CIRCULAR ECONOMY REQUIRES BOTH MATERIAL CYCLES AND FINAL SINKS

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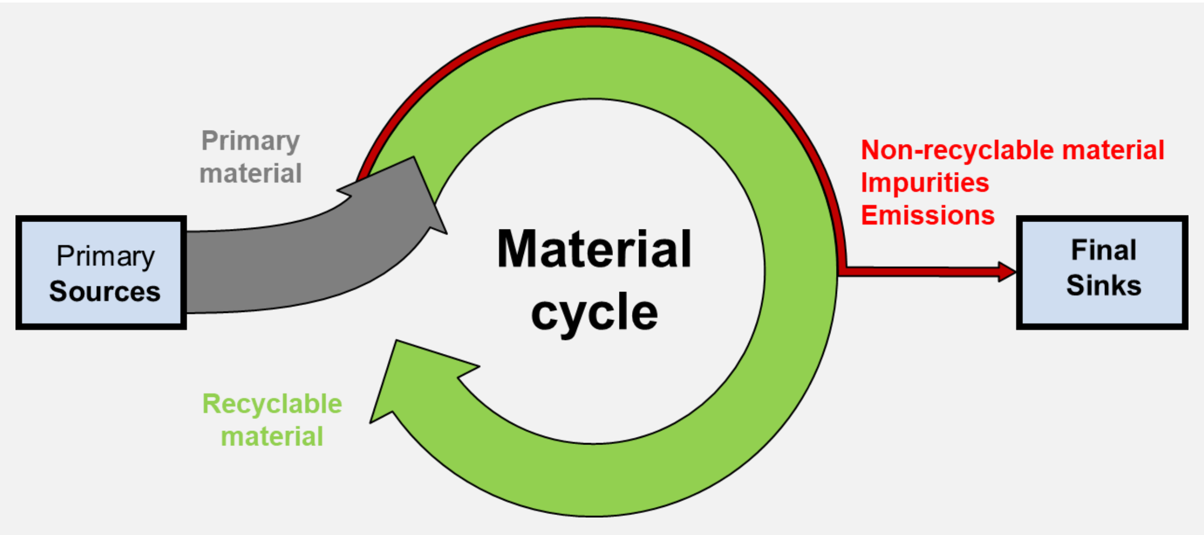
Abstract: Modern products contain a wide range of materials. Most of them are harmless, but some are hazardous, cause risks for human and environmental health or constrain the quality of future secondary raw materials. Ways must be explored to phase out detrimental materials during recycling and direct them to final sinks. Final sinks can be end-of-pipe technologies (man-made sinks) or environmental media (natural sinks). They are limited in capacity and have to be protected against overloading. Two examples for integrating material cycles and final sinks in a strategy for circular economy are presented. First, polycyclic aromatic hydrocarbons (PAH) in asphalt pavements and copper (Cu) in waste flows are selected as examples of organic and inorganic substances, respectively. Second, a regional waste management system is analyzed by mapping the PAH and Cu flows. Third, using a scenario approach, effective measures are discussed for circulating safe and high quality materials as well as utilizing appropriate final sinks. Findings indicate a linkage between the quality of recycled material and the need for final sinks. Final sinks such as thermal treatment plants and sanitary landfills are inevitably needed in a sustainable circular economy in order to meet environmental and resource-oriented goals.

1 Introduction

Recycling plays a key role in a circular economy: On one hand, it aims at delivering high quantities of valuable recycled materials, and on the other hand, it is limited by economic, technological and ecological constraints. The result of this dual objective situation potentially yields recycling materials of low quantity and quality. Impurities diminish the technical functionality of the recycled material, and hazardous substances pose risks for human and environmental health. Examples can be found in the literature, such as, copper scrap as impurity in the steel cycle (Pauliuk et al. 2013, Daehn et al. 2017), contaminants in the paper cycle (Pivnenko et al. 2016), brominated flame retardants in plastic cycles (Chen et al. 2009, Samsonek and Puype 2013) and carcinogenic substances in construction waste (Rubli 2013, Deutscher Bundesrechnungshof 2014). To establish safe and high quality recycling products, Sakai (2000) suggested a "Clean, Cycle and Control" concept and Sutherland et al. (1975) proposed a "Clean Cycle" strategy. It is inherent to clean cycle strategies that quality requirements go along with the removal of non-recyclable, hazardous materials during recycling and pose the question about the final fate of these substances. Simply spoken, safe final sinks are required, which are able to take up substances without harming human and environmental health in the long-term. In practical terms, such final sinks can be end-of pipe technologies in the waste sector or environmental media (c.f. Brunner 1999, Döberl and Brunner 2001, Brunner 2013, Heiskanen 2013, Kral et al. 2013). Thermal treatment plants are such sinks mineralizing organic materials and reducing waste volume, which avoids risk to human health and the environment and reduces the need for landfill space. Sanitary landfills take up non-recyclable waste fractions and - ideally – are free of after-care for the coming generations. From a generic system perspective, Figure 1 visualizes the optimized cycling of materials, including the removal of non-recyclable materials and their direction to final sinks.

