International Symposium

SCIENCE TO SUPPORT CIRCULAR ECONOMY

Hosted by the Christian Doppler Laboratory
for Anthropogenic Resources

September 19, 2018
TU Wien / Kuppelsaal, 1040 Vienna, Karlsplatz 13

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Editors: J. Fellner, D. Laner, J. Lederer

Vienna, 2018

urn:nbn:at:at-ubtuw:3-3831

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SESSION 1:

ANALYSIS OF ANTHROPOGENIC RESOURCE FLOWS

CIRCULARITY OF PLASTICS PACKAGING AND ENVIRONMENTAL PERFORMANCE OF THEIR WASTE MANAGEMENT

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Introduction

The European Commission (EC), in its “action plan for the circular economy” and “strategy for plastics in a circular economy” communications (EC 2015, 2018), has named the circular economy in general and a responsible use of plastics in particular key in achieving increased resource efficiency as well as decreased environmental and human health damage. The proper management of waste plastics is thus crucial, especially from short-lived products such as packaging. To further encourage the (plastic packaging) waste management system in this direction, the EC has proposed a considerably increased recycling target (EPC 2018). However, formulating quantitative recycling targets without underlying data may prove to be counterproductive, as trade-offs within the waste management system might not be accounted for. It is therefore crucial to assess the environmental consequences of this increased target from a systems perspective.

A case study was thus carried out, where the waste management system of plastic packaging in Austria was assessed (with 2013 as the reference year). First, Material Flow Analysis (MFA) was used to quantify the flows of waste plastics in detail with respect to product types and polymers, and to identify if the current and future recycling targets are met and what improvement potentials exist. Second, Life Cycle Assessment (LCA) was used with the MFA results as a basis to evaluate the potential environmental impacts and benefits of plastic packaging waste management. Two alternative scenarios were built to explore the relationship between the recycling rate and the environmental performance of the waste management system, considering a wide range of impact categories to investigate whether burden shifting goes along with increasing the recycling rate.

Results

The results of the MFA for waste plastic packaging, subdivided by polymer, are displayed in Figure 1. About half of the total waste input, which amounted to 300,000 t/a or 35 kg/cap·a, was composed by small and large films, while one third consisted of small hollow bodies including PET bottles. The polymer composition was consequently dominated by LDPE (46%), PET (19%) and PP (14%). 34% of the waste was sent to mechanical recycling, after which 26% was recovered as regranulate, while 40% was treated in waste-to-energy plants and 33% was incinerated in the cement industry. The fact that 34% was sent to mechanical recycling means that the current recycling target of 22.5% was reached, but leaves large improvements needed to reach the

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recently increased targets of 50% and 55% by 2025 and 2030, respectively. Three product types, which represent 40% of the total waste mass, already (almost) reach the required increased target of 55 %: EPS large (68 %), films large (55 %) and PET bottles (54 %). However, the other categories are far away from the target, with required increases of 24 to 51 percentage points. For collection, efforts should be focused on the hollow bodies (except PET bottles) and others product types. Moreover, improving sorting of especially the small product types (films small and hollow bodies small) as well as the others has a large potential to increase the mass of plastic packaging sent to the recycling process. For a more detailed discussion on the waste plastic packaging flows in Austria, the reader is referred to Van Eygen et al. (2018a).

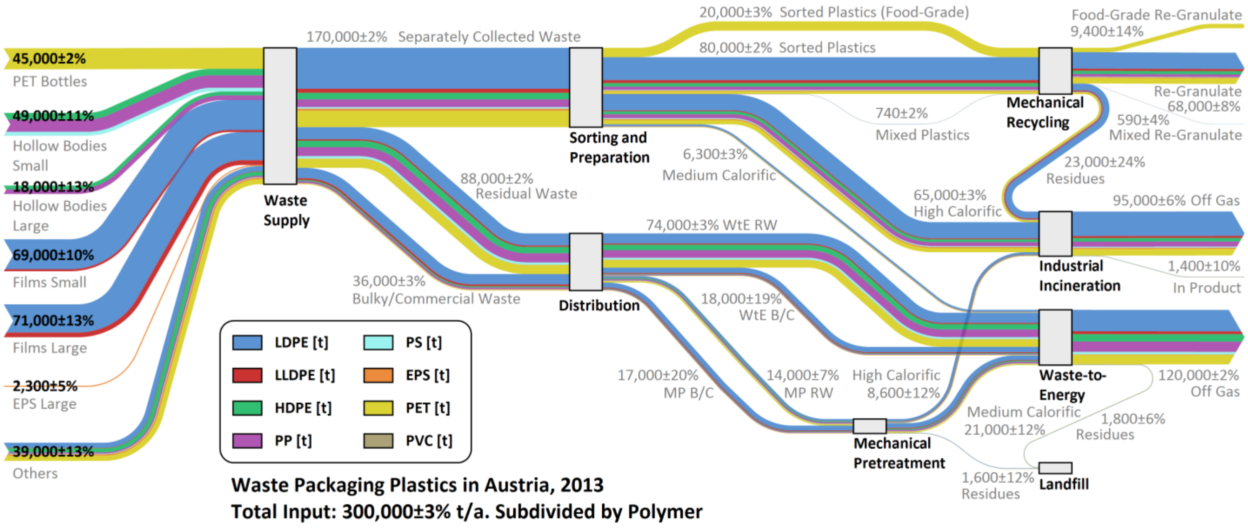

Figure 1 **Results of the MFA for the status quo of waste plastic packaging in Austria, subdivided by polymer (after Van Eygen et al. (2018a)).**

For the environmental assessment, the results for the status quo, as presented in Figure 2, show that for all 16 investigated impact categories, the waste management system achieves higher benefits, due to e.g. production of secondary materials and energy, than the impacts that are caused, resulting in net benefits. The exception is human toxicity (non-cancer), however, although here the tipping point between net impacts and benefits lies within one standard deviation. The benefits are achieved through a combination of all three major treatment options (mechanical recycling, waste-to-energy, industrial incineration), although their shares differ strongly regarding the various impact categories. Looking at the results for the treatment of the separately collected waste stream (58% of waste plastic packaging) compared to the material in the residual waste, it is clear that the former accounts for the majority of all achieved benefits across all impact categories, for instance 100% of global warming benefits, 87% for human toxicity (cancer), 78% for particulate matter emissions, 82% for ecotoxicity and 91% for mineral resources. For a more in depth discussion of the results of the status quo and the alternative scenarios, the reader is referred to Van Eygen et al. (2018b).

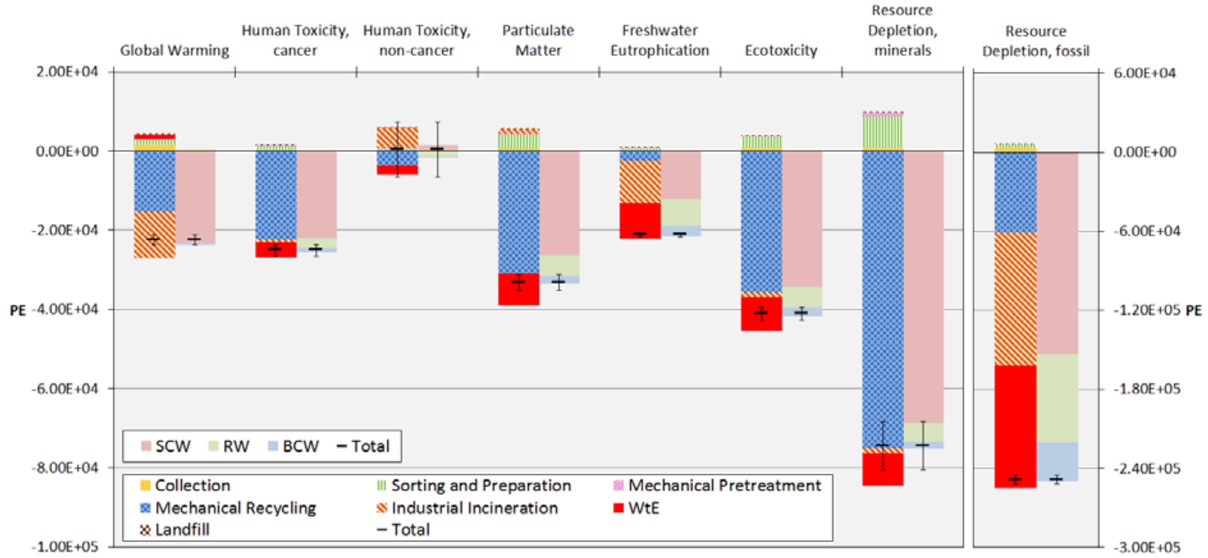

Figure 2 **Results for eight selected impact categories of the LCA for the status quo of waste plastic packaging in Austria, subdivided by treatment process and collection route (SCW: separately collected waste; RW: residual waste; BCW: bulky & commercial waste) (after Van Eygen et al. (2018b)).**

The two alternative scenarios represent a waste management system where about 60% of the waste is landfilled (based on the situation in 1994 in Austria) and 17% is sent to mechanical recycling ("Mainly disposal"), as well as a system which reaches the increased recycling target of 55% ("EU-target-SP"). The results of these scenarios in relation to the recycling rate are presented in Figure 3. Three types of relationships between the normalized results and the recycling rate can be observed (see Figure 4b and Figure S8 in the SI), as indicated by the stylized trend lines. An increasing marginal net benefit with respect to the recycling rate is recognized for human toxicity (non-cancer) due to the large net impacts of industrial incineration, the share of which increases strongly for the status quo but decreases again for the EU-target-SP scenario. On the other hand, eight impact categories (i.a. ecotoxicity, freshwater eutrophication and fossil resource depletion) display decreasing marginal benefits or even an absolute decrease in the net benefits when comparing the status quo and the EU-target-SP scenario, due to (a combination of) various reasons: the large net impact of landfilling in the mainly disposal scenario, the overall dominance of the incineration processes with respect to the net benefits, the large net impact of the sorting process, as well as the fact that mechanical recycling has a net impact itself. For the six remaining impact categories (i.a. global warming, human toxicity (cancer), particulate matter and mineral resource depletion), an approximately linear or slightly decreasing marginal benefit is apparent, generally due to the relative dominance of mechanical recycling in achieving the net benefits.

