projections:

- 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 environmental 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.
- Glass bottles could contribute to reduce marine litter.
- Great improvements can be obtained using bottles made with recycled materials, as R-PET.
- It is necessary to disadvantage waste dispersion, giving incentives to returnable packaging and raising people's awareness of eco impacts.

Sources: Butler et. al (2019, p. 308, p. 313) – Stefanini et. al (2020, p. 1).

Rating card

Glass	Maturity of market	Design4CE compliance in legislation / jurisdiction	Availability of RE-Tech.	Level of knowledge and cognition for CE
World				
China				
USA				
Europe				
Brazil / South America				
South Africa / Africa				
Australia / Oceania				

Glass in a nutshell:

- For Europeans, glass recycling is very present due to the infrastructure of glass containers for collection. For North Americans, glass recycling is just as normal as for Europeans.
- For the rest of the world, surprisingly, it is not common at all. Most countries are lacking infrastructure to collect glass for recycling and don't understand its economic value.
- Data gaps only leave room for interpretation: It seems like economies didn't realize sand scarcity, yet.
- As for the other materials, glass is also part of eco-discussions. Its recyclability and easy collection offer great potential.
- Anyhow, glass is quite heavy, which is leading to higher CO2 emissions during transportation, which is why glass is supporting the argument of regional economies.

7

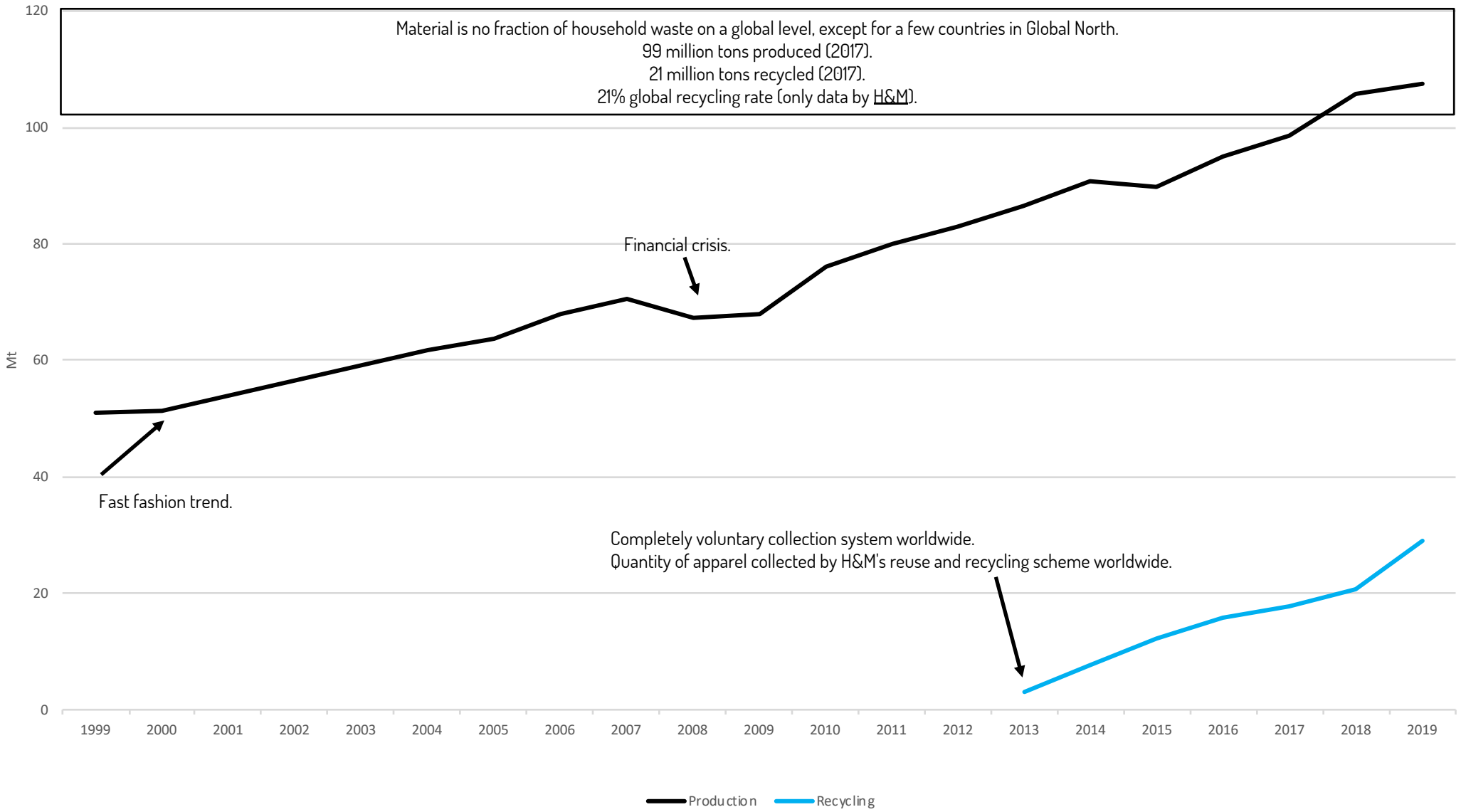
99 million tons produced (2017).

21 million tons recycled (2017).

21% global recycling rate (only data by H

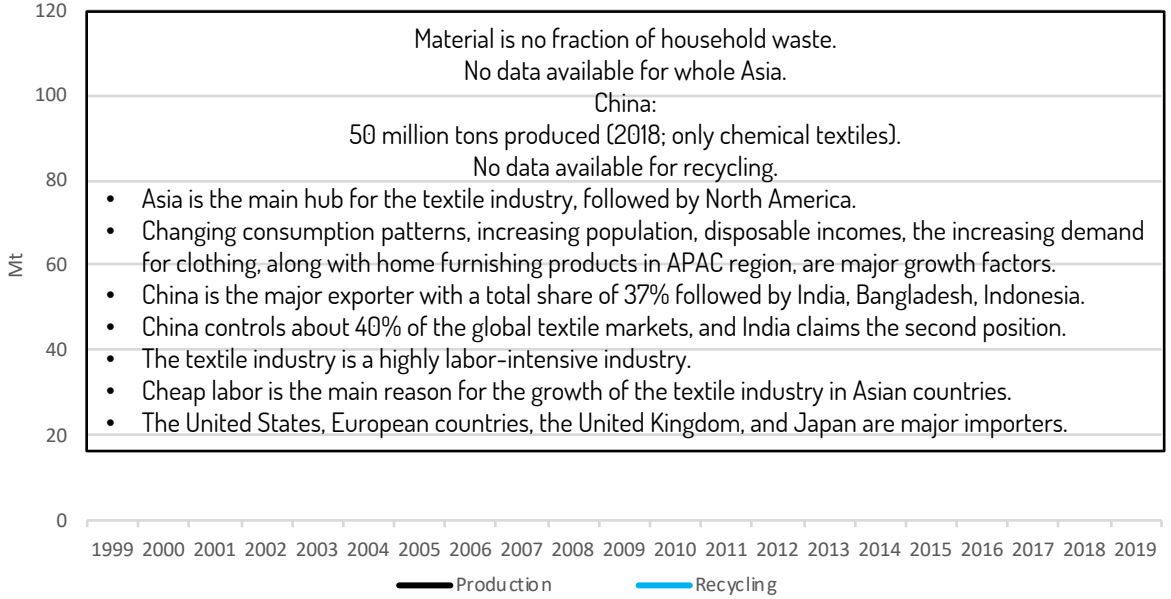
Photo by BVSE – Fachverband Textilrecycling

Historic Development of Textiles Recycling in the World

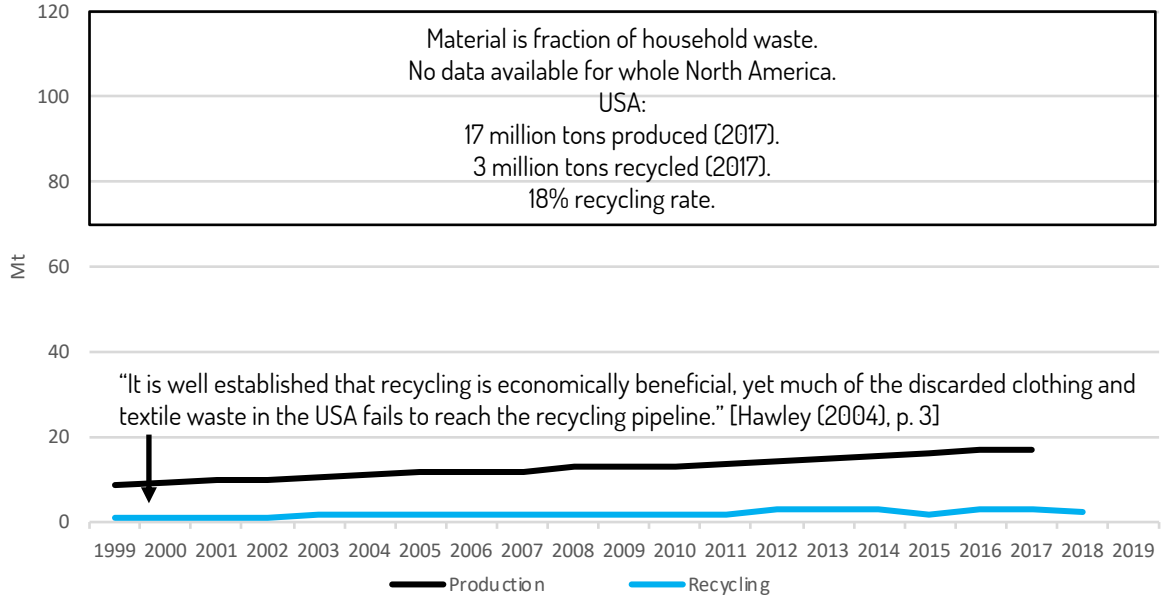


Sources: Garside (2020c) – H&M Group (2019b, p. 26) – Shahbandeh (2020).