Figure 1: Circular economy should strive for clean recycled materials, which requires the utilization of final sinks.



2 Case studies

The case studies originate from an extensive study in the canton of Zurich, Switzerland. It is published in the report "Schutz und Nutzung von Senken durch die Zürcher Abfall- und Ressourcenwirtschaft: Ein zukunftsgerichteter Ansatz zur Steuerung von Entsorgungssystemen. [Protection and use of sinks by Zurich waste and resource management: A future-oriented approach to the control of waste disposal systems.]" by Ulrich Kral, Dana Vyzinkarova and Paul H. Brunner (Kral et al. 2015).

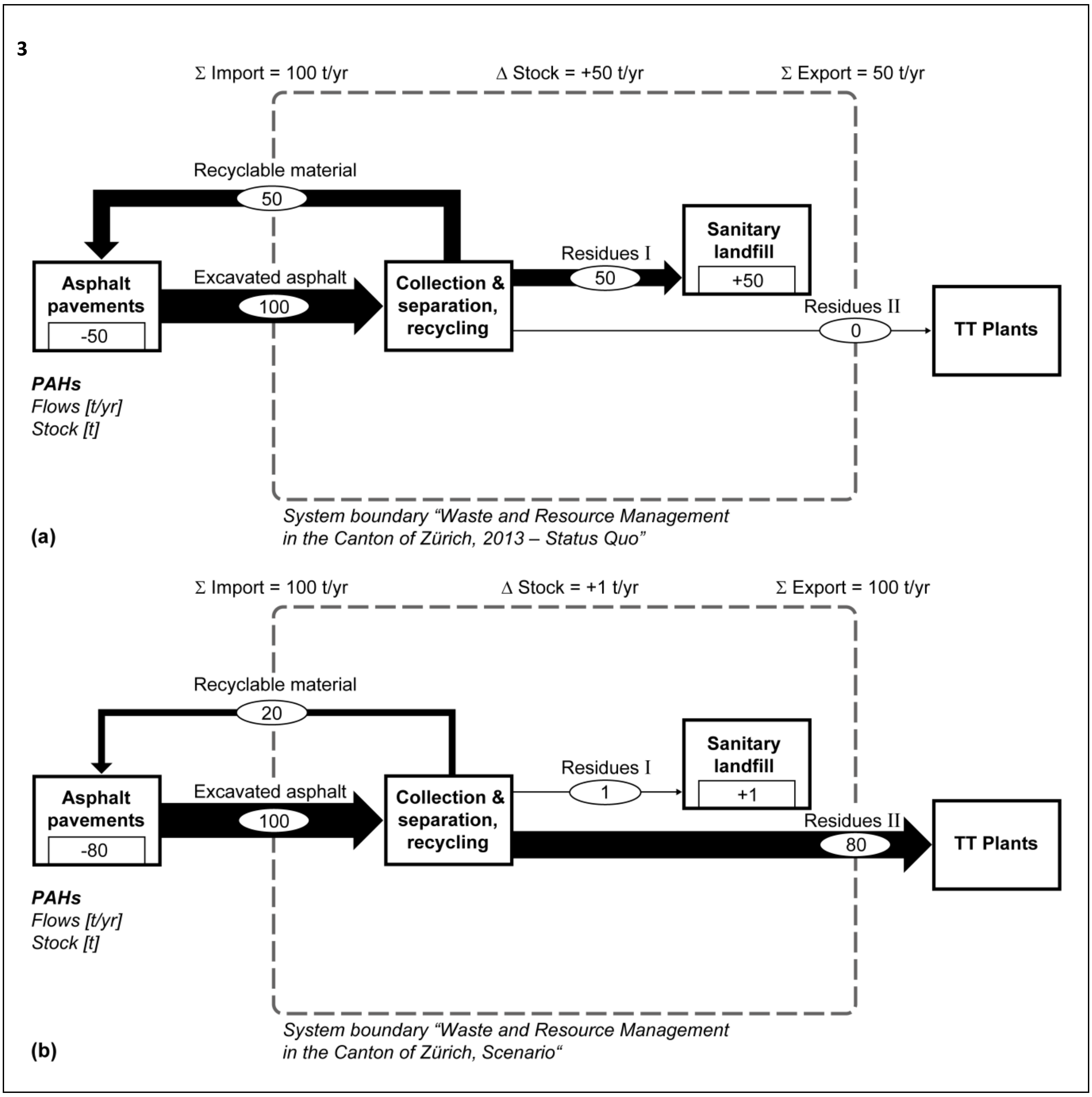
The substances PAH and Cu have been selected to demonstrate the different requirements for final sinks utilized to get rid of non-recyclable material. The different requirements in terms of different end-of-pipe technologies need to be addressed in the design and management stage of modern waste and resource management systems.