The alternative waste management scenarios thus indicate that for most impact categories increasing recycling rates lead to increased benefits. However, the marginal benefit decreases with increasing recycling rates for many impact categories, and for four impact categories the EU-target-SP scenario achieves lower net benefits than the status quo. This suggests that the environmentally optimal recycling rate is below 100% depending on the impact category. This is further reinforced by the fact that in the scenario for the EU target, no non-linear effects of e.g.

increasing separate collection on transport distances and sorting efficiency are included, which can potentially further decrease the benefits for this scenario. Therefore, future research should address these effects to create a sound basis for proposing recycling targets leading to an environmentally optimal outcome.

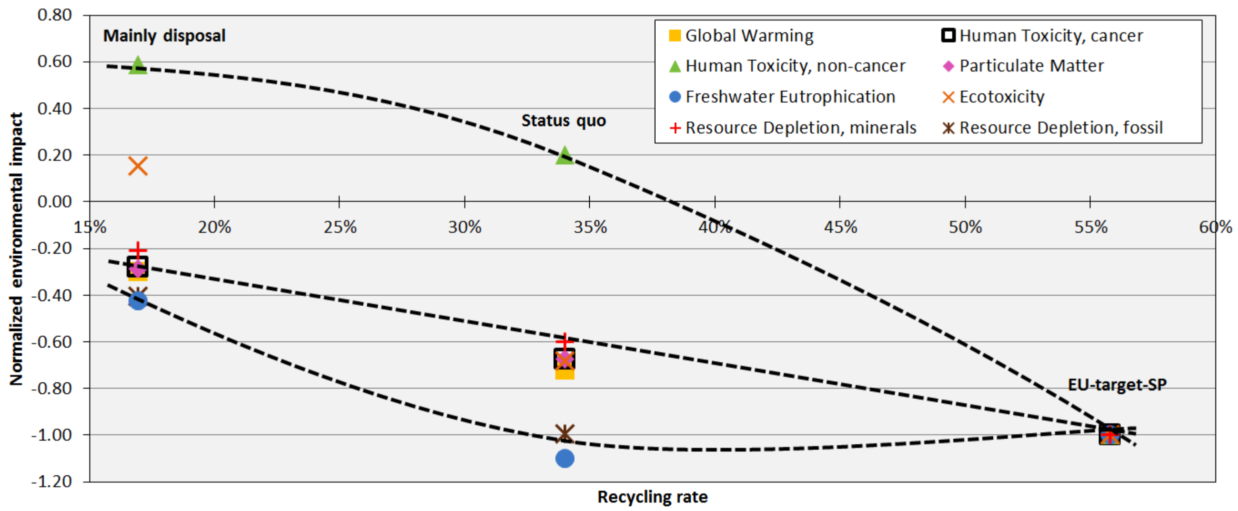

Figure 3 **Results for eight selected impact categories of the LCA for the status quo and two alternative scenarios in relation to the recycling rate. Three types of relationships between recycling rate and impact are observed, as indicated by the stylized trend lines (after Van Eygen et al. (2018b)).**

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CHARACTERIZING STOCKS AND FLOWS OF CRITICAL METALS IN PASSENGER VEHICLES

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Due to their unique properties, geochemically scarce metals (Skinner et al., 1978) have become increasingly important in emerging technology applications. Accordingly, many of them have been identified as being critical regarding supply risks and their importance for the economy in "criticality" studies (see e.g. EC, 2017). A particularly relevant application of these metals is electrical and electronic equipment (EEE) embedded in passenger vehicles: it has been estimated that around 30 tonnes of gold, 200 tonnes of silver and 1700 tonnes of neodymium were contained passenger vehicle EEE placed on the market in the European Union, Norway and Switzerland in 2014 (Huisman et al., 2017)[2].

In our contribution, we will present and discuss three projects involving Empa's Technology and Society Laboratory and aiming at characterizing stocks and flows of critical metals in passenger vehicles, with a particular focus on their classification approaches. By classification, we understand the organisation and arrangement of items into groups according to their similarities. A classification system is a system, which organises the classes according to their common relationships or affinities (van Straalen et al., 2015).

EVA project

Under the lead of the Swiss federal office for the environment (FOEN), the Swiss ordinance on the return, taking back, and disposal of electrical and electronic equipment (ORDEE) is currently being revised to include, amongst others, the recovery of scarce technology metals (STM) from EEE embedded in cars and buildings.

In particular, the revision plans to set the legal framework for a mandatory dismantling and subsequent recycling of selected embedded electronic devices (EED[3]) in end-of-life vehicles (ELV). The selection will be based on STM content and ecological and economic feasibility. However, the mass distribution of STMs among the large variety of EED is still poorly understood, and the devices to be included in the amended WEEE regulation are yet to be defined.

To support the revision, Empa’s Technology & Society Laboratory has been commissioned by the FOEN to evaluate the recovery potential of STM from ELVs in the project "Elektronik Verwertung Altautos" (car electronics recycling, EVA), which is being supported and steered by major

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[2] the corresponding numbers in non-vehicle electrical and electronic equipment, such as mobile phones and computers, were 26 tonnes of gold, 130 tonnes of silver and 1200 tonnes of neodymium, respectively, in 2015 (Huisman et al., 2017).

[3] we use the terms "EEE embedded in passenger vehicles", “EED in cars” and “car electronics” interchangeably.

stakeholders in the Swiss ELV management system. The goal of die EVA project is to inform the ORDEE revision by providing reliable data regarding:

- mass and distribution of STMs in EED in cars and the dismantling time and dismantling rate of selected EED in selected Swiss ELV dismantling facilities;
- mass fractions of selected metals[4] in the shredder light fraction (SLF) from Swiss ELV shredders;
- environmental consequences of different STM recovery interventions in the Swiss ELV management system (covering the entire Swiss car fleet).

A car is a complex system whose subsystems can be defined and classified for various purposes. In the EVA project we were interested in estimating the mass and distribution of STM in car electronics and, in particular, in identifying "hot spots", i.e. EED containing most of the mass of a specific metal. This task can be accomplished by subdividing the car into different constituent subsystems that will locate each of the considered EED, for example by physical proximity or by functionality. The chosen approach should ensure, among others, clear delimitations as to avoid double counting.

In the EVA project, we classify EED according to their role within the car system (Du et al., 2015). The EED addressed in the EVA project are part of electronic control systems (ECS), which in turn are related to the car’s electrical system. ECS are network structures in which the EED interact to accomplish specific functions in the car. EED within ECS are grouped in sensors, controllers, actuators and their interaction can be wired or wireless. The STM stocks and flows of the Swiss car fleet are characterised by applying a dynamic material flow analysis (MFA). MFA addresses goods and substances, whereby substances are constituents of goods. Accordingly, an MFA considering goods regards substances as distinct material layers.

From an MFA perspective the Swiss *vehicle fleet* is considered to be the top layer of the EVA classification system, consisting of the sublayer *individual vehicles* distinguished in types and cohorts. The vehicles consist of sublayer such as *ECS* specifically addressed in the EVA project, which is further subdivided into *devices*, *parts*, *components* and *critical metals* (see Figure 1). By incorporating the network structure of ECS within an MFA, the totality of EED (sensors, controllers and actuators) is accounted for. Moreover, the grouping of EE devices remains consistent across different car types, allowing the identification of hot-spots.

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[4] STMs (Au, Co, Dy, La, Nd, Pt, Sn, Y, Yb), hazardous metals (Cd, Pb, Sb) and base metals (Al, Cr, Fe, Ni)

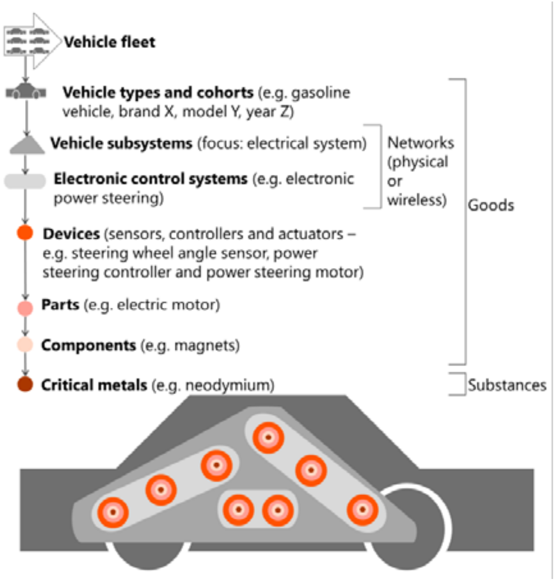

Figure 2. **The EVA project classification system (Restrepo et al., 2017)**

H2020 projects ProSUM and ORAMA

The ProSUM project was funded through the European Union Horizon 2020 programme following a call to establish an "EU network of relevant institutions […] in order to improve the sustainable supply of raw materials through an inventory component of an EU knowledge base with data and information on secondary raw materials […]" (European Commission, 2014). A consortium of universities, research institutes and industry associations worked together for 3 years to establish the first EU-wide, open access Urban Mining Platform (UMP, http://www.urbanmineplatform.eu). The UMP allows to access state-of-the-art knowledge and data on secondary raw materials in electrical and electronic equipment (EEE), batteries, passenger vehicles and mining wastes.

The project involved harmonization and consolidation of unstructured data from a large number of sources, using a 5-level classification system developed within in the project (Figure 3). This classification system conceptualizes stocks and flows as aggregations of many *products* (e.g. batteries, mobile phones, vehicles). Each product is assumed to consist of a set of *components*, such as printed circuit boards and cables, which may consist of yet other, smaller components. All components, as well as the product itself, can also be described in terms of their constituent *materials*. Finally, stocks, flows, products, components and materials may all be described in terms of the chemical elements they are composed of. All data processed in ProSUM were described by reference to these 5 levels and their code lists specifying instances of products, components, materials or elements. For the product "vehicle", the developed code list corresponded closely to data found in EU statistics, classifying passenger vehicles based on their mass, engine size and fuel type(s). Suitable code lists for components and materials did not exist prior to ProSUM and had to be developed within the project.

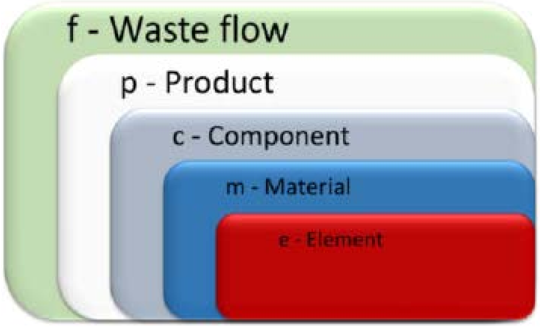

Figure 3 **The five levels of the ProSUM classification system (Huisman et al., 2016; Løvik et al., 2017)**

While the ProSUM project ended in January 2018, the work to improve data reporting methods for primary and secondary raw materials continues in the H2020-funded project ORAMA, its goal being to optimise data collection for primary and secondary raw materials in European Member States. This includes a critical evaluation of the approaches developed in the ProSUM project.