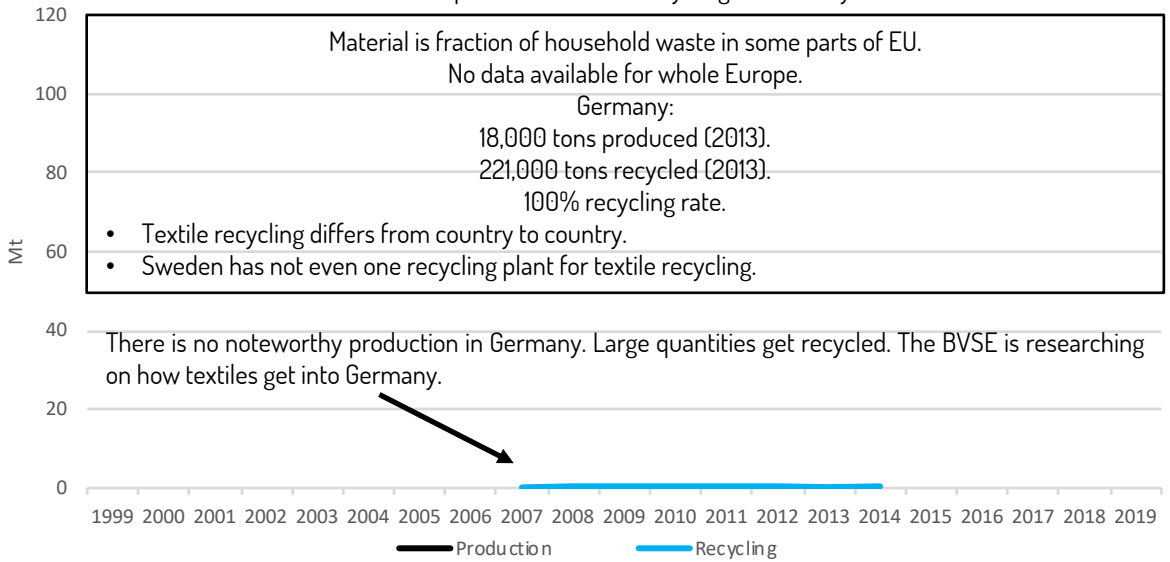
Historic Development of Textiles Recycling in Asia



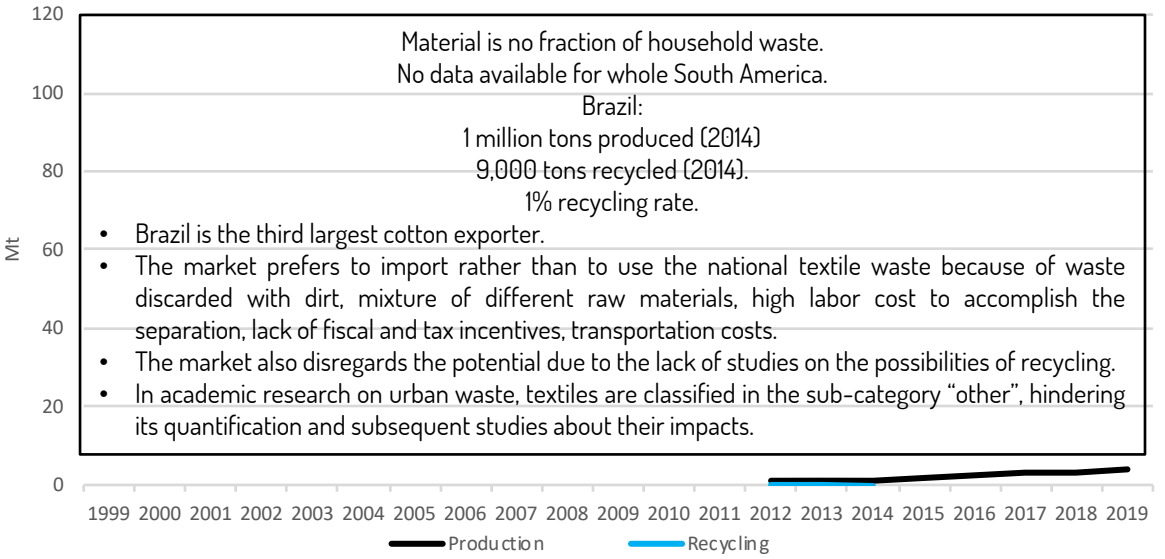
Historic Development of Textiles Recycling in the USA



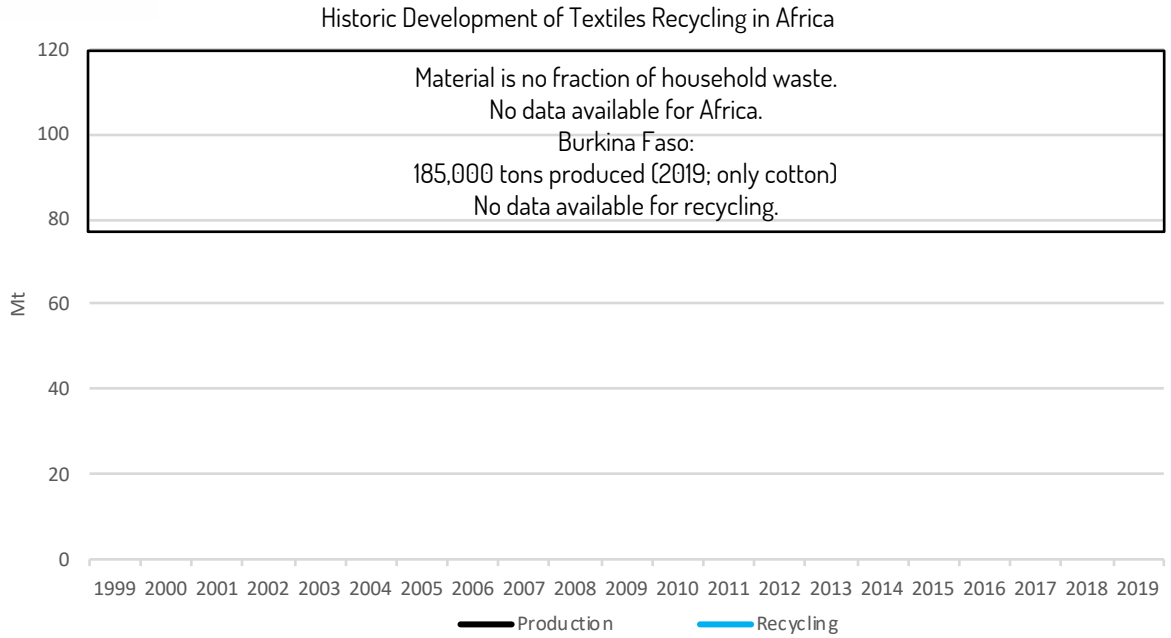
Historic Development of Textiles Recycling in Germany

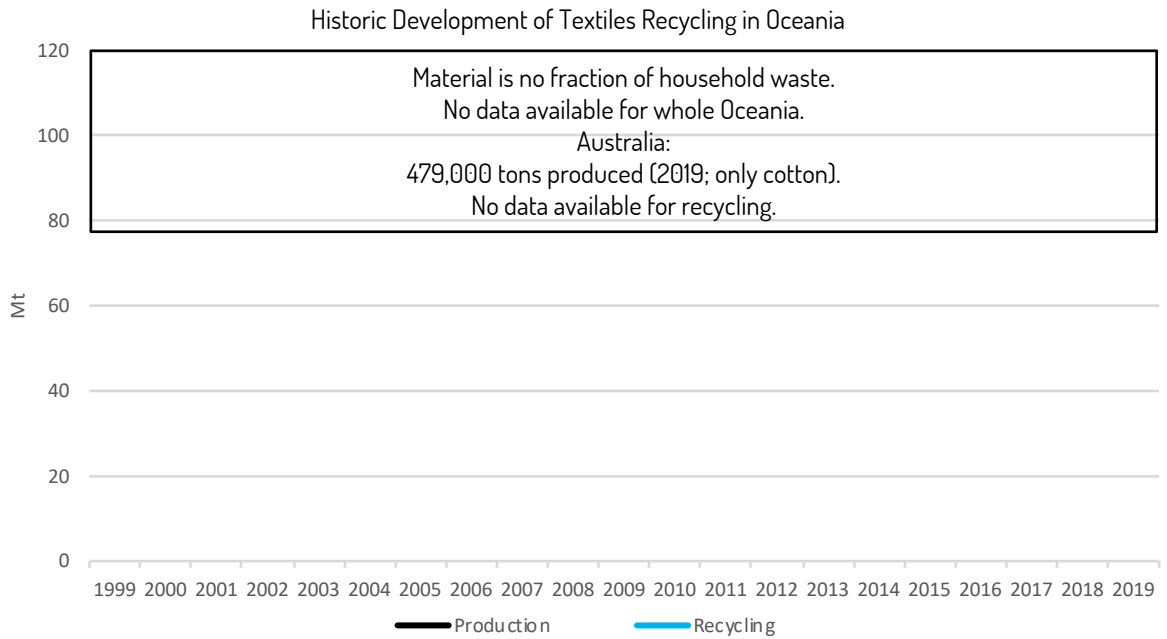


Historic Development of Textiles Recycling in Brazil



Sources: Bundesverband Sekundärrohstoffe und Entsorgung e.V., Fachverband Textilrecycling (2015, p. 1, p. 20, p. 23, p. 32) - Do Amaral et. al (2018, p. 2, p. 4, p. 6, pp. 8-9) - Fairwertung.de (2016) - United States Environmental Protection Agency (2016, p. 8) - United States Environmental Protection Agency (2019, pp. 1-2) - United States Environmental Protection Agency (2020a, pp. 1-2) - Wright (2020) - Zamani et. al (2015, p. 1).





Best available projections:

- Apparel companies are increasingly investigating circular fashion models including the recycling and upcycling of textiles.
- European consumers are increasingly conscious about the impact of purchasing fast fashion.
- The recycling trend is expected to accelerate.
- Manufacturers from developing countries with better technologies and fashionable apparel made from recycled materials will be at advantage.
- There are some promising new technologies that are able to separate the most common blend of cotton and polyester.
- There is a number of companies who are innovating textile recycling, e.g. turn PET bottles and packaging into new textile raw materials.
- Mainstream companies increasingly embrace sustainability and recycling strategies, e.g. H&M, Nike, Patagonia or C&A, offer consumers incentives for returning their used clothing. Adidas, Ralph Lauren and Aquafil have launched collections made of recycled plastic waste.

Sources: Centre for the Promotion of Imports from developing countries (2020) - Wright (2020).