2.1 PAH in asphalt pavements

Background: Polycyclic Aromatic Hydrocarbons (PAH) are constituents in tar, which was used for road pavements for over a century. Between 1926 and 1991 about 45 million tons of tar containing PAH was applied in construction in Switzerland (Buchser 2012). Due to the long lifetimes of road pavements, large amounts of PAHs are still stocked in many roads (Rubli 2013). At the end of their lifetime, the pavements are removed by reconstruction and demolition activities and directed to recycling facilities. At this stage, recyclable and non-recyclables are separated based on technological, economic and environmental criteria. Due to risks to human and environmental health, Swiss regulatory bodies envisaged tightening the ecological criteria - the legal limit for PAH in recycled and disposed of pavements. Consequently, today PAH needs to be removed during recycling and directed into safe final sinks. This results in recycling pavements with less PAH and therefore fewer risks to humans and the environment.

Mapping PAH flows to sinks: The mapping demonstrates the effects of changing the legal limits for PAH on the recycling rate. Without changing legal limits, about 50% of the PAH quantities remained in the material cycle and 50% were directed to landfills, respectively (Figure 2a). In the scenario analysis, a limit for PAH concentration of 5'000 ppm is set for wastes going to sanitary landfills. Wastes with more than 5'000 ppm are directed to thermal treatment plants. The results show that 80% of the total PAH amount is oxidized and 20% still remains to be recycled (Figure 2b).

Figure 2: PAH flows and stocks in the Canton Zurich for a) the year 2013 and b) the scenario with limited PAH concentrations in the recycling goods. Differences in mass balances at process level result from rounding the numbers. The figures are taken from Kral et al. (2018).



Conclusions: The case study on PAH shows that precarious amounts of PAH are stocked in road pavements. PAH removal during recycling is thus needed to produce recycled road pavements with lower risks to humans and the environment. As a consequence of removal, PAH need to be decomposed without causing environmental risks. This can be done with thermal processing or alternative technologies, which constitute a final sink for PAH. To conclude, circular economy does not mean eo ipso that recycling is favored against thermal treatment. Health and environmental standards and the availability of technology and financial resources determine the fate of materials and therefore the recycling rate.

3.1 Cu in waste flows

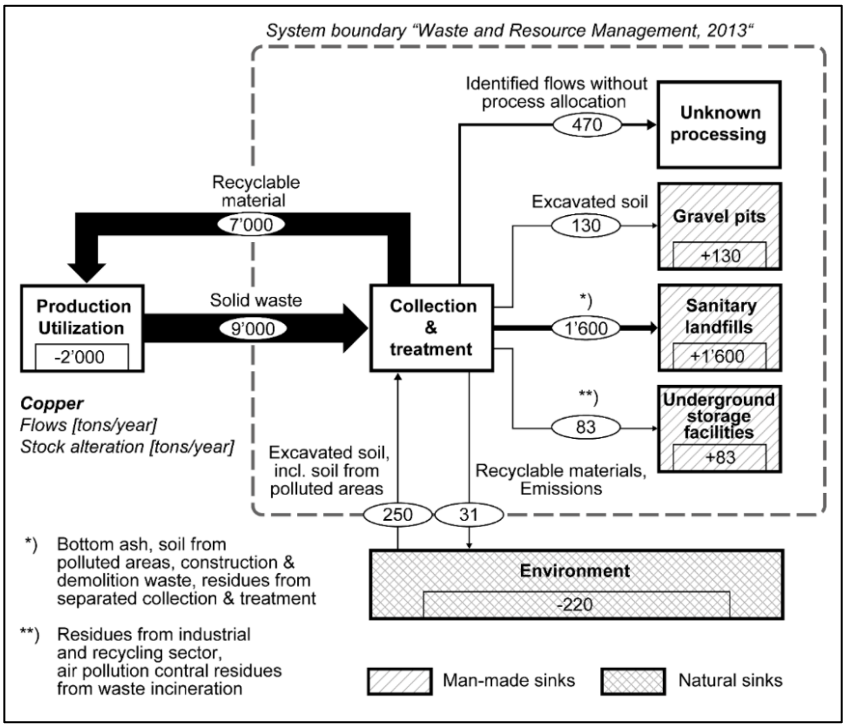
Background: Copper is a valuable metal of significant importance for today's societies. The power grid, electronic devices and building materials include copper due to its high conductivity and corrosion resistance. Copper originates from two sources: from primary production by means of treated copper ore and from secondary production by means of smelting new scrap and subsequent recovery of copper from end-of-life products and production residues. Copper has excellent recycling characteristics and often sells at high prices on the world market. Secondary copper production also has fewer environmental impacts than primary production. For these reasons, copper recovery from wastes is attractive and facilitates circular economy. Despite high recycling rates today, full recovery of copper fails because of economic, technological and environmental constraints. This results in non-recyclable fractions, directing the material towards man-made sinks such as landfills. A vital question in this context is whether or not copper recovery can be increased by keeping copper out of landfills.