Discussion

While having different goals and scopes, the EVA- and ProSUM projects both required the development of a dedicated classification approach. We will tentatively discuss these approaches with regard to the following questions:

- Which were the main challenges in establishing classification approaches?
- How suitable were the classification approaches in their specific research context?
- What did we learn with regard to establishing future classification approaches?
- Are there suitable criteria for evaluating the quality of classification approaches?

Conclusions and outlook

When it comes to characterizing stocks and flows of critical raw materials, classification is a crucial step, as it is the precondition to match available data with the purpose of the project. Classification should, however, not become an end in itself. Rather, a balance has to be found between the (scientific?) impulse to organise and arrange items into groups as detailed and consistently as possible, and the constraints and possibilities given by, amongst others, data availability, compatibility with existing databases and new data management options. Future research may focus on developing a framework to assess different classification systems regarding, among others, their ability to “communicate” with the classifications of other methodologies.

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CURRENT AND FUTURE RECYCLING POTENTIALS FOR ALUMINIUM IN AUSTRIA

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Introduction

Aluminium (Al) is the second-most widely used metal after iron due to its unique material properties in various aspects (lightweight, flexibility, corrosion resistance, conductibility). It is increasingly used in for light-weight construction in the building sector as well as in the automotive sector. Recycling is a key strategy to satisfy part of the Al demand in a resource efficient and environmentally friendly manner, because secondary Al production causes significantly lower emissions and requires only about 10% of the energy input compared to primary Al production. In Austria and many countries of the European Union, Al production is dependent on Al scrap as an input material and the share of metal scraps in the production process is expected to further increase in the future (cf. circular economy package of the European Union).

In the present study, Austria is chosen as a case study for investigating current and future Al flows and stocks using the method of Material Flow Analysis (Brunner and Rechberger 2016). Based on the analysis of the Austrian Al cycle from a quantitative (total amounts) and qualitative (groups of alloys) perspective, the focus is put on the use of Al in the packaging sector. A detailed account of Al packaging product flows in Austria is given and major recycling loops and losses along the product lifecycle are highlighted. Finally, strategies for increasing Al recycling levels in the packaging sector are identified and discussed based on a comparison of national recycling schemes for Al packaging across Europe.

The Austrian Al cycle: Quantity and quality

A detailed analysis of Al use in Austria is presented for the year 2010 (cf. Buchner et al. 2014), when around 200,000 Mg of metallic Al was consumed domestically. Around 60,000 Mg of Al were collected as wastes and 33,000 Mg of Al were exported via end-of-life vehicles. Hence, total end-of-life flows amount for less than half of domestic Al consumption. Al supply is therefore dependent on primary and secondary sources. This is aggravated by the fact, that not all waste Al is recycled, but around 20% of the collected Al wastes are lost to landfills or oxidized during waste incineration. The difference between consumption and end-of-life flows is added to the stock. The sectors with the largest annual stock increase are the building and infrastructure (+50,0000 Mg) and the transport sector (+25,000 Mg). The only major Al consuming sector with a very small stock increase is the packaging sector, because most packaging products have short lifetimes and, therefore, do not accumulate in the use phase.

The significant growth of Austria´s Al stock indicates that even in highly developed economies, metals stocks are growing at a significant rate. Although this growth will slow down in the coming decades, the total stock of Al in Austria is expected to grow from 360 kg/capita in 2012 to around 530 kg/capita in 2050 (cf. Buchner et al. 2015). During the same period Al scrap generation will more than double (from 14 kg/capita to 31 kg/capita). Hence, due to end-of-life Al flows growing faster than Al consumption (i.e. partial saturation of some metal stocks) metal self-supply via scrap will increase. Nevertheless, even in extreme scenarios a maximum of 2/3 of domestic final Al demand could be satisfied based on domestic scrap only. Furthermore, input of primary Aluminium, is not only required due to quantitative disparities between Al demand and scrap supply, but also because of qualitative constraints (alloy compositions, product specifications, etc.). The latter is a consequence of changing Al applications over time and thus different Al alloys demanded and arising as scrap (as well as scrap contamination with materials such as organics or other metals). In addition, qualitative constraints might be increased by the absence of alloy specific sorting of Al scrap (e.g. joint recovery of cast and wrought alloys from EOL vehicles). For instance, assuming a closed Austrian Al system, mixed (wrought and cast alloys not sorted) Al scrap generation in the transport sector would exceed the demand for cast Al alloy in Austria within the next 10 to 20 years (cf. Buchner et al. 2017). Therefore, higher domestic added value of Al scrap utilization could be generated by applying advanced sorting technologies to produce high quality (alloy specific) scrap, which could be utilized for defined product specifications and alloy compositions thereby facilitating high-value regional material cycles.

The Al packaging product cycle

Al is used ever more frequently for household goods and packaging material, which represents a readily available source for secondary Al due to its short lifetime. To investigate the extent to which this potential source for recycling of Al is already utilized in Austria, a detailed material flow analysis for Al used in packaging & household non-packaging in 2013 was conducted.

In practice, all Al flows starting from market entrance through waste collection and processing until its final recycling or disposal have been investigated. The results indicate that about 25,100 t/a (2.96 kg/cap/a) of Al packaging & household non-packaging arose as waste. At present about 9,800 t/a, or 39%, are recycled as secondary Al, of which 26% is regained from separate collection and sorting, 8% from bottom ash and 5% from mechanical treatment. The type of Al packaging & household non-packaging affects the recycling rate: 82% of the total recycled quantities come from rigid packaging & household non-packaging, while only 3% of the total recycled Al derives from flexible materials. A significant amount of Al was lost during thermal waste treatment due to oxidation (10%) and insufficient recovery of Al from both waste incineration bottom ash and municipal solid waste treated in mechanical biological treatment plants (49%) (Figure 1). Overall it can be concluded that once Al ends up in commingled waste the recovery of Al becomes less likely and its material quality is reduced. Although Austria can refer to a highly developed recycling system, the Austrian packaging industry, collection and recovery systems and waste management need to increase their efforts to comply with future recycling targets.

These recycling targets have become more ambitious within the European Union through the EU Action Plan for the Circular Economy, an initiative to increase the re-use and recycling and

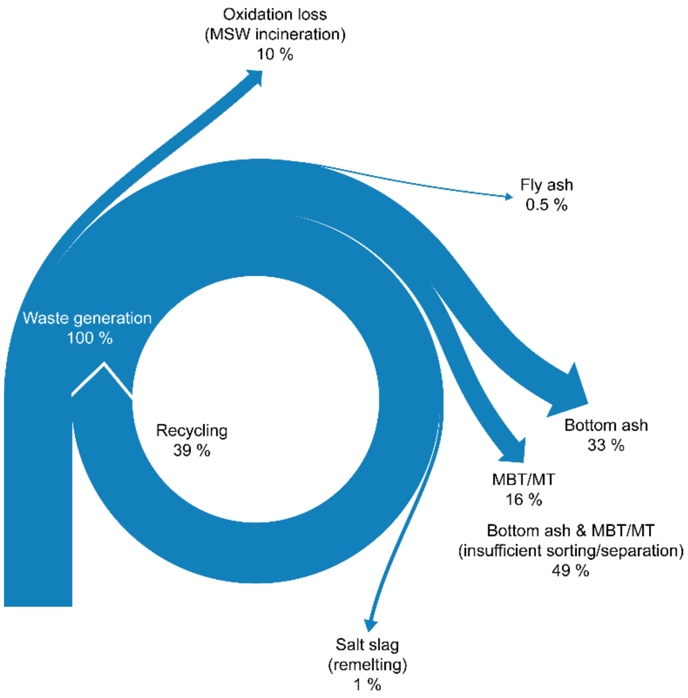

Figure 4. Circular representation of Al packaging & household non-packaging, Austria 2013.

recovery of manufactured goods and consumer goods (EC, 2014) in order to reduce the use of raw materials and associated (environmental) burdens. The proposal to amend the Packaging and Packaging Waste Directive requires that for Al packaging a recycling rate of 50% (2025), resp. 60% (2030) will be required (Official Journal L 150, 2018). A research project on waste management tried to evaluate the actual state of recycling quantities for Al packaging in comparison to the projected targets of the EU Circular Economy. As Al packaging is recovered through different systems (separate collection, deposit refund system, informal collection, bottom ash of MSWI or mechanical treatment), it was aimed to find out through which system and to what extent Al packaging was recovered.

The study examined the management of Al packaging in 16 selected European countries, with results for 11 countries. The results show that six out of 11 countries recycle at least 2/3 of the Al packaging from MSW and only three report very low recycling rates of 20-35%. The countries generate between 0.9 and 2.7 kg Al packaging per capita per year (Figure 2). Two countries (Sweden and Germany) use a deposit refund system (DRS) and have the overall highest rates of collected Al packaging (selective collection and DRS), whereof in Germany a larger part comes from selective collection. Other countries with similar or higher recycling rates (Belgium and the Netherlands) do not use DRS, but recover large volumes from bottom ash (BA) treatment from municipal solid waste incineration (MSWI). Low recovery rates can be correlated to high landfilling (50-84%), while the six countries with the highest recycling rates (except Italy) only deposit 1-3% of their MSW at landfills. No overall correlation between consumption and recycling rate could be demonstrated, as for example Germany has a low consumption rate (1.4 kg/cap) and a high recycling rate (88%), while the UK has a high consumption rate (2.7 kg/cap) and a medium recycling rate (50%).