Rating card

Textiles	Maturity of market	Design4CE compliance in legislation / jurisdiction	Availability of RE-Tech.	Level of knowledge and cognition for CE
World				
China / Asia				
USA				
Germany / Europe				
Brazil / South America				
Africa	Second hand market well established.			
Australia / Oceania				

Textiles in a nutshell:

- Textiles is a material group that is highly undervalued and underdeveloped.
- Except than for the USA, there is almost no worldwide interest in the collection and recycling of textiles.
- Main reason is the fast fashion trend. Apparel are status symbol and as long as people can afford new clothing, they prefer to buy first, not second hand.
- In order to satisfy customers who want to have trendy clothes at home, the fast fashion industry focuses on quantity instead of quality.
- For recyclability, the quality leaves a lot to be desired, hindering the qualitative re-manufacturing of worn clothes.
- Along with the slow food, the slow economy and other slow-down trends, textiles experience a reverse trend. Customers are asking for more quality and also want be informed about how the clothes are made in order to make better decisions in terms of ethical and ecological questions.
- Second hand is experiencing an increasingly positive image.
- Textiles are also market place for innovative materials used to make clothes, e.g. plastic bottles.

8

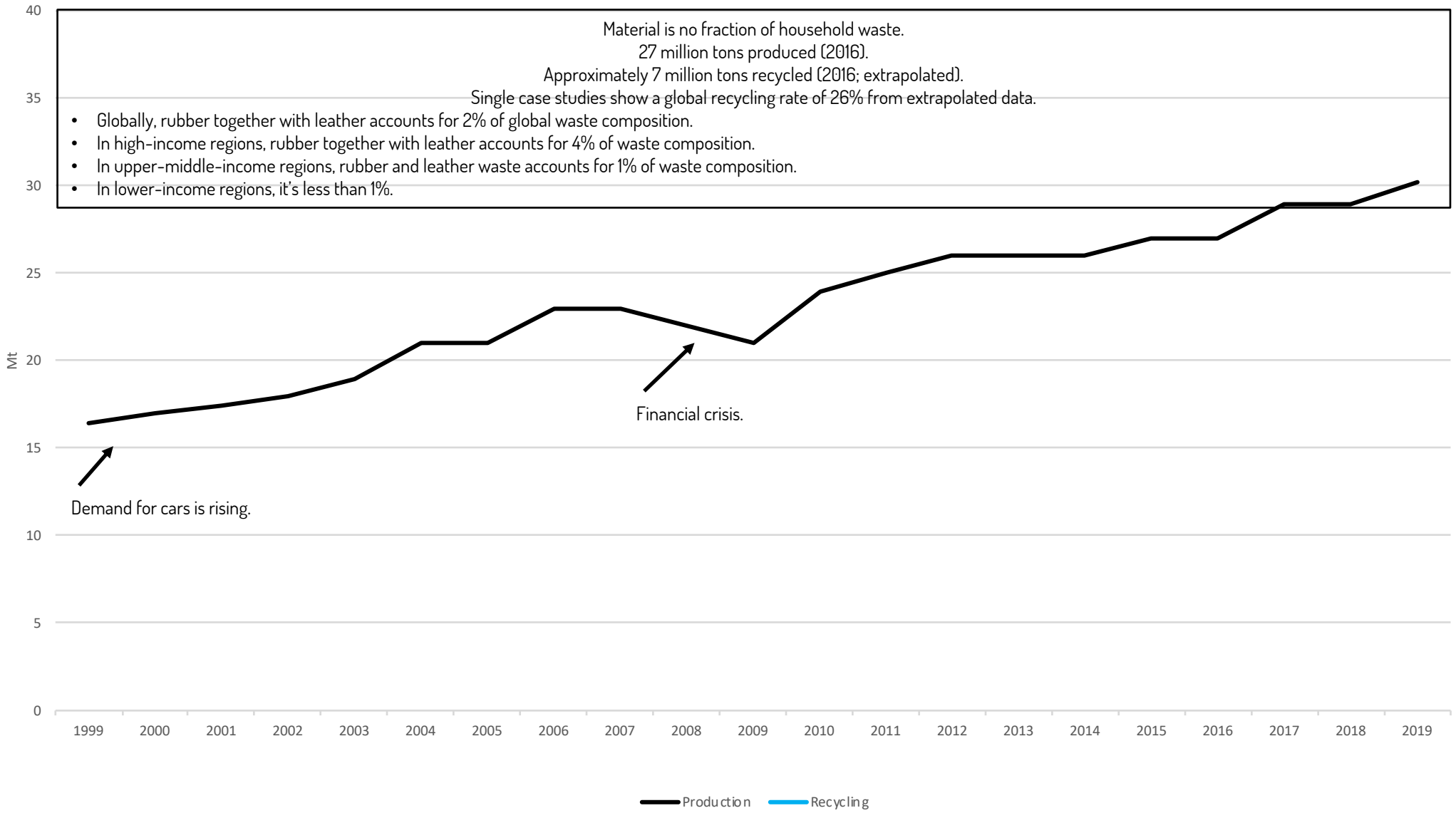
27 million tons produced (2016).

Approximately 7 million tons recycled (2016; extrapolated).

Single case studies show a global recycling rate of 26% from extrapolated data.

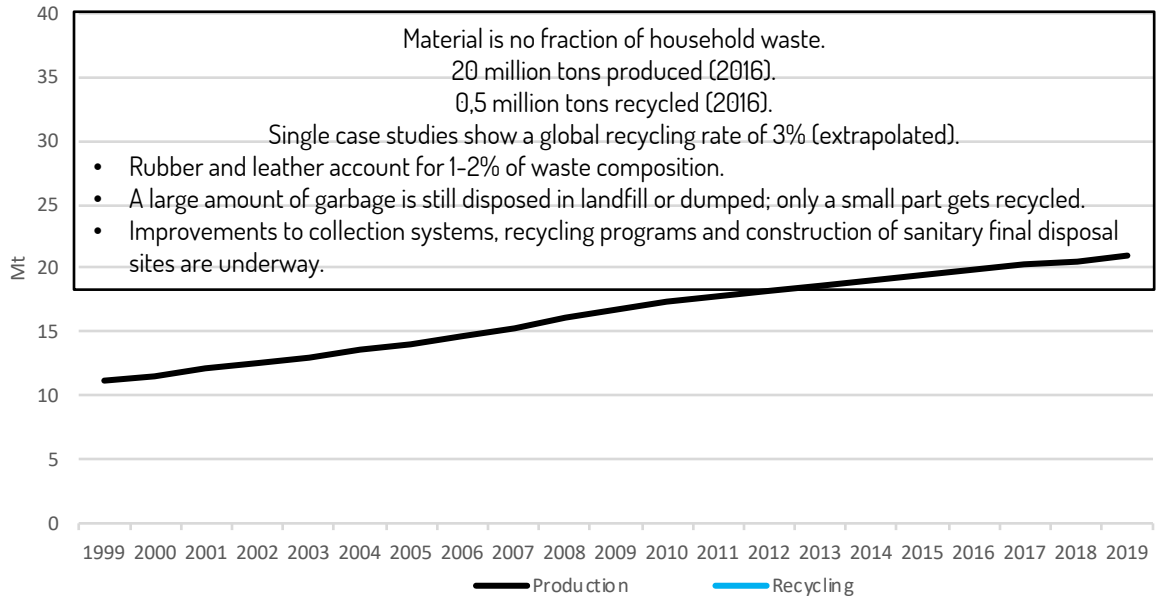
Photo by Tomasz Pro from Pixabay.

Historic Development of Rubber Recycling in the World

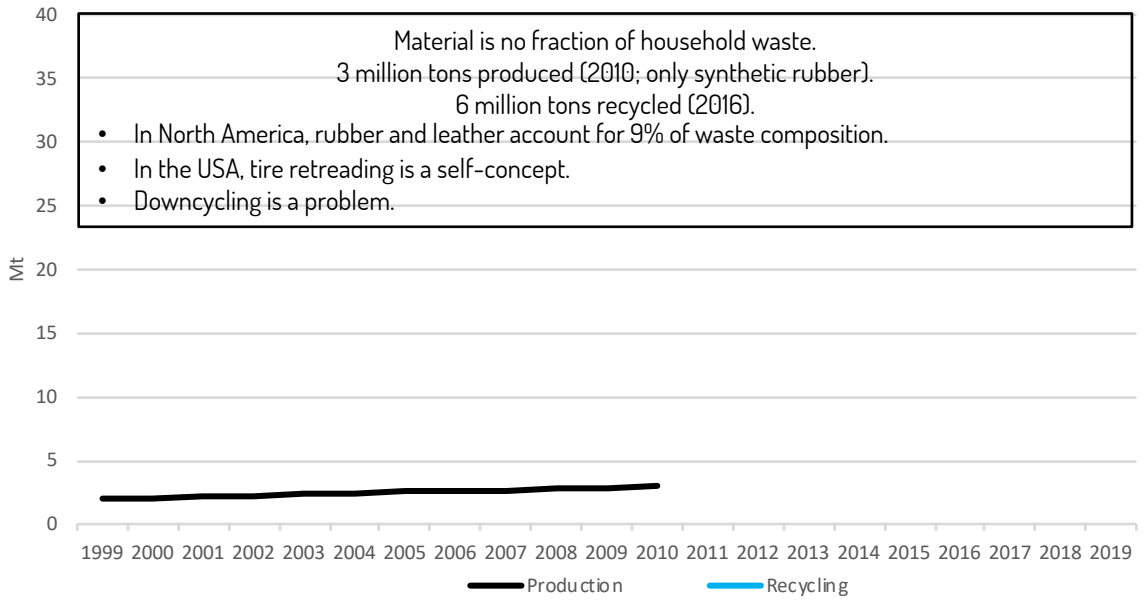


Sources: Garside (2020a) - Grilli et. al (1980, p.19, p.33, p.42, p.80) - Kaza et. al (2018, pp. 29-30) - Lembaga Getah Malaysia, Malaysian Rubber Board (2019, pp. 1-2) - The Rubber Economist Ltd. (2020).