This question is addressed in a case study, taking again the waste and resource management system of the Canton Zurich as an example.

The Office of Waste, Water, Energy and Air developed an action plan (AWEL 2015) that encompasses the increase in copper recovery from waste to energy (WTE) residues, and therefore reduces the copper loads into landfills.

Mapping Cu flows to sinks: In 2013 about 9'300 t Cu (6.7 kg / cap) were collected in waste materials, of which 7'000 tons Cu (75%) were recovered during recycling and sent to the production and utilization phase, 1'810 tons Cu (19%) ended up in man-made sinks (sanitary landfills, gravel pits, underground storage facilities), and 31 tons Cu (0.3%) in natural sinks. About 1% of the annual copper flows lack information details and therefore data on allocation to a specific process (Figure 3).

Figure 3: Copper flows in the waste and resource management system of the Canton Zurich for 2013. The numbers are rounded to two significant digits. Differences in mass balances at process level result from rounding the numbers.



In 2013 the solid residues from WTE plants included about 240 t Cu that were recovered and 1'200 t Cu that were disposed of in sanitary landfills. One option to improve circular economy is to redirect copper from landfills to recycling. Assuming a 95% recovery rate (referring to the metallic copper content) results in about 430 t Cu/a, which is 190 t more than in 2013. This reduces the copper flow to landfills from about 1’200 t/a to 1’000 t/a, which is a reduction of nearly 20%.

Recycling and recovery of bio-waste causes about 31 tons of copper emissions per year that enter the environment. For instance, manure, compost and digestate are applied to agricultural areas. Consequently, copper accumulates in the environment and causes potential long-term risks to human and environmental health.

Conclusions: Copper is a metal of high price and therefore attractive for being recovered from waste streams. The case study shows that there is still a good potential for recovering more copper from solid waste residues, such as bottom-ash from WTE plants. Doing so requires research and technology, which is presently being undertaken by the "Zweckverband Kehrrichtverwertung Zürcher Oberland [Zurich Oberland Waste Management Association]" (KEZO 2017) and the "Development center for sustainable management of recyclable waste and resources" (ZAR 2018). There is still a need for disposing of non-recyclable copper fractions in sanitary landfills (man-made sinks). Copper is also included in biogenic wastes that are applied on agricultural soil (natural sink) in order to improve its quality. The tradeoff between resource conservation and environmental health needs to be tackled, and monitoring by material flow analysis (MFA) is required to avoid potential overloads.

4 Conclusions

The case studies from PAH in road pavement and Cu in waste flows allow the following general conclusions:

- The environmental and product quality of secondary materials can be impaired by hazardous constituents in waste fractions. They must be removed before or during recycling (clean cycles) and directed to appropriate (final) sinks.
- Many end-of-pipe technologies represent appropriate (final) sinks in the waste management sector. During WTE processing, organic materials are mineralized to CO_2, water, and a few other mostly harmless compounds. WTE is therefore an appropriate final sink for organic materials such as PAH. Sanitary landfills are appropriate sinks for inorganic materials as long as the quality of the residues meets high quality standards in a long-term perspective.
- Appropriate (final) sinks are also environmental media. For instance, soil is an appropriate sink for copper inside recyclables from the agricultural sector as long as environmental and human health standards are guaranteed in the long run.

5 Recommendations

The case studies from PAH in asphalt pavements and Cu in waste flows allow the following general recommendations:

- Current efforts towards a circular economy need to be amended by a clean cycle and final sink strategy.
- The development of early detection methods and tools for monitoring the quality of material cycles and recognizing potential sink overloading is required.
- Sufficient disposal capacities for thermal waste treatment and sanitary landfilling is inevitably needed in a circular economy to maximize mineralization and immobilization of non-recyclable wastes while recovering maximum amounts of secondary resources and avoiding human and environmental risks.

Acknowledgements

The authors are grateful to Franz Adam, Elmar Kuhn and their expert team from the Office of Waste, Water, Energy and Air (AWEL) in the Canton of Zurich for data collection, provision, and fruitful discussions. Ingeborg Hengl designed the figures for this paper.

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