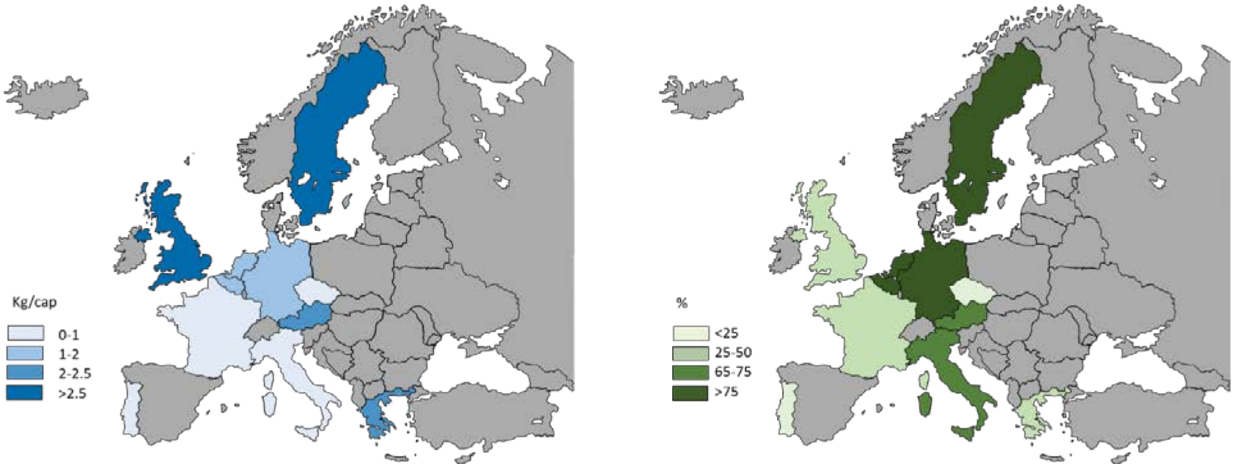

Figure 5. Al packaging in selected EU Member States. Market volumes (kg/cap) and recycling rates (%).

It was not the purpose of this work to question or review the data obtained. But the results show that the recycling rates in the various EU Member States are based on different assumptions and are therefore difficult to compare. The recovery from BA from MSWI e.g. is sometimes based on the assumption that 100% of the Al in BA is originating from Al packaging, while other consider less (Portugal 55%) or do not include recovery of Al from BA is in the recycling rate for Al packaging (Sweden). Furthermore, recovery rates from BA are mostly based on estimations of average recovery yields for non-ferrous and vary depending on particle size and degree of separation (e.g. 50% for Austria >4 mm; Netherlands 77% > 5.6 mm). Considerable quantities of waste are imported (e.g. Netherlands) from countries for which it is advantageous to be able to reduce their waste volumes. This leads to modified recycling rates both in the exporting country with a lower waste volume and in the importing country with a higher recycling rate (Eunomia, 2011).

Some countries gain almost the entire amount of recycled Al packaging through selective collection. Italy has thereby the highest rate of selectively collected Al packaging (67.8%) of all countries, which is remarkable as only 43% of the MSW is recycled and more than ¼ of Italy’s waste is landfilled (EUROSTAT, 2017). To which extent e.g. non-related materials (impurities, adhesives) affect the recycling rates of the various EU Member States is not known. As the EC (2015) stated should the “weight of materials or substances that are not subject to a final recycling process […] remain below 10% of the total weight to be reported as recycled”, but a survey by Eunomia (2016) indicated for Al packaging losses up to 60-70% during collection, sorting and recycling processes.

The study clearly demonstrates the differences in official data and the consequent need for a uniform and precisely formulated requirement for data collection. Finally, the question arises why the originally intended higher goals for Al packaging (70% for 2025) within the EU Action Plan for the Circular Economy (EC, 2015) were not realized as a lot of countries already reach these targets.

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CHALLENGES FOR THE RECYCLING AND RECOVERY OF END-OF-USE TEXTILES

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Introduction

Textiles are the most common usage of fibres and a life without textiles is unthinkable today. Textiles are both, a basic human need and a matter of fashion and style. In 2016, worldwide fibre production has exceeded 90 million t (CIRFS 2017). For the next years, a strong increase in fibre production can be expected. It has to be considered that fibres are not a final product and that the production of apparel and home textiles requires a long and elaborate processing chain. The energy that is consumed for 1 t of final garment adds up to 330 GJ which is equivalent to about 8 t of petroleum (Woolridge et al. 2006). In view of the large amounts of resources and energy that are consumed for textile production, a proper handling of end-of-life textiles is highly recommended.

End-of-life textiles

Any re-use or recycling of end-of-life textiles is only possible if a separate collection scheme is established. It has to be noted that, in contrast to packaging waste, any separate collection is usually not based on extended producer responsibility. Many consumers have ethical concerns about disposing of textiles that are still functional. Thus, the market is dominated by organizations that use the profits of textile reuse for charity purposes. However, also public and private entities are active in this field.

For the collection of end-of-life textiles different systems are possible, namely container collection, collection campaigns or recycling centres. Container collection represents the most effective method and in Germany it is responsible for 88 % of the collected material (Korolkow 2014).

Table 1 shows the amount and share of separately collected end-of-life textiles for selected countries. Germany is the leading nation with an annual collection volume of more than 1 million t, corresponding to 74 % of the textiles put on the market (Korolkow 2014). Other countries lag behind and the collection rate can be as low as 15 % as reported for the USA (EPA 2015). It should be considered that data acquisition is not consistent as it might include apparel and light home textiles only (e.g. Germany) or also cover carpets and shoes (e.g. USA). Nevertheless, the conclusion can be drawn that significant improvements in end-of-life textile collection are necessary.

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Table 1 **Amount of collected post-consumer clothing and the collection rate (collected amount in relation to amount put on market) for selected countries.**

Country	Year	Collected amount of end-of-life textiles		Reference
		[1000 t]	[mass %]	
Germany	2013	1,011	74	Korolkow 2014
Denmark	2010	35	48	Tojo et al. 2012
Finland	2010	25	39	Tojo et al. 2012
UK	2008	523	24	Morley at al, 2009
Sweden	2010	26	22	Tojo et al. 2012
USA	2013	2,300	15	EPA 2015

Waste prevention

Even though waste prevention has the highest priority according to the waste hierarchy, in the textile sector the opposite takes place. Apparel is getting disposed of more often and the useful life is distinctly decreasing as shown in Table 2. A not insignificant reason are the ever lower prices for clothing, especially from Asia.

Table 2 **Useful life of different groups of apparel in 1998 and 2005; the percentages show the values for 2005 in relation to 1998 (Korolkow 2014).**

Product	Mean useful life [Months]		Change [%]
	1998	2005	
Stockings, underwear	21	18	- 14.3 %
T-shirts, shirts, blouses	36	27	- 25.0 %
Jeans and trousers	40	24	- 40.0 %
Dresses, suits	67	46	- 31.3 %
Pullovers, coats	63	40	- 36.5 %
Tracksuits	46	24	- 47.8 %

Sorting

Commonly collectors of end-of-life textiles ask the customers to put items in the container only, if they are clean, not worn and still functional. In any case the collected material has to undergo a sorting procedure. On the one hand, waste and damaged items have to be removed. On the other hand, the textiles have to be sorted into different fractions according to product group, material or colour. In Germany on average 154 fractions are obtained, however, some sorting facilities generate up to 350 fractions (Korolkow 2014).

Reuse

The reuse of collected textiles is well established and is called second-hand clothing (SHC). The most effective solution is so sell SHC in the areas where they have been collected. Thus the transportation is minimised and a profit of about 10,000 €/t can be obtained. However, in practice the fraction of SHC to be sold in industrialized countries is only 1 to 3 % of the collected items. Commonly customers prefer to buy new clothing and thus the major fraction of SHC is exported to emerging and developing countries. Regardless of whether charity, commercial or municipal collector, SHC is commonly sold at market prices.

Even if the exported apparel is actually used, the question must be asked if this corresponds to the idea of the Circular Economy. At some point in time, the exported SHC will reach the end-of-life status, but in the recipient countries no proper waste management exists. Worn and damaged items will end up in open dumps or rivers and might finally contribute to marine litter. It should also be considered that rather cheap SHC might damage the textile industry in the receiving countries.

Recycling

There is a great spectrum of procedures for the recycling of end-of-life textiles. Generally it has to be considered that the production chain for apparel and textiles is long and consumes large amounts of energy and resources. It must therefore be emphasised, that recycling processes should avoid a redoing of the textile processing chain as much as possible. The savings potential of the methods listed in the Table 3 decreases from top to bottom.

Table 3 Different categories of recycling textile wastes.

Category	Features
Cleaning and wiping rags	• Only for hydrophilic fibres such as cotton, linen or viscose • Removing of fastenings, eyelets or zippers • Cutting into 30 x 30 cm pieces • Feasible for damaged items • At the interface of reuse and recycling (fabric is reused) • Market price relatively high (1,500 to 2,000 €/t) • Elaborate, expensive and labour intensive production
Fibre recovery	• Fabric is disintegrated into individual fibres • Commonly using a Garnett machine • Feasible for dirty and damaged items • At the interface of reuse and recycling (fibre is reused) • Fibres are short and contain dust • Commonly mixture of different materials and colours • Theoretically feasible for yarn formation • In practice used for nonwovens (low quality)
Fibre Flock	• Fibres with low length, not feasible for spinning • Feasible for all kinds of fibrous wastes • Can be used for numerous applications (e.g. adjusting viscosity of liquid and pasty products)

Table 3 (continuation) Different categories of recycling textile wastes.

Category	Features
Re-spinning	• End-of-life textiles are molten or dissolved and used for de novo fibre spinning • Melting: for thermoplastic materials (e.g. Polyester, Polyamide, Polypropylene) • Solving: for polymers such as PAN or cellulose • Limited applicability as textiles contain different fibre types • Using selective solvents (e.g. NMMO for cellulose) • Removal of certain fibre types (e.g. cellulose by enzymatic hydrolysis)
Feedstock recycling	• Polymers are broken down into monomers and de novo polymerization • Wide range of applicability • Repeated pass of complete textile processing chain

Summary

Textiles represent a considerable amount of waste and in view of the large quantities of energy and resources that have been spent for their production, reuse and recycling are of great importance. Ostensibly, waste management of end-of-life apparel seems to be far developed. In some countries, such as Germany, a large fraction is collected separately from residual waste and is to a large extent reused as second hand clothing. However, it has to be considered that reuse of textiles mainly takes place outside of the EU. As waste management in the receiving countries is usually poor, environmental protection and are not guaranteed and health problems might occur. In view of the Circular Economy new strategies for end-of-life textiles are urgently required.

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SUSTAINABLE MANAGEMENT OF FLY ASHES FROM WASTE INCINERATION

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Introduction

The main goals of waste management are the protection of humans and the environment from the hazards potentially caused by waste and the conservation of resources. A treatment option for municipal solid waste (that is not separated at source) in line with these goals is waste incineration (Brunner and Rechberger, 2015). However, about 25 % of the waste input into a waste incineration plant arise as bottom ash and about 3 % of the waste input arise as fly ash (Morf et al., 2000). This fly ash constitutes a hazardous waste and has to be disposed of accordingly.