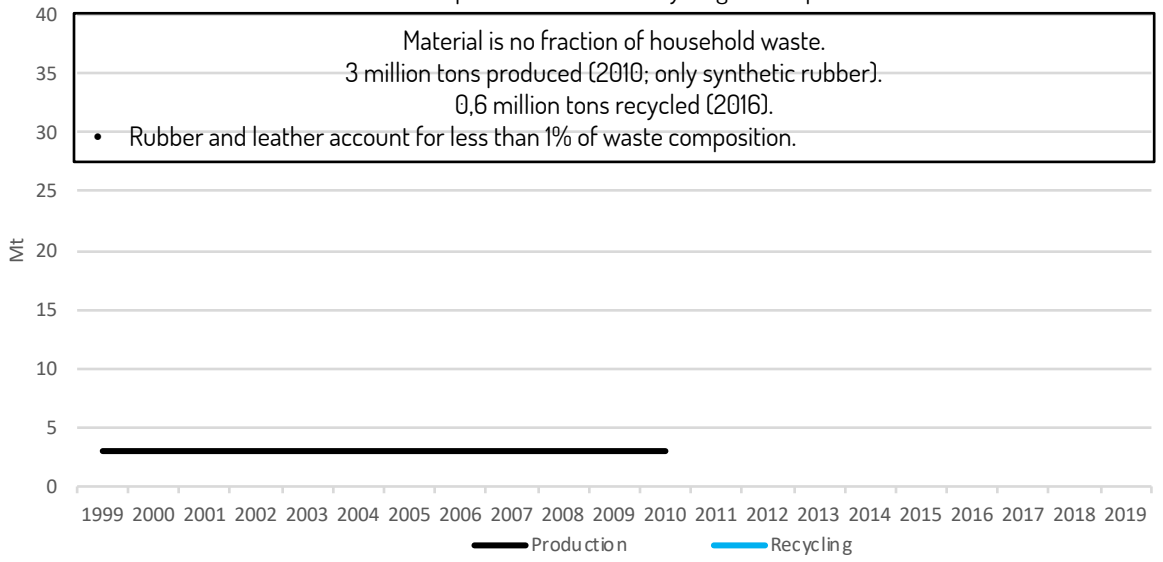
Historic Development of Rubber Recycling in Asia



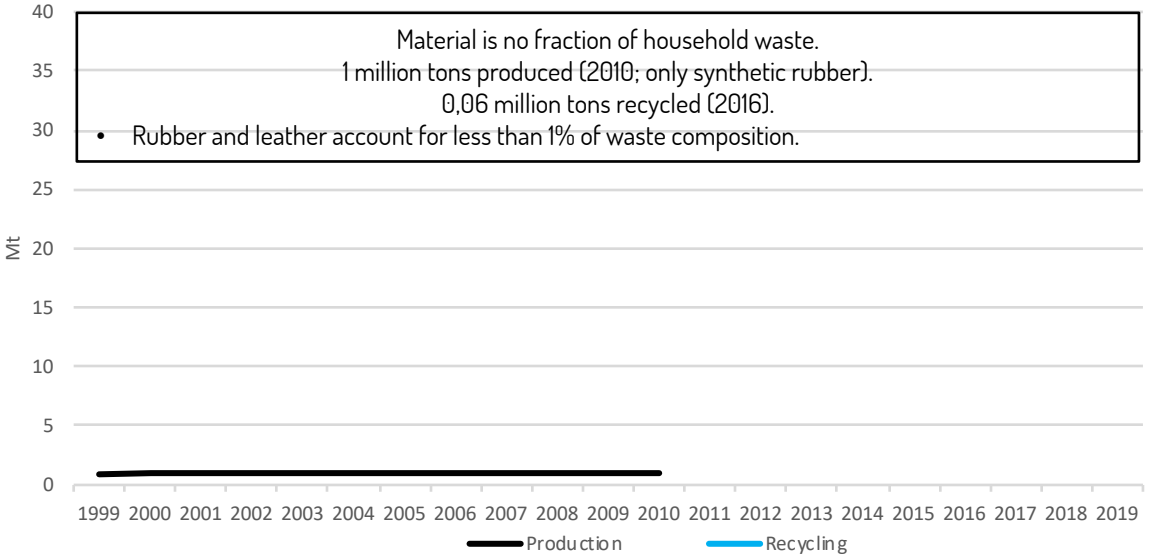
Historic Development of Rubber Recycling in North America



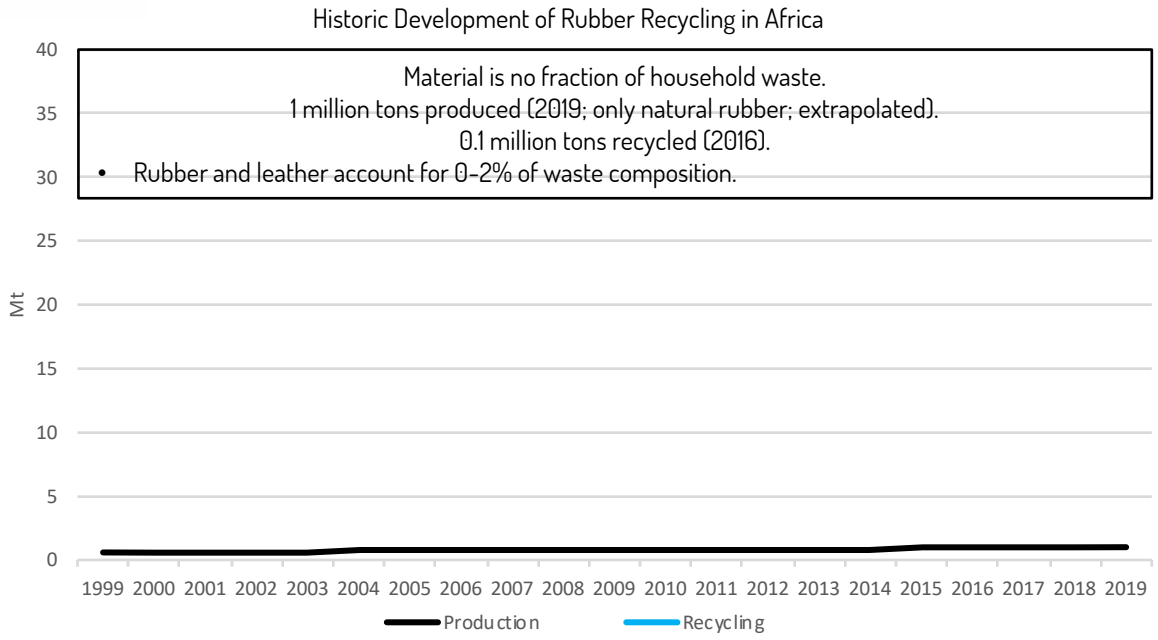
Historic Development of Rubber Recycling in Europe

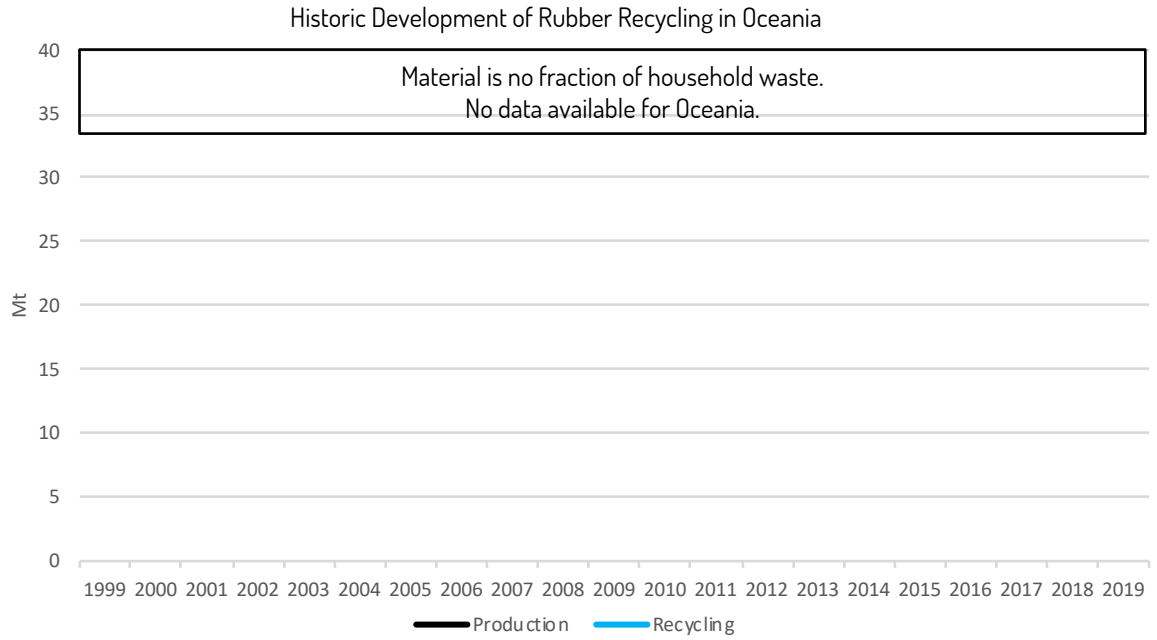


Historic Development of Rubber Recycling in South America



Sources: Grilli et. al (1980, p.19, p.33) - Kaza et. al (2018, p. 41, pp. 46-47, pp. 53-54, p. 67, p. 71) - Misurelli et. al (1997, p. 14) - The Rubber Economist Ltd. (2020).





Best available projections:

- Tire retreading in Europe is confronted with new challenges due to tire imports.
- Climate mitigation potential through retreading is scientifically evaluated.
- Retreading offers significant carbon savings over a tire lifecycle in comparison to new tire manufacture.
- The figure clearly shows that with successive retread cycles, the emissions from the casing become lower.
- Greater reductions in emissions for the retreaded tire are achieved.

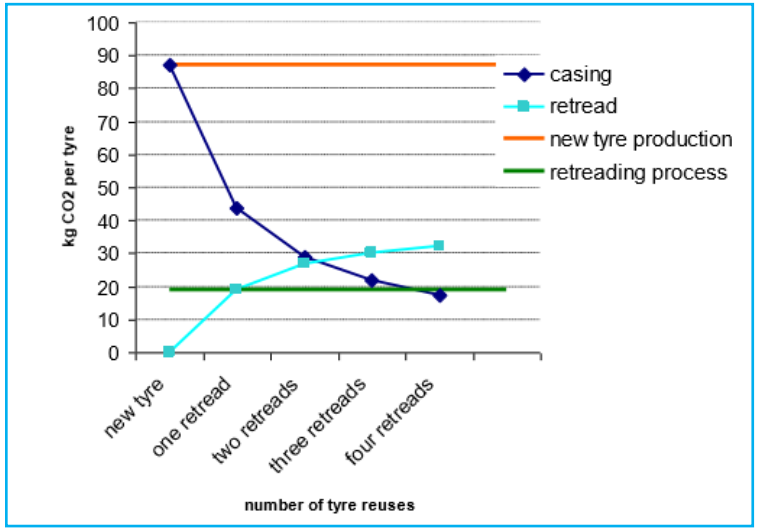


Figure Carbon footprint of different stages of a tire re-use [Data on basis 17.5 inch light truck] (Centre for Remanufacturing and Reuse (2008, p. 19).