There is a multitude of different utilisation and disposal options for municipal solid waste incineration (MSWI) fly ash. The most common ones are stabilisation with cement, which allows disposal at non-hazardous waste landfills, and disposal at underground deposits, while recovery of secondary raw materials from MSWI fly ash has awoken more and more interest (Quina et al., 2018). As all of the available MSWI fly ash management options are associated with various disadvantages, an innovative process for the treatment of MSWI fly ash is presented. This process comprises the thermal co-treatment of MSWI fly ash together with combustible waste in an already existing MSWI plant.

Materials and methods

In a large-scale experiment, up to 300 kg moistened fly ash per Mg of combustible waste were treated in a rotary kiln hazardous waste incinerator for 102 h. The inserted MSWI fly ash as well as bottom ash, fly ash and scrubber water from the rotary kiln were sampled and chemically analysed (Huber et al., 2016).

The moistening of fly ash effectively prevented dust emissions during transport and storage. However, hydration reactions in the moistened material caused a temperature increase and formation of lumps of hardened fly ash in the waste bunker, which both impair the continuous and safe operation of the incinerator. As a possible solution to this problem, agglomeration was investigated as pretreatment prior to insertion in the waste bunker. About 400 kg of pelletised MSWI fly ash were produced and treated in a pilot-scale electrically heated rotary kiln at different temperatures and angles. The original fly ash, fly ash pellets (prior and after treatment) and secondary fly ash collected by a filtering device were sampled and chemically analysed. Furthermore, physical tests of the fly ash pellets were performed (Huber et al., 2018a).

Based on the recorded mass flows and the results from the chemical analysis of the above mentioned experiments, transfer coefficients on goods and substance level were established.

The experimental data was used to determine the environmental impact of thermal co-treatment of MSWI fly ash together with combustible waste by life cycle assessment (LCA). In order to compare the presented process with the state of the art, a total of 7 different MSWI fly ash management scenarios (comprising underground deposit, stabilisation with different amounts of cement, metal recovery, chloride salt recovery, thermal treatment in furnaces fueled by coal, natural gas or combustible waste and utilisation in cement clinker production) were established and modelled. The life cycle inventory data was sourced from ecoinvent database V3.2 (2015). The life cycle impact assessment was conducted using the ReCiPe model (Hierarchist perspective) (Goedkoop et al., 2009). The impact in all midpoint and endpoint impact categories was calculated for two different timeframes (100 a, infinite) (Huber et al., 2018b; Huber and Fellner, 2018).

Uncertainty analysis was performed by Monte Carlo simulation (MCS) and an discernibility analysis according to Clavreul et al. (2012) was conducted.

Results and Discussion

The material flows determined in the large-scale and pilot-scale experiments suggest that more than 90 % of the inserted MSWI fly ash are bound into the bottom ash of the rotary kiln.

The results of the chemical analysis indicate that the addition of MSWI fly ash to the waste input increased the Cl content of bottom ash by about 75 % (+3,700 mg/kg). As no other significant changes in bottom ash composition and leachability were detected, the bottom ash still complied with all legal limits for non-hazardous waste landfills.

The pilot-scale experiments demonstrated that the transfer coefficients of certain elements (Cd, Cu, Hg, Pb, Zn) were larger at higher temperatures. Yet, treatment at 450 °C for about 10 min was already sufficient to generate a non-hazardous waste from MSWI fly ash. Notably, the leachate content of Ag, As, Cd, Co, Cu, Hg, Ni, Pb, Sb and Sn was decreased by the pelletisation process and even further decreased to close to 0 by the subsequent thermal treatment.

Chemical analysis of the secondary fly ash generated in the pilot-scale experiments revealed that this residue is enriched in Cu (up to 11,000 mg/kg), Pb (up to 91,000 mg/kg) and Zn (up to 21,000 mg/kg), depending on the treatment temperature. Due to this high metal concentration, secondary fly ash could have a considerable potential for resource recovery, e.g. by acidic leaching (Fellner et al., 2015; Schlumberger, 2010).

The aggregated overall impact is lowest (close to 0) for metal recovery by FLUREC process, mainly due to the benefit in human toxicity and metal depletion caused by production of secondary metals and the low impact in most other midpoint impact categories. The total environmental impact is especially high for the thermal treatment in coal-fired furnace and utilisation in cement kiln with salt recovery mainly due to the high consumption of hard coal and natural gas, respectively. This is in agreement with the findings of Fruergaard et al. (2010), which already state that thermal treatment of MSWI fly ash has a very high environmental impact due to the high energy demand. In contrast, the environmental impact of thermal co-treatment of MSWI fly ash together with combustible waste is in many midpoint and all endpoint impact categories significantly lower compared to thermal treatment in a separate furnace. Therefore, it could be shown that the presented process provides a more environmentally friendly option than other thermal treatment processes. Furthermore, the environmental impact of the new process is also lower than many other common disposal options for MSWI fly ash, e.g. stabilisation with cement. The low environmental impact of metal recovery as determined by LCA is in line with the results of Bösch et al. (2011).

Conclusions and outlook

It could be demonstrated that co-treatment of MSWI fly ash together with combustible waste in an existing waste incinerator represent a feasible management option. Pelletisation of MSWI fly ash prior to its thermal treatment is a promising pretreatment process that can facilitate the introduction of fly ash into the incinerator and thereby ensure its continuous operation. Due to the transfer of volatile heavy metals, effective decontamination of MSWI fly ash takes place and the remaining material (transferred to the bottom ash) complies with legal limits for non-hazardous waste landfills after treatment.

Yet, the combination of pelletisation and thermal treatment of MSWI fly ash was only conducted in an electrically heated pilot-scale kiln without the addition of combustible material. Consequently, further investigations on the co-treatment of MSWI fly ash pellets and combustible waste are advisable in order to confirm the results presented. As all experiments carried out so far were performed using rotary kilns, future experiments should also be conducted in grate furnaces, which constitute the most common type of furnace used in MSWI.

The transfer of volatile metals (e.g. Cd, Cu, Pb and Zn) to secondary fly ash is not only a mechanism for decontamination of the bulk of the material but also leads to higher concentrations of these elements in the secondary fly ash. As metal recovery is only economically feasible for fly ashes with very high Zn concentrations, combined pelletisation and thermal co-treatment together with combustible waste can be used to generate residues with a higher metal concentration and subsequently recover these metals at acceptable costs. The environmental impact assessment performed showed that the newly developed MSWI fly ash treatment and disposal process is preferable over stabilisation with cement and, thus, contributes to the goals of waste management, protection of humans and the environment and conservation of resources.

Acknowledgements

The work presented is part of a large-scale research initiative on anthropogenic resources (Christian Doppler Laboratory for Anthropogenic Resources). The financial support of this research initiative by the Federal Ministry of Digital, Business and Enterprise and the National Foundation for Research, Technology and Development is gratefully acknowledged. Industry partners co-financing the research centre on anthropogenic resources are Altstoff Recycling Austria AG (ARA), Borealis group, voestalpine AG, Wien Energie GmbH, Wiener Kommunal-Umweltschutzprojektgesellschaft GmbH (WKU), and Wiener Linien GmbH & Co KG.

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SESSION 2:

ANALYSIS OF ANTHROPOGENIC RESOURCE STOCKS

DATA BASE FOR A RESOURCE EFFICIENT MANAGEMENT OF VIENNA´S BUILDING STOCK

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Background

Buildings constitute a major contributor to material use and accumulation in human settlements. Therefore, they play an important role when moving toward a more circular use of natural resources. Data about the material composition of buildings and dynamics in the building stock are considered a prerequisite to defining effective resource management measures. This work, therefore, aims at providing such data through investigating buildings as potential urban mines in the sense that existing material stock can be used as a future mine for secondary resources. The city of Vienna has been chosen as a case study.

Specific material intensities for different building categories

In order to generate data about the composition of buildings in Vienna, specific material intensities for different building categories are defined. This is done based on different data sources. A practical method is presented to characterize the material composition of buildings prior to their demolition. The characterization method is based on the analysis of available construction documents and different approaches of on-site investigation. The method is tested in case studies carried out, and results indicate that the documents are useful to quantify bulk materials (e.g. bricks, concrete, sand/gravel, iron/steel and timber). On-site investigations are necessary to locate and determine materials of lower concentration such as metals (e.g. copper and aluminium) or plastics.

Figure 6 **Analysis of plan documents, on-site investigation, and analysis during the demolition.**

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To enlarge the sample size of buildings being investigated, construction files of already demolished buildings are analysed to determine the specific material composition of the buildings. Additionally, new buildings are investigated based on existing life cycle assessments, accounting documents and construction plans. The database for specific material intensities for different building categories is complemented with data from the literature.

Building structure and material stock

In a second step material stocks in buildings and their spatial distribution are analysed. In particular, the building structure is analysed by joining available geographical information systems (GIS) data from various municipal authorities. The previously generated specific material intensities for different building categories are subsequently combined with the data on the building structure. This allows the overall material stock in buildings in Vienna to be calculated as well as the spatial distribution of materials in the municipal area to be assessed. This research forms the basis for a resource cadastre, which provides information about gross volume, construction period, utilization, and material composition for each building in Vienna.

In a further step, the information about the material composition of buildings is combined with data on the demolition activity in order to estimate quantity and quality of demolition waste generated. The volume of demolished buildings is calculated based on two different data sources (demolition statistics and change detection data) and multiplied with the respective material composition.