Sources: Centre for Remanufacturing and Reuse (2008, p. 17, p. 19) - Grilli et. al (1980, p.19) - Kaza et. al (2018, p. 59, p. 61, p. 65, p. 78) - The Rubber Economist Ltd. (2020).

Rating card

Rubber	Maturity of market	Design4CE compliance in legislation / jurisdiction	Availability of RE-Tech.	Level of knowledge and cognition for CE
World				
China / Asia				
USA / North America				
Europe				
South America				
Africa				
Australia / Oceania				

Rubber in a nutshell:

- Rubber is a material that is often not even categorized as waste.
- It lacks data collection, infrastructure for collection and acceptance of economic value.
- This can be seen through the development of the European retreading industry, which is suffering from the import of cheap new tires from Asia.
- Though rubber is criticized for its tire wear particles, tire retreading is no focus of political agenda.
- In the USA, tire retreading is common practice, but the material is still downcycled.

9

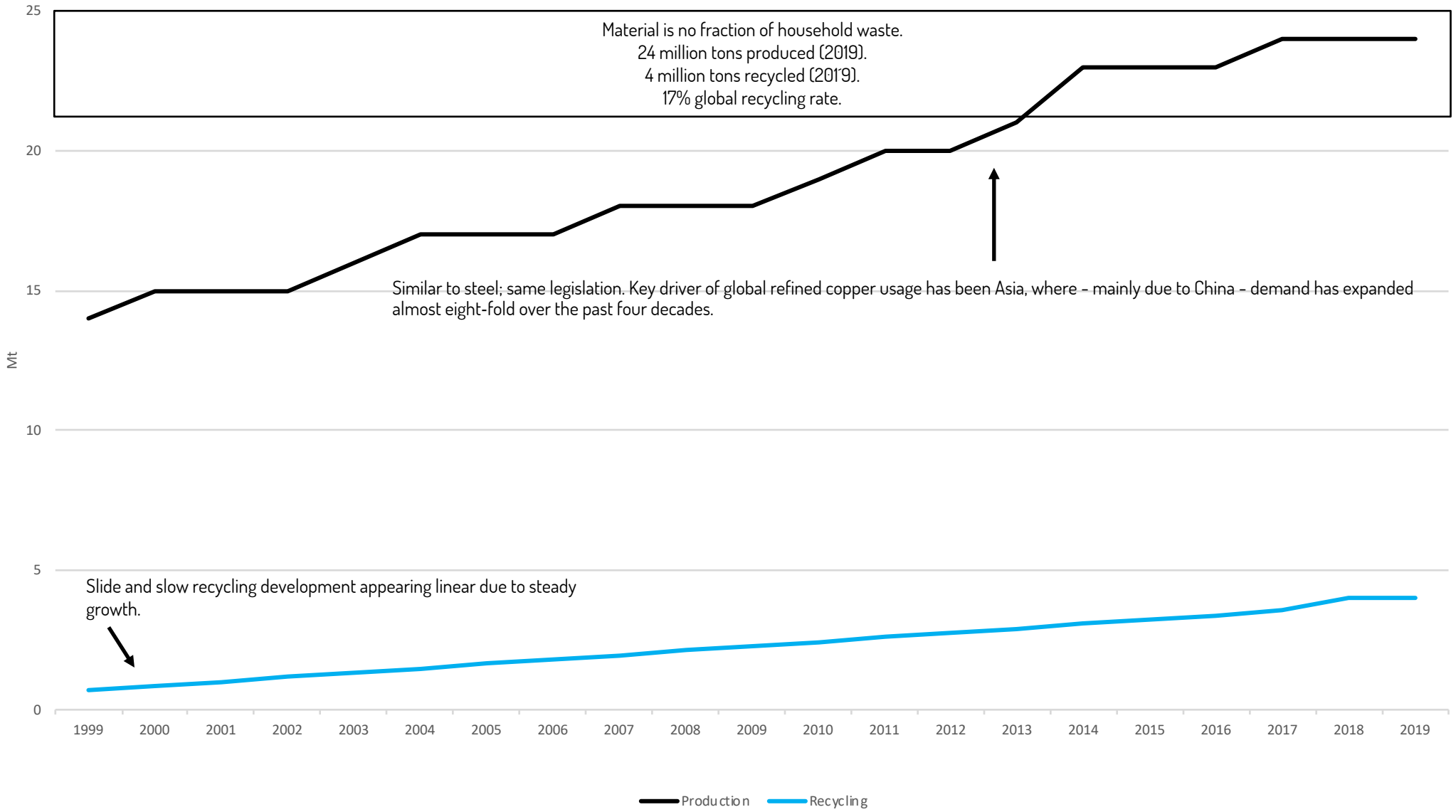
24 million tons produced (2018)

4 million tons recycled (2018)

17% global recycling rate

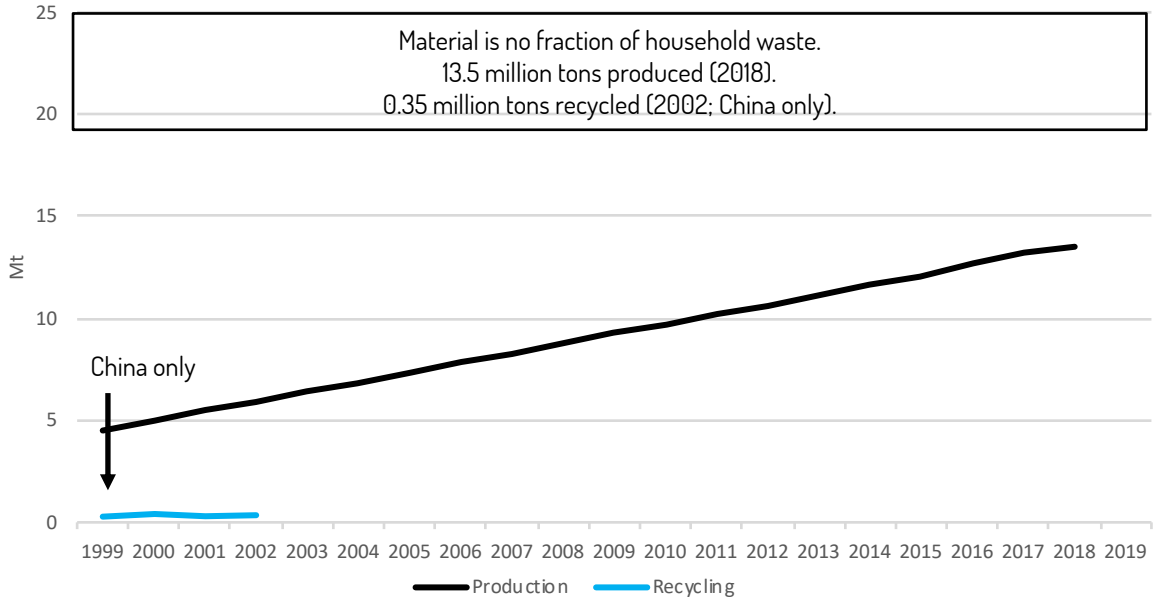
Photo by Alexas Fotos from Pixabay

Historic Development of Copper Recycling in the World

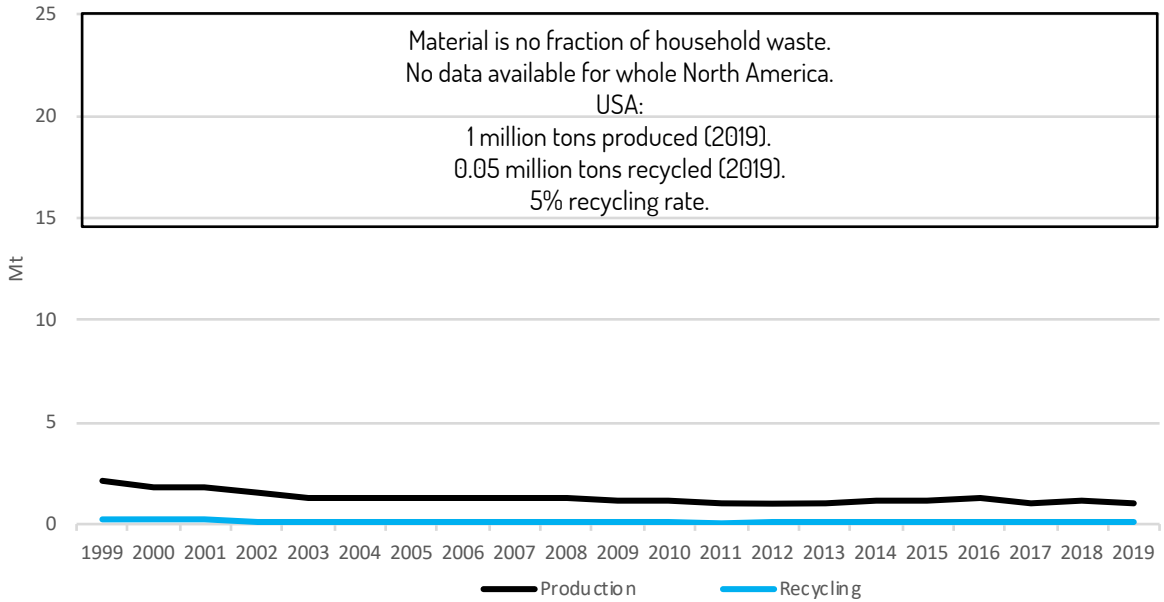


Sources: Goonan (2009, p. X8) - International Copper Study Group (2019, p. 21, p. 40, p. 59) - International Copper Study Group (2020).