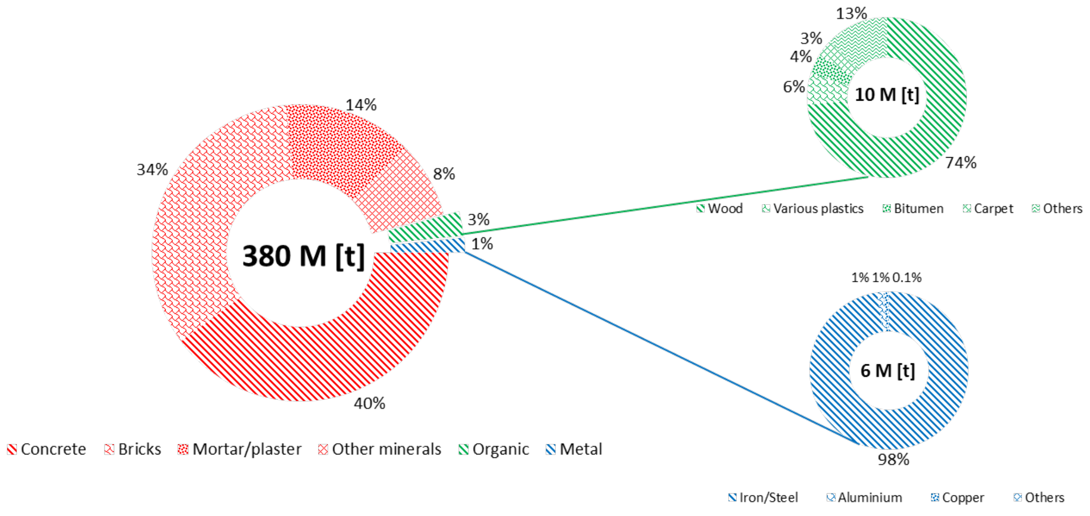
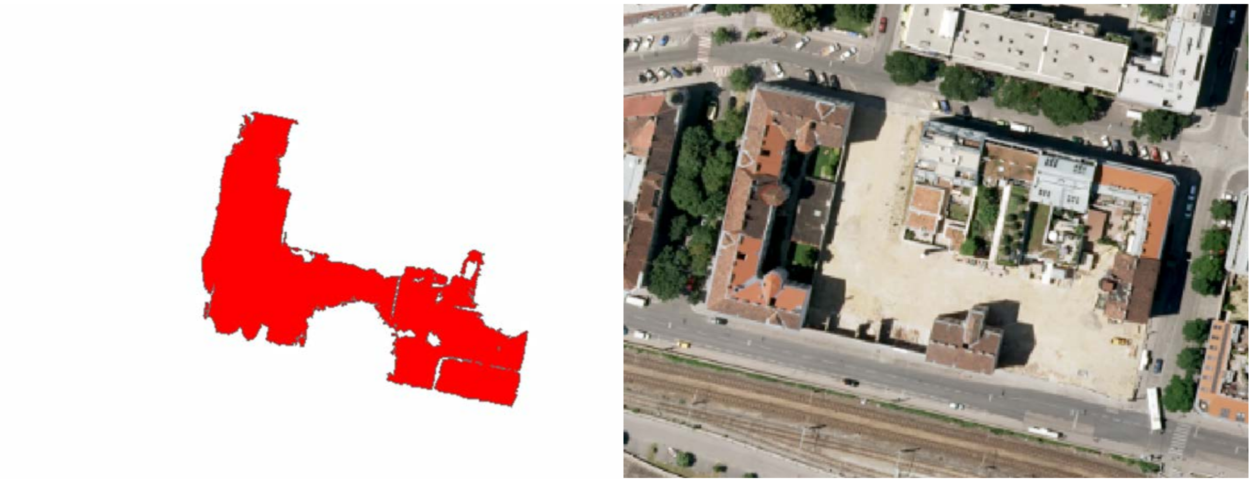


Figure 7 **Material composition of the building stock in Vienna in million tons.**

Demolition activity and associated demolition waste

In a third step an approach is presented that allows demolition statistics to be validated by using data of automatized change detection of the building stock. Based on this technique, building demolition activities in the municipal area are detected based on yearly aerial images. Results show that demolition statistics do not cover all demolition activity in Vienna and, consequently, demolition waste generation figures solely based on statistical data of demolition activities would underestimate the total waste generation. The approach used in this study can be useful for validating existing data on demolition waste generation and demolition statistics or to generate data if no data is available.

Difference Model (2013/2014) Orthophoto (2014)



Orthophoto (2013) GIS Data (2012)

Figure 8 **Identification of a demolition project based on the difference model from image matching change detection.**

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MEASURING PROGRESS TOWARDS A CIRCULAR ECONOMY IN EUROPE: A MONITORING FRAMEWORK FOR ECONOMY-WIDE RESOURCE USE, WASTE AND CIRCULARITY

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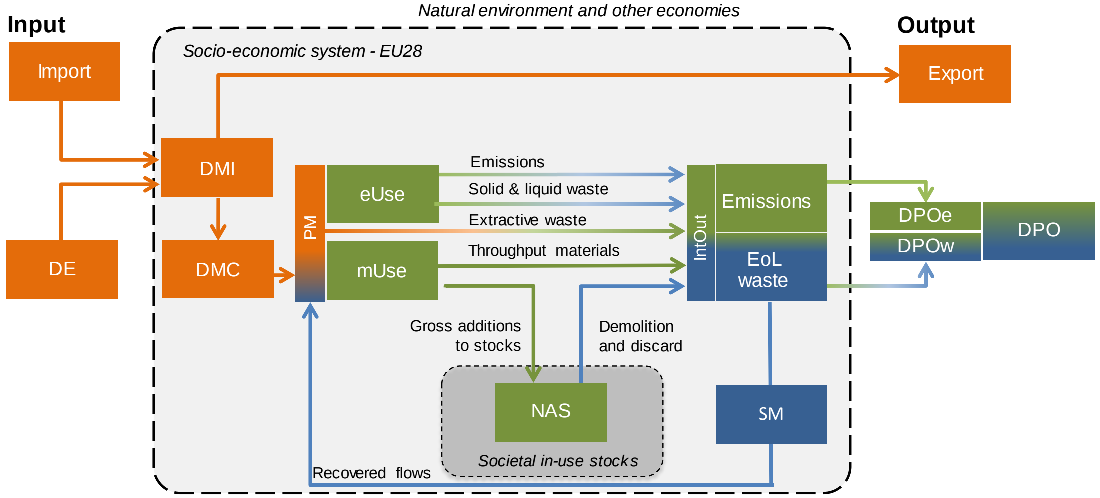
Requirements for monitoring the circular economy at the macro-level

The concept of a circular economy is gaining increasing attention from policy makers, industry and academia. There is a rapidly evolving debate on definitions, limitations, co-benefits, the potential contribution to a wider sustainability agenda and a need for indicators to assess the effectiveness of circular economy measures at larger scales. In order to also achieve progress towards sustainability, the transition to a circular economy must not only be limited to materials of particular concern (e.g. plastics), sectors (the metal-processing industry) or end-of-pipe recycling, but requires a systemic change that encompasses the entire economy with all products and services - i.e. all resource flows (Haas et al. 2015; Geissdoerfer et al. 2017).

The European Union is pushing for a transition towards a circular economy with the aim of reducing waste and emissions, conserving natural resources, while increasing net benefits to local communities and creating jobs. For them, the circular economy refers to an economy in which the value of products, materials and resources within the economy is maintained for as long as possible. For this transition to a more circular economy, continuous monitoring of resource use is crucial in order to be able to take successful measures. For this purpose, the European Commission introduced The *Circular Economy Policy Package* in January 2018, containing a monitoring framework for identifying and evaluating progress and barriers on the way towards a circular economy, which was jointly developed by researchers from the Institute of Social Ecology and the EU Joint Research Centre (JRC) in Ispra (Mayer et al. 2018).

Herein, we present this recently published framework for a comprehensive and economy-wide biophysical assessment of a circular economy, utilizing and systematically linking official statistics on resource extraction and use and waste flows in a mass-balanced approach (Mayer et al. 2018). This framework builds on the widely applied framework of economy-wide material flow accounting and expands it by integrating waste flows, recycling and downcycled materials (Figure 1). We propose a comprehensive set of indicators that measure the scale and circularity of total material and waste flows and their socio-economic and ecological loop closing. We applied this framework to assess the circularity of the European Union (EU28) for the year 2014.



DE = Domestic extraction; DMI = Direct material inputs; DMC = Domestic material consumption; PM = Processed material; eUse = Energetic use; mUse = Material use; NAS = Net additions to stocks; IntOut = Interim outputs; EoL waste = End-of-life waste; SM = Secondary materials; DPOe = Domestic processed output of emissions; DPOw = Domestic processed output of wastes; DPO = Domestic processed output

Figure 9: The economy-wide monitoring framework for the circular economy (Mayer et al. 2018)

We found 7.4 Gt of materials were processed and used in the EU and only 0.71 Gt of them were secondary materials (Figure 2). The derived input socio-economic cycling rate of materials was therefore 9.6%. Further, of the 4.8 Gt of interim output flows, 14.8% were re- or downcycled. About one fifth of the resources consumed consist of fossil fuels that cannot be recycled, as they are mainly emitted in the form of climate-damaging CO2 after combustion. Since the monitoring framework is accounting for all materials turned over in the EU28, it is robust against resource savings of one material at the expense of another, since it records both savings and extra consumption based on statistics on extraction and trade.

Based on these findings and our first efforts in assessing uncertainty and sensitivity of the framework, a number of improvements and next steps are deemed necessary: Improved reporting of wastes, explicit modelling of societal in-use stocks, introduction of criteria for ecological cycling, and disaggregated mass-based indicators to evaluate environmental impacts of different materials and circularity initiatives.