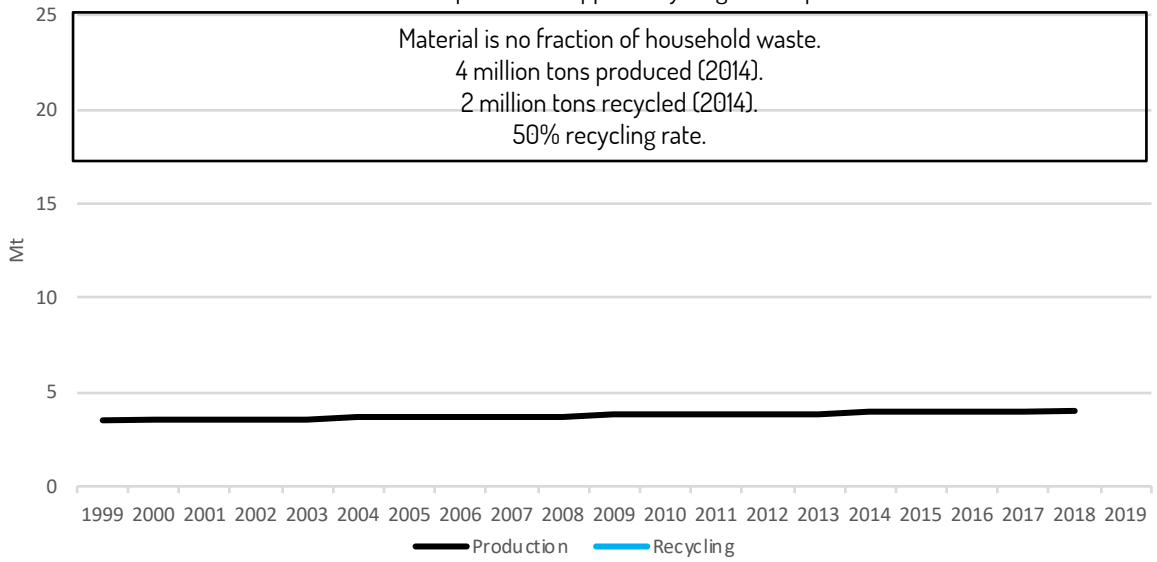
Historic Development of Copper Recycling in Asia



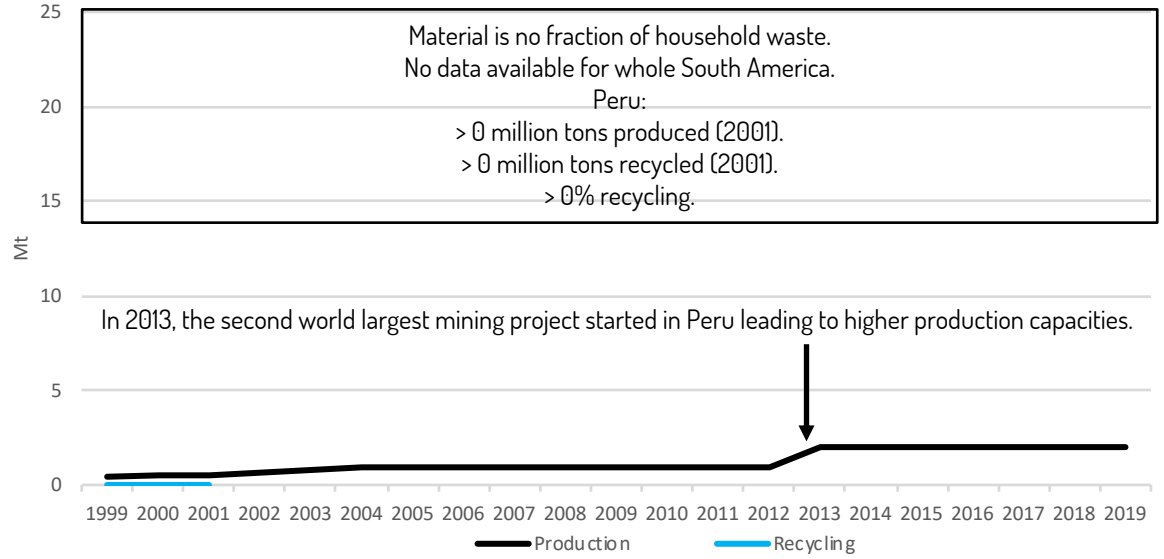
Historic Development of Copper Recycling in USA



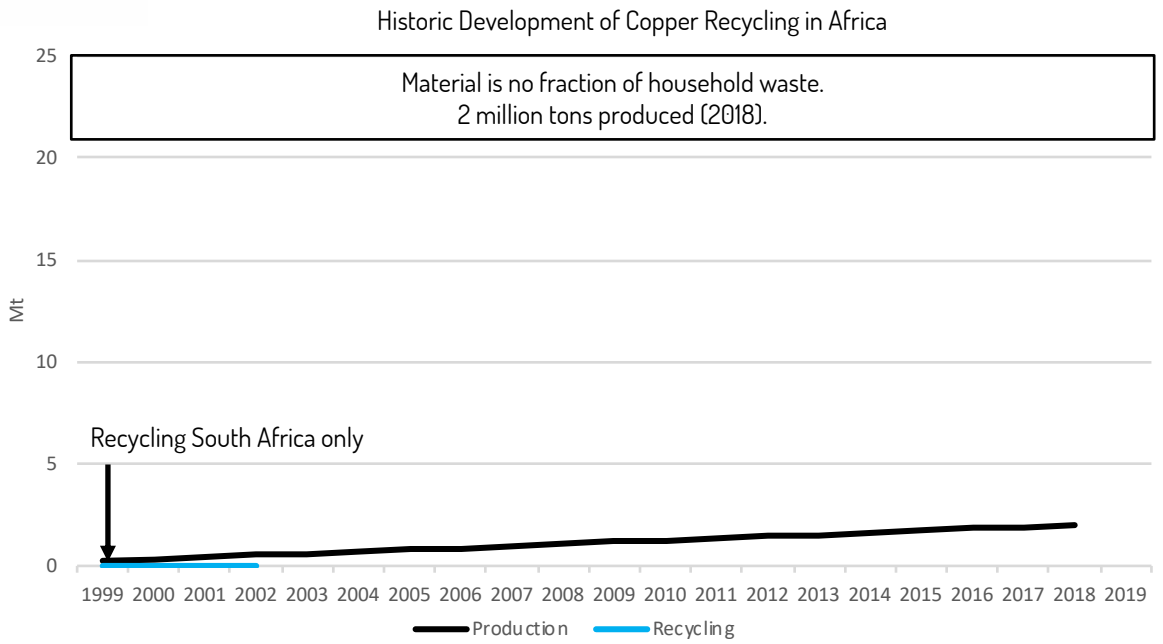
Historic Development of Copper Recycling in Europe

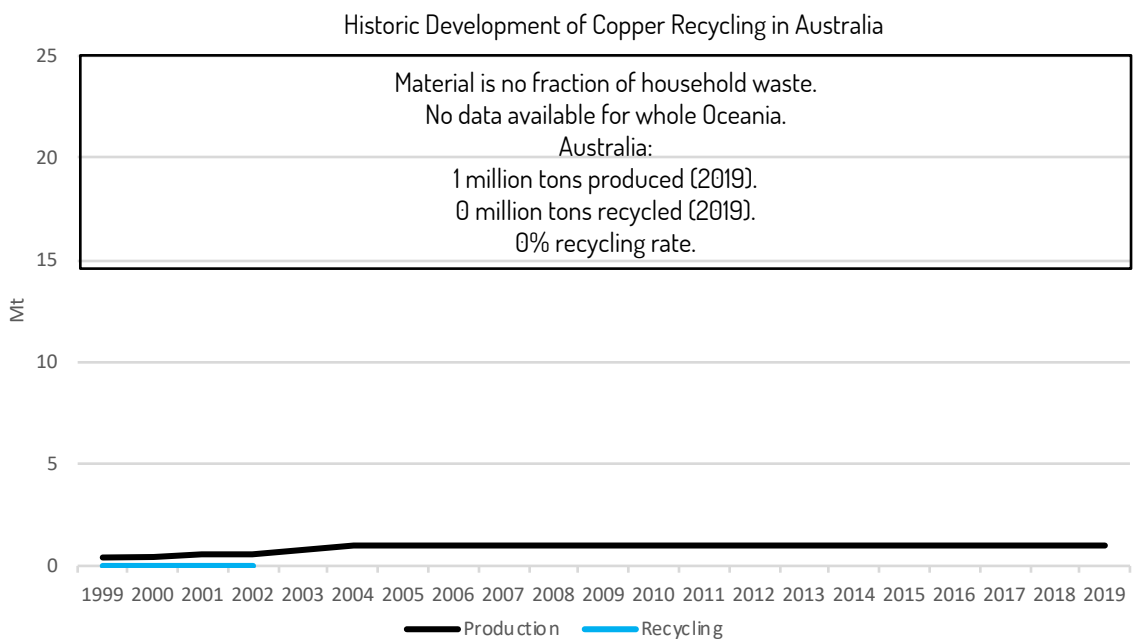


Historic Development of Copper Recycling in Peru



Sources: Brininstool (2015, p. 48) - Dorner (2020, p. 15) - Edelstein (2001, pp. 25-27) - Edelstein (2002, pp. 25-27) - Edelstein (2005, p. 54) - Edelstein (2010, p. 48) - European Copper Institute (2018) - Flanagan (2020, p. 52) - Goonan (2009, p. X8) - International Copper Study Group (2019, pp. 23-24) - International Copper Study Group (2020a).





Best available projections:

- Copper plays an important role as conductive material in the green revolution and the decarbonization of society.
- Increased growth in demand is expected for electromobility.
- This will likely not yet have an impact on demand until 2025.
- Copper recycling is making an important contribution for the supply of copper.
- Chinese copper demand now accounts for over 50% of global demand.
- China is further expanding its dominant position.
- Since the end of 2018, new import restrictions for copper scrap have been in force in China.
- It remains to be seen to what extent the Chinese import restrictions will affect global secondary raw material production.

Sources: Dorner (2020, pp. 43 – 45) - Edelstein (2001, pp. 25-26) - Edelstein (2002, pp. 26-27) - Garside (2020a) - Goonan (2009, p. X8) - International Copper Study Group (2019, p. 23) - International Copper Study Group (2020).

Rating card

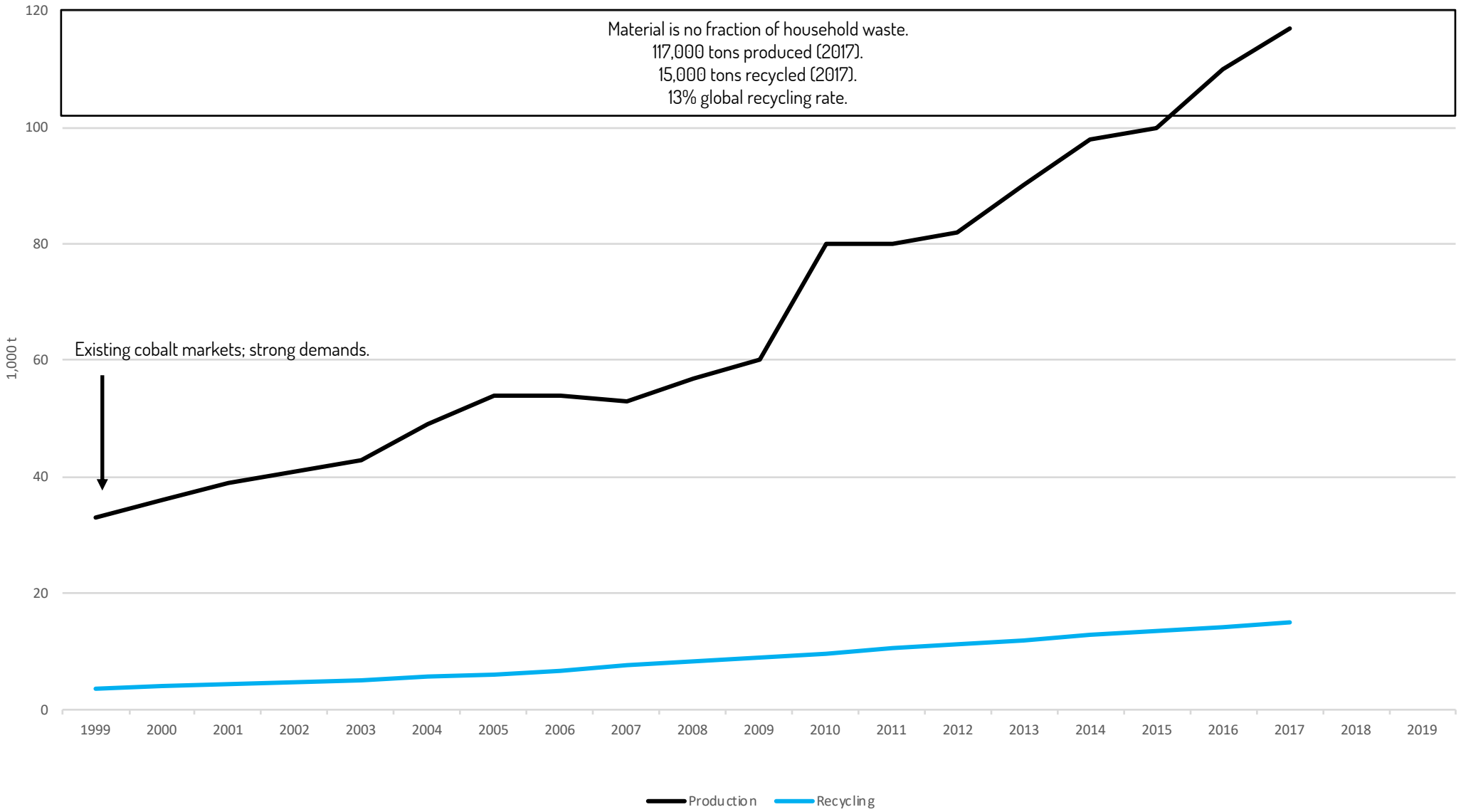
Copper	Maturity of market	Design4CE compliance in legislation / jurisdiction	Availability of RE-Tech.	Level of knowledge and cognition for CE
World				
China / Asia		Political announcement for Circular Economy.		
USA				
Europe				
Peru / South America				
Africa				
Australia				

Copper in a nutshell:

- Just as steel, copper looks back on a long journey of material history. Archaeological evidence demonstrates that copper was one of the first metals used by humans and was used at least 10,000 years ago for items such as coins and ornaments in western Asia.
- The discoveries and inventions relating to electricity and magnetism of the late 18th and early 19th centuries and the products manufactured from copper, helped launch the Industrial Revolution.
- Today, copper continues to serve society's needs. Innovative applications for copper are still being developed as evidenced by the development of the copper chip by the semi-conductors industry.
- It is a material that is appreciated for its economic value, its high recyclability and even for its health benefits.
- As copper is nowadays part of electronics, recycling is not used to its full potential as it is hard to retrieve.

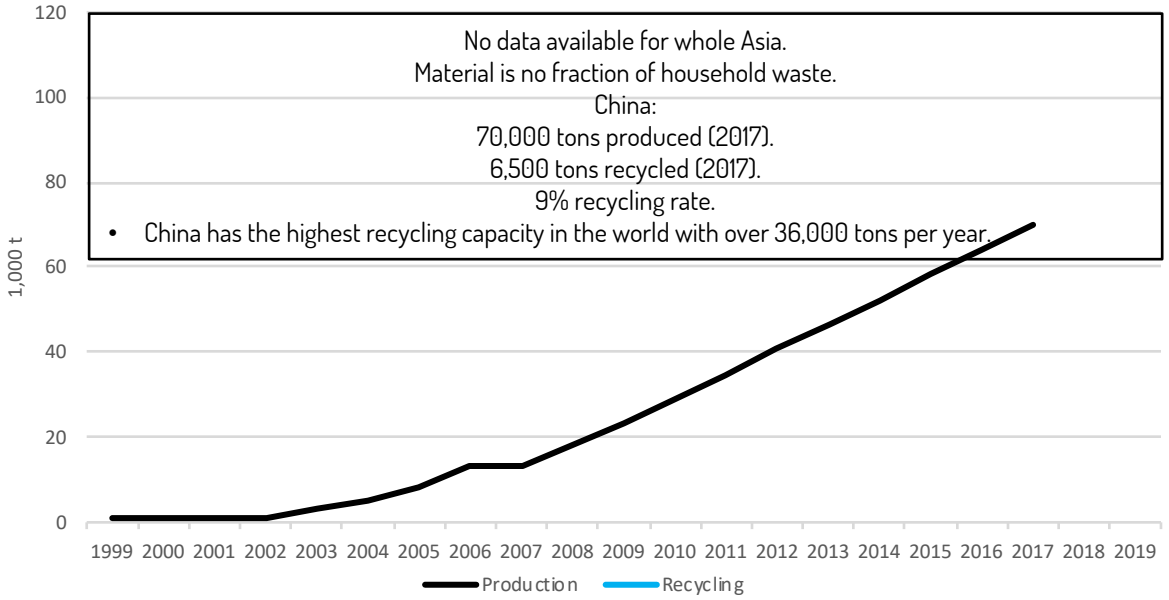
Photo by Willfried Wende from Pixabay.

Historic Development of Cobalt Recycling in the World

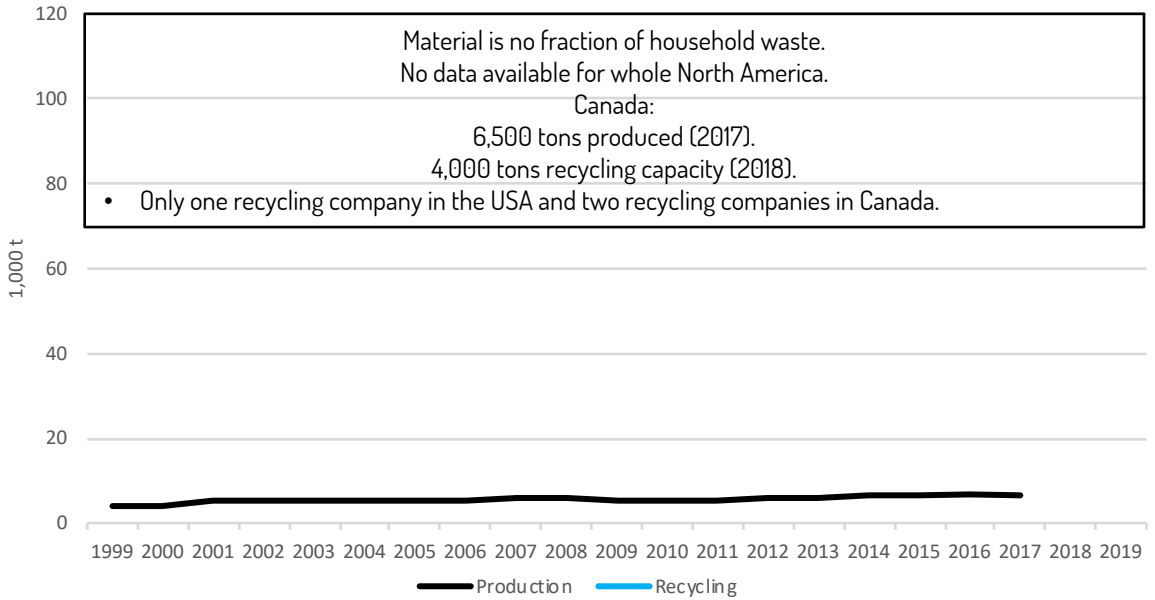


Sources: Al Barazi et. al (2018, p. 45, p. 53, p. 59) - Barry et. al (2013, Table 17) - Sun et. al (2019, p. 48).

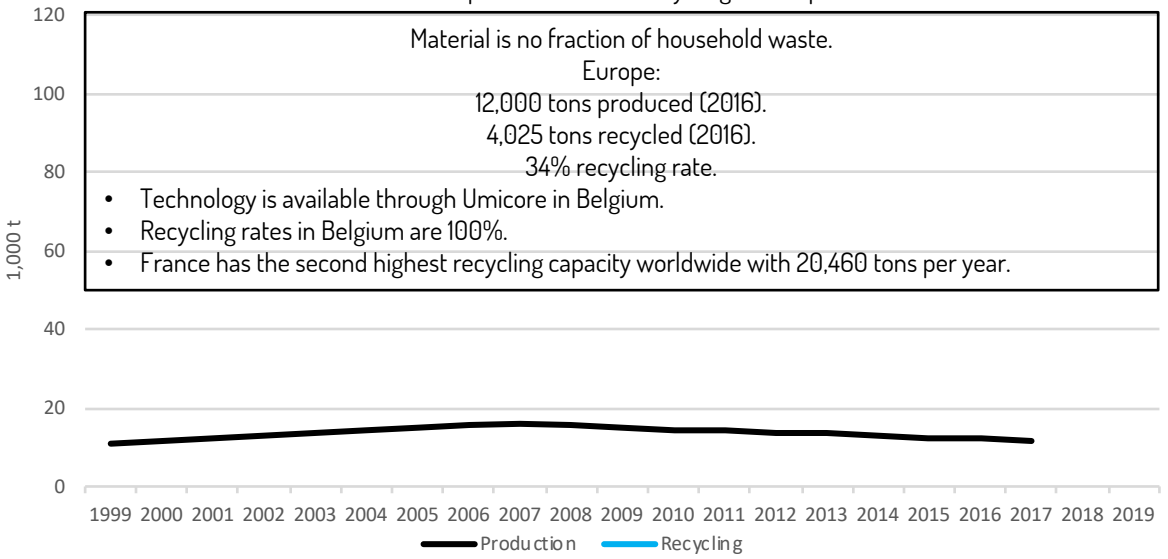
Historic Development of Cobalt Recycling in the China