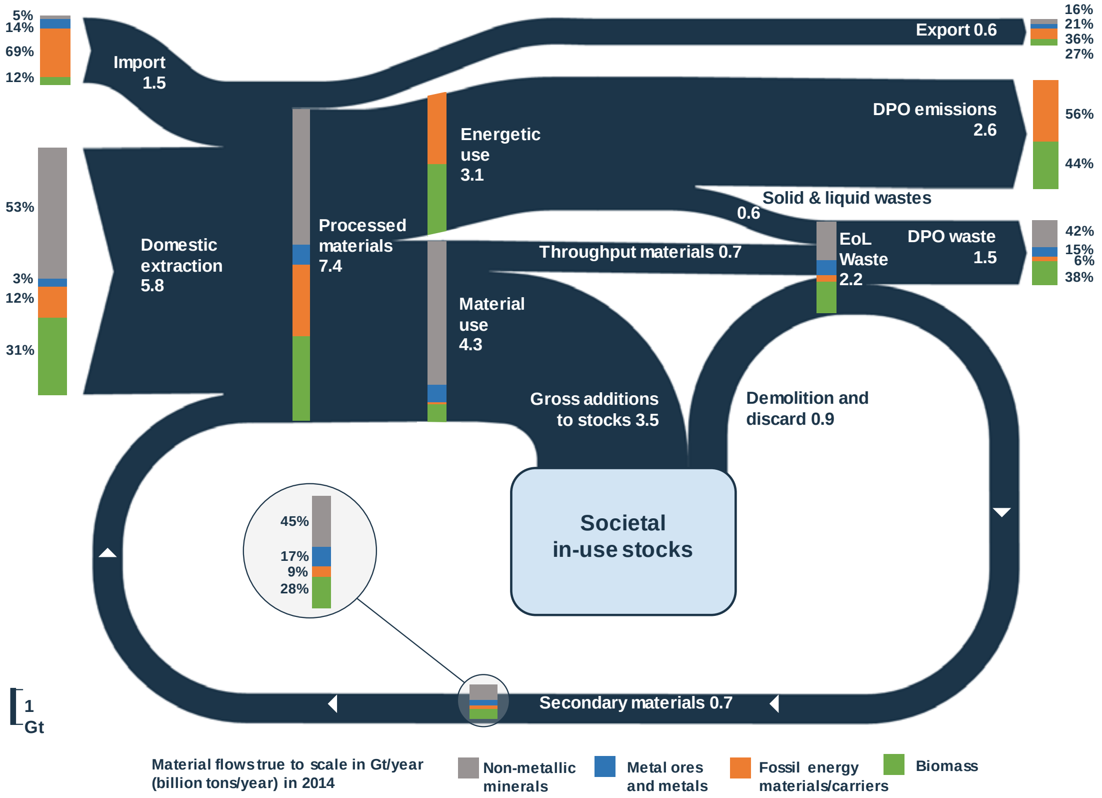


Figure 10: The state of circularity in the EU28 in 2014. In this Sankey diagram the width of the arrows is proportional to the size of material flows (dark blue); the numbers show the size of the material flows in Gt/yr and the bars their composition (share of four main material groups in %). Note that numbers may not always sum up to total due to rounding. (Mayer et al. 2018)

This scalable framework can also be applied for national level monitoring, which can then be (re)aggregated to the European level, to identify national contributions to European targets and developments. A first application of this framework to the country-level has also been conducted (Jacobi et al. 2018). In a further step, a dynamic modelling perspective can be introduced into the economy-wide MFA framework (Wiedenhofer et al. accepted), to a) investigate long-term trends in resource use, waste and circularity and b) to improve the derived understand of the potentials for future loop closing due to ageing stocks of buildings, infrastructure and machinery and the resulting waste potentials.

Conclusions

The consumption of resources in the EU currently indicates several "hotspots" where there is an urgent need for action to close material cycles. Almost 60% of the resources are used for the construction and maintenance of buildings and infrastructures (Mayer et al. 2018). These built-environments do not only require a lot of energy during operation or use, but also need primary materials for maintenance and expansion (Wiedenhofer et al. 2015; Krausmann et al. 2017). Additionally, their long life expectancy, which keeps resources in the loop and thus deliver net benefits to society for decades, also postpones closing the loop, which means that secondary raw materials from demolition and recycling will only be available in the far future (Krausmann et al. 2017; Wiedenhofer et al. 2015, accepted). Moreover, the massive use of fossil fuels and the partly unsustainable use of biomass are further major problems that keep overall circularity low, despite high recycling rates for e.g. metals.

Contrary to the current low circularity rates of less than 10% in the EU28, there are also a few encouraging signals. Upward trends in building renovations targeted to improve thermal-insulation reduce the consumption of fossil fuels, as well as the construction of long-lasting infrastructures and products with low maintenance intensity and low energy-demand during operation reduces the consumption of natural resources. Furthermore, the recyclability of products is increasingly being considered in the design phase, and consumers increasingly prefer repairs over new purchases, but overall the positive effects are very limited if not negligible yet. In order to actually achieve a clearly positive effect for the environment, however, decisive measures are needed and there is definitely a need for (policy, industrial, individual, etc.) initiatives to make the use of natural resources more efficient.

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URBAN MINING – A CHALLENGING CORNERSTONE FOR A SOUND CIRCULAR ECONOMY

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Abstract

The transition to a circular economy necessitates fundamental changes to production and consumption patterns. These major challenges can only be overcome by greatly expanding the knowledge base and by developing a comprehensive analytical framework (Reichel et al., 2016). To realize the circular economy it is necessary to consider material flows from the perspective of an entire life-cycle, encompassing the entire value-creation chain from raw material extraction to the management of waste. Success can be measured in terms of reducing the outflows from material cycles, lowering the amount of material disposed as waste and reducing dissipative emissions while conserving the utmost of natural resources (UBA, 2015).

Until now, a major factor underpinning the circular economy has been insufficiently regarded, namely the strongly time-dependent dynamic of material stocks, particularly in relation to the lifespans of durable goods. In some cases, material cycles can only be closed after several decades (Wittmer and Lichtensteiger, 2007). Whereas fossil fuels and biomass are largely consumed to produce energy or as foodstuffs/animal feed, the vast bulk of metals and mineral building materials is retained in the anthroposphere for many decades, contributing to an ever-increasing anthropogenic stock of material (Gerst and Graedel, 2008). A country’s productive capabilities are largely influenced by the existing anthropogenic stock and the structure of durable goods such as buildings, infrastructure and industrial capital goods. Durable goods of the anthropogenic material stock provide services while also creating certain dependencies in regard to meet future raw material requirements (Liu and Müller, 2013).

The concept of *Urban Mining* calls attention to those important deposits and occurrences of anthropogenic materials and possibilities of their exploitation. The German Environment Agency understands Urban Mining as integral management of the anthropogenic stock with the aim of obtaining secondary raw materials from durable products, buildings, infrastructures and deposits. In the context of environmental policy, it encompasses the prospection, exploration, collection and consumption of anthropogenic material stocks as well as the processing of the extracted secondary raw materials (Müller et al., 2017a and 2017b).

Urban Mining may provide the necessary systematic, interdisciplinary framework for material flow management in order to integrate growth and shrinkage dynamics in the anthropogenic stock into a resource-efficient circular economy policy. Yet, many challenges remain to be overcome:

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substance and product diversity, rapid technology cycles, international trade flows, dissipation contamination and down-cycling in processing and usage. Hence, it is key to the future high quality and non-detrimental management of secondary raw materials to apply a holistic, dynamic and proactive approach which takes into account dynamics and discrepancies in time, place and across the multitude of stakeholders who are involved along value chains. There is still an insufficient knowledge base lacking the integration of scattered knowledge about anthropogenic flows and stocks, their material composition and life cycles of goods for the systematic analysis and management of stocks. Growing interest in this subject is reflected in current research topics.

Behind this background, the German Environment Agency initiated a series of major projects with a focus on the “Mapping the anthropogenic stocks in Germany” (KartAL[9]). The series is not only supposed to provide compiled knowledge on the composition of the current stock and its dynamics of change but also a forecast model for secondary raw materials. For this purpose, a database was being developed and combined with a calculable material flow network to allow for dynamic MFA-modeling (See Figure 1). The resulting system DyMAS (Dynamic Modeling of Anthropogenic Stocks) is meant to represent an inventory of goods and materials respecting their specific dynamics. It is being used to share knowledge on the urban metabolism along the value chains to improve an effective material flow management in the long run. A complementary action of the project series makes use of the DyMAS system and addresses the existing technical, informational, logistical, organisational and legal barriers which currently hamper a qualitative closure of material cycles. The requirements raised from producers’ standpoints for secondary materials and for the removal of contaminants and impurities from them are discussed in the course of dialogue forums with all stakeholders involved in the recycling chain. Also, quality and purity standards for the respective secondary materials are developed. In addition, the most recent project of the research series harmonizes the concept for a material inventory for buildings as part of building passport and material cadastre concepts for regionally registering the material budget. This could create the planning basis for an effective, regional material flow management.

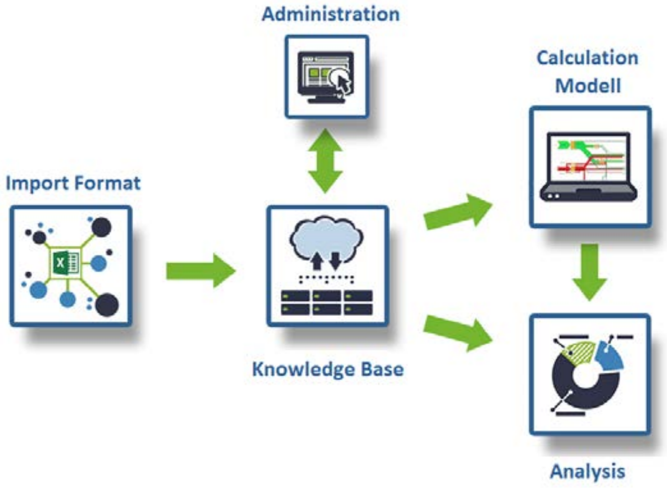

Figure 11 Overview of the DyMAS System Components (Hedemann et al., 2016)

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[9] Acronym for „Kartierung des Anthropogenen Lagers“

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LANDFILL MINING – A FEASIBLE OPTION TO ENHANCE MATERIALS CYCLING?

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Introduction

Landfill mining has been proposed as a potential strategy to address unwanted impacts of waste deposits while simultaneously recovering deposited materials and energy resources. So far, however, realization of such projects is rare and the further development of the area suffers from a deficit in knowledge and practical experiences on how landfill mining could be executed in a cost-efficient and environmentally sound way.

For any emerging concept, systems analysis could be useful for dimensioning the potential, assessing feasibility of specific solutions and not the least for guiding knowledge and technology development towards essential areas for facilitating implementation. When it comes to landfill mining, quite a few economic and environmental assessments have been conducted during recent years but there is not yet any systematic synthesis of this body of knowledge.

This study involves a review of 12 recent economic and environmental assessments constituting published, peer-reviewed journal articles in which the full value chain of landfill mining has been quantitatively evaluated in specific case studies. With the aim to provide guidance on essential future research topics to facilitate further development the landfill mining area, the review targets both the empirical findings and employed methodologies in the studies.

Main findings and applied methodologies in conducted landfill mining assessments

In essence, all except one of the economic assessments conclude non-profitability under current policy and market conditions and they only provide superficial knowledge on what actually builds up the economy of landfill mining (Figure 1). Typically, only main process steps are highlighted as important (e.g. Material processing & Separation or Waste-to-Energy) while systematic and more fine-grained knowledge on the contributions and interactions of the numerous model parameters that build up these value chain processes is lacking. When it comes to environmental performance, climate change is the only impact that has been comprehensively studied. For this specific impact category, conducted assessments display somewhat opposing results partly dependent on different project settings influencing avoided emissions from landfill gas generation and replaced primary material production and energy generation.