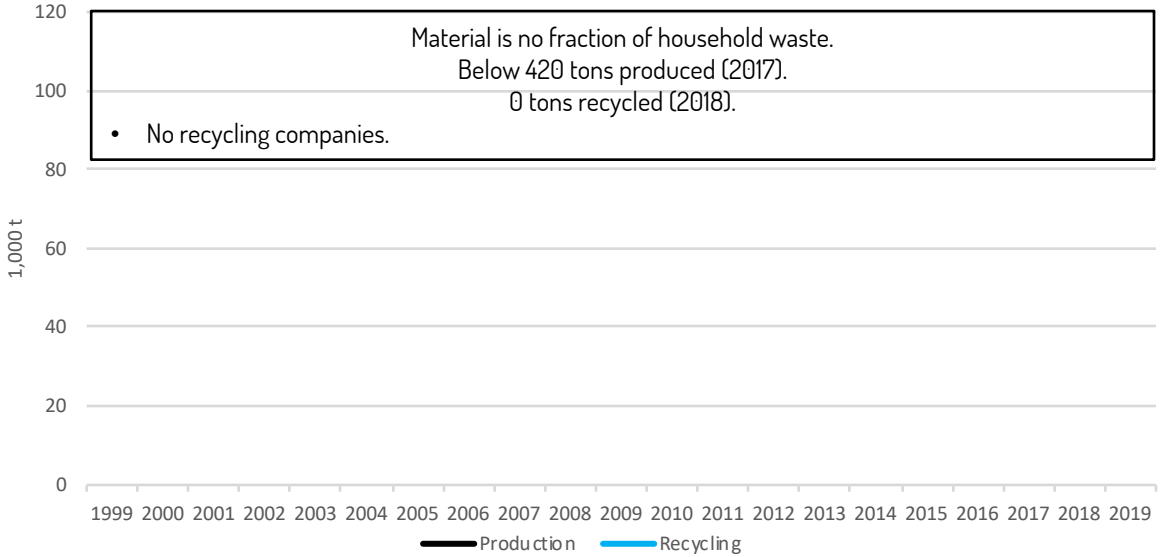
Historic Development of Cobalt Recycling in Canada



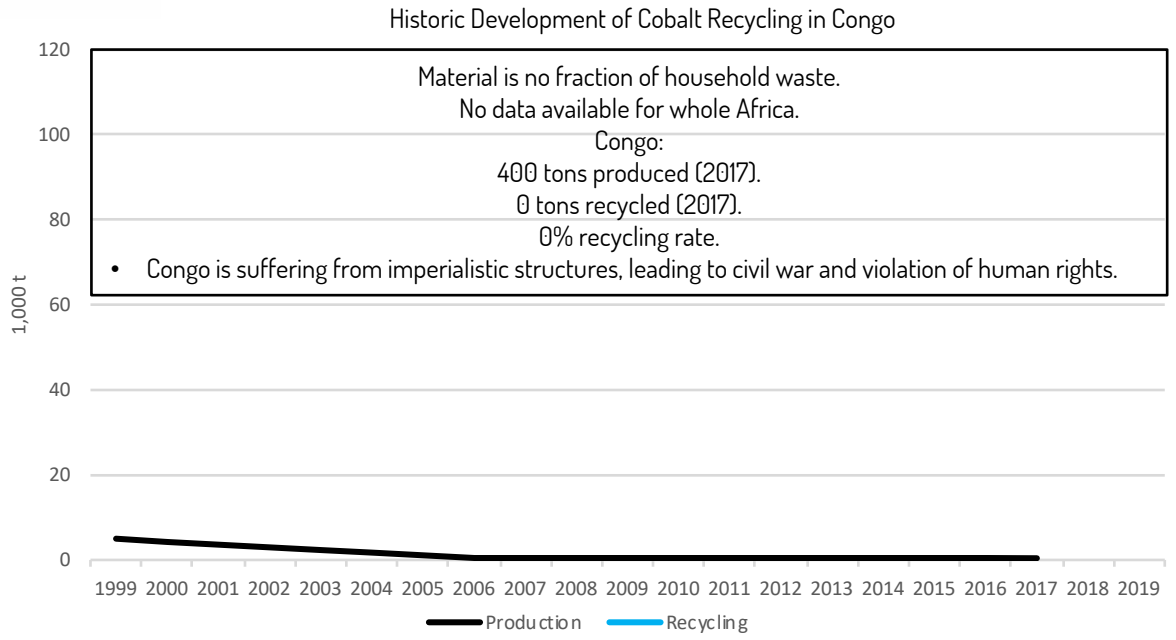
Historic Development of Cobalt Recycling in Europe

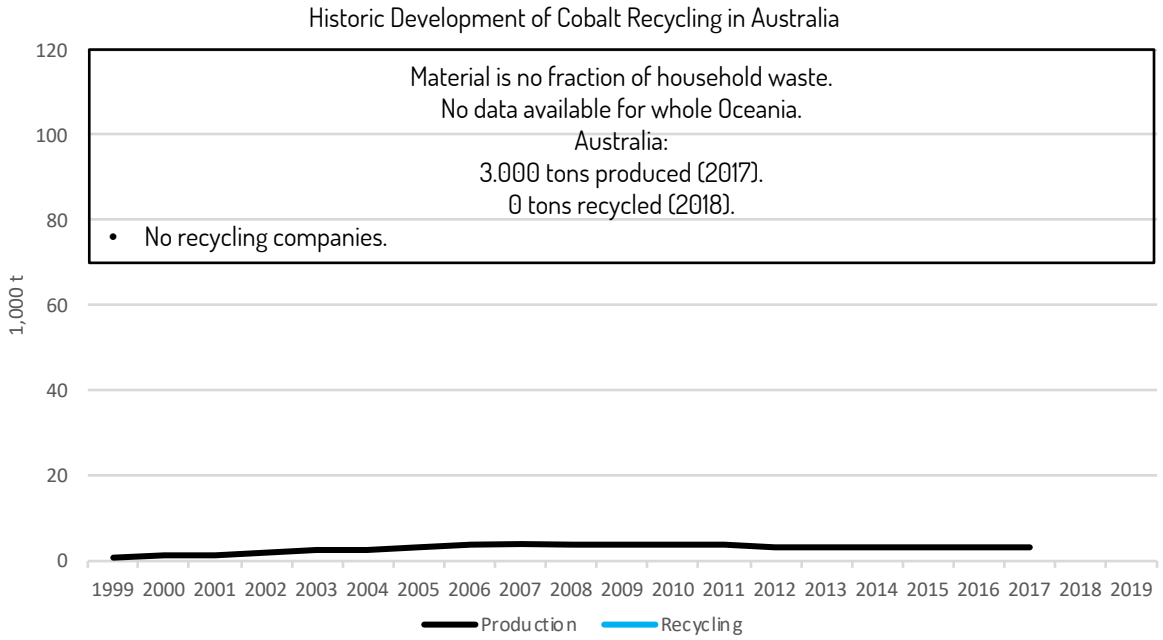


Historic Development of Cobalt Recycling in South America



Sources: Al Barazi et. al (2018, p. 45, p. 50, p. 53, p. 55) - Barry et. al (2013, Table 17) - BIO by Deloitte (2015, p. 108).





Best available projections:

- The market has been volatile in the last two years due to the industry's high expectations for the application of rechargeable batteries.
- Renewable energy storage and portable applications will play an increasingly important role in this context.
- Cobalt will continue to be an indispensable key component in the coming years in lithium-ion based batteries.
- The market expects high annual growth rates in demand in the near future.
- Reliable statements about exploration technology or new industrial applications for cobalt are not useful due to a number of uncertainties.
- Recycling of lithium-ion batteries is possible, and corresponding large-scale processes are available.
- Recycling of battery cells will play an important role in the raw material cycle.
- A significant contribution of secondary cobalt from electric vehicle battery recycling is not expected until 2030.

Sources: Al Barazi (2018, p. 45, p. 55) - Barry et. al (2013, Table 17).

Rating card

Cobalt	Maturity of market	Design4CE compliance in legislation / jurisdiction	Availability of RE-Tech.	Level of knowledge and cognition for CE
World				
China		Political announcement for Circular Economy.		
Canada / North America				
Europe				
South America				
Congo / Africa				
Australia				

Cobalt in a nutshell:

- Just as copper, cobalt is a systemically relevant material today.
- The material is especially important for the e-mobility industry and the renewable energy sector.
- Technologies for recycling are already available. Cobalt is recovered through the recycling of lithium-ion batteries.
- Anyhow, data gaps prevent to find out details on how much cobalt is actually recycled in regions worldwide.
- As e-mobility becomes more widespread, recycling and reuse will be important to the future raw material cycle of cobalt.

Summary

Material	Recycling in million tons (Mt)	Production in Mt	Recycling Rate in %	Key Findings	CE Rating
Steel	600 Mt	1,730 Mt	35%	Liability of data good. Steel markets developed since 1st industrial revolution, though world markets are still growing faster than recycling material can be recovered.	
Asphalt	530 Mt	936 Mt	72%	Liability of data bad. Japan has clear leadership in circular governance and performance; great role model for closed-loop recycling. Recycling technology existing, well-known and with high economic value.	
Paper	221 Mt	420 Mt	53%	Liability of data good. The advancement of paper recycling worldwide is worse than expected.	
Plastics	50 Mt	390 Mt	13%	Liability of data bad. Not scientifically evaluated. Plastics recycling is entering governance' agendas. But so far, waste management structures and legislative impact has been weak. Technology is available.	
Aluminum	29 Mt	77 Mt	38%	Liability of data fair. Similar development like steel or other mineral ores.	
Glass	27 Mt	130 Mt	21%	Liability of data fair. Glass recycling market is underdeveloped.	
Textiles	21 Mt	99 Mt	21%	Liability of data bad. Fast fashion growth and recycling worse than expected. The charity-driven character of collection systems in the Global North is driving the topic, which has been neglected since clothes are status symbol and have a deep cultural meaning. The Global South as poorer part in the world has established second-hand markets. The figures by H&M have not been solicited scientifically.	
Rubber	7 Mt	27 Mt	24%	Liability of data bad. Tire retreading is less expensive in some parts of the world (USA). It lacks image in other industrial countries. Rubber can only be downcycled.	
Copper	4 Mt	24 Mt	17%	Liability of data fair. The electrification is key driver and key problem in copper recycling.	
Cobalt	0,015 Mt	0,117 Mt	13%	Liability of data fair. No cobalt stocks available. Handling of small amounts. Resource scarcity.	