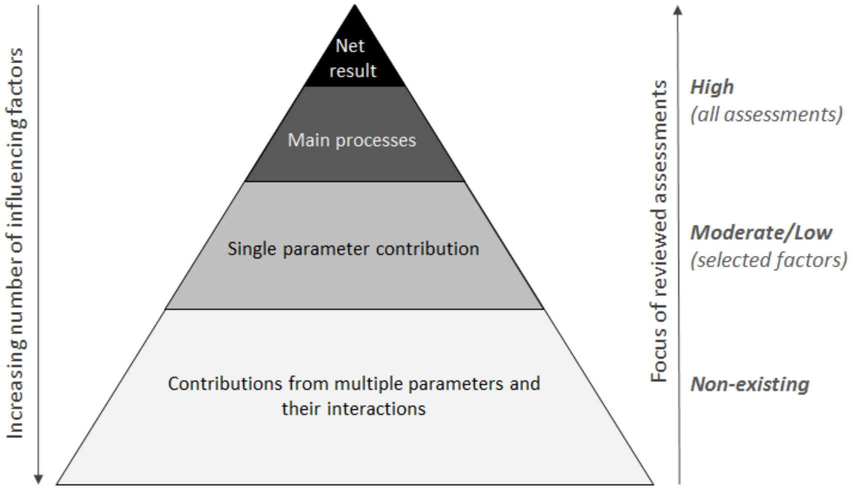

Figure 12 **Critical factors for performance of landfill mining could be assessed on different levels, ranging from just identifying main process steps as important to specifying the contributions of multiple and inter-related model parameters occurring throughout the value chain.**

Virtually all of the studies constitute ex-ante assessments in which the net outcome of a planned or even hypothetical project is estimated. Although such forecasts are inherently uncertain, they are nowadays common practice not the least within the financial world. However, the fact that landfill mining also is an emerging concept makes such assessment particularly challenging, for one thing, due to an inaccurate or incomplete scientific understanding of the studied processes. Our review reveals several issues when it comes to the applied methodologies in the studies – all of them having direct implications on the validity and usefulness of the obtained results (Figure 2). Lack of clear criteria for selection of landfills and material processing lines, scopes limited to just one, single scenario, arbitrary assumptions on the marketability of exhumed resources, use of unconditioned data from adjacent knowledge fields and neglecting stochastic and epistemological uncertainties are some examples of such reoccurring concerns.

Key future research topics and approaches

Our review reveals several epistemological and methodological challenges for the further development of the landfill mining area. At the conference, we will carve out some specific guidance on how these challenges could be addressed in future research. Special attention will be given to the need for (1) explorative studies using systems analysis as a learning tool, (2) applied research targeting the current black boxes of the landfill mining value chain and (3) common knowledge and broader scopes on the various consequences of landfill mining to support policy and market interventions.

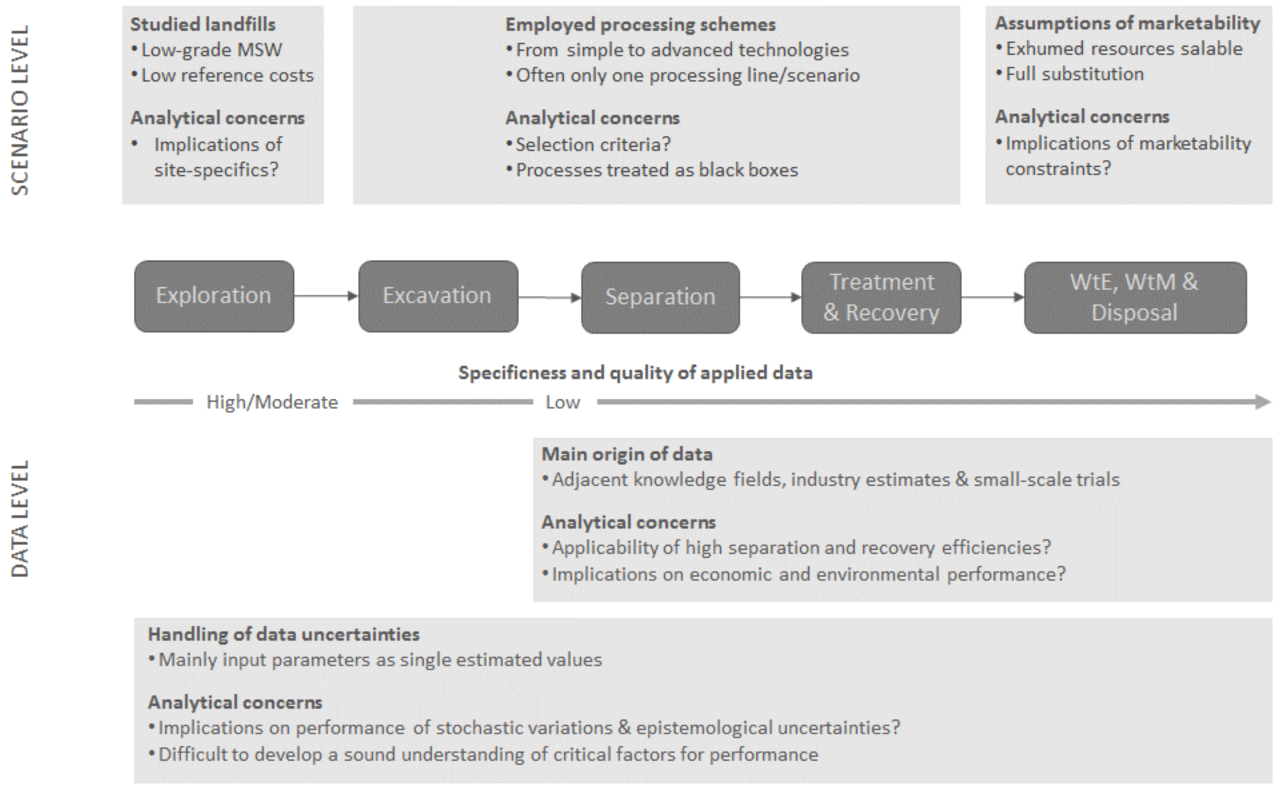

Figure 2 **Overview of methodological characteristics of the reviewed assessments throughout the landfill mining value chain and divided on the scenario and data levels.**

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THE ROLE OF IN-USE STOCKS FOR CIRCULAR ECONOMY AND CLIMATE CHANGE MITIGATION

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“Human well-being includes the use of physical services from buildings, infrastructure, and consumer products. These in-use stocks link the services enjoyed by humans to energy and material consumption. Climate change mitigation requires us to transform current in-use stocks to decouple energy and material throughput from service provision. Assessing the potential environmental benefits of emissions mitigation and other sustainable development strategies requires a solid understanding of in-use stocks and their dynamics” (Pauliuk and Müller 2014).

In-use stocks have important functions in society’s metabolism, and understanding these functions helps us appreciate their role in the transition to a circular economy and a low-carbon society. The role of in-use stocks (fixed capital) include (Pauliuk and Müller 2014):

Service suppliers: In-use stocks provide service to end-users and industries. In-use stocks can serve as measure of physical service (e.g., car ownership and living space per person), and the stock levels in industrialized countries can serve as benchmark for future development in other regions.

Resource repositories (urban mines): In-use stocks represent large monetary investments and material stocks.

Dynamics determiners: In-use stocks determine the long-term dynamics of the social metabolism: Stocks have a slow turnover in many sectors. For example, blast furnaces in the steel industry can reach a lifetime of up to 100 years. This poses constraints to how quick new technologies can replace old ones. The availability of post-consumer scrap for recycling is to a large extent determined by the retirement rate of in-use stocks (van der Voet et al. 2002).

Wealth watchers: The size of in-use stocks represents a different perspective on human wealth that may complement flow-based affluence measures such as gross domestic product (GDP).

Consumption couplers: The physical properties of in-use stocks link the provision of service to energy and material throughput.

City shapers: The spatial arrangement of built environment stocks in human settlements has strong influence on urban density, accessibility, transport distance, and choice of transport mode (Brunner and Rechberger 2004; Kennedy et al. 2007).

Decoupling material and energy throughput from stocks, and decoupling stocks from service provision as core strategy to mitigate climate change: “Decoupling service from stocks and stocks from throughput bears a substantial emissions mitigation potential, which demonstrates that adequate long-term planning and management of in-use stocks may be essential to reaching ambitious climate targets. The combined emissions reduction potential of supply side measures and stock decoupling may be higher than what is needed to reach the 2 8C target, which makes it easier to consider other objectives than mere emissions reduction.” (Pauliuk and Müller 2014)

Stocks in the circular economy: “A core question for organizations in the circular economy (CE) is whether their products contribute to stock growth or replace or maintain existing stocks, as in the case of stock growth primary production must be attributed to that product, nullifying the CE intention. If stocks continue to grow a circular system remains an illusion (Fellner et al. 2017; Haas et al. 2015).” (Pauliuk 2018) From the mass balance of the use phase, one finds that the final material consumption C always has two components: replacement of outflow O and stock expansion dS:

$$C = dS + O \quad (1)$$

“Developing countries need to build up stocks, and I show that for steel, the ratio of stock growth to consumption (dS/C) lies almost at 100%, rendering the CE into a vision for the future and not into something that could be implemented in the present system. More developed countries use a higher share of their steel consumption for stock maintenance and thus dS/C attains values below 30% for the richest countries and even negative values for countries where stocks were found to be shrinking.

In cases where there are no links between the foreground material system and other product systems, or at the global scale, the entire material cycle has the following mass balance, which also applies to material flow accounting (Fischer-Kowalski et al. 2011):

$$P = dS + L \quad (2)$$

Primary production P is either replacing system-wide losses L or contributing to stock expansion dS. An analysis of this relation for the global steel cycle shows that the share of stock expansion in total primary production has not changed substantially in the last 60 years, it has even gradually increased from 60 to 70% in the 50ies to 73–79% in the period 1998–2008.

Ever-growing material stocks drive resource depletion and production-related GHG emissions. Although individual product systems within an expanding material economy can show high degrees of circularity, the overall system cannot if stocks continue to grow. The CE principles systems thinking and stewardship entail that organizations monitor the contribution of their products and services to stock development to understand how their decisions impact the material cycles at the large scale." (Pauliuk 2018)

While 'circularity' is best translated into the two dimensions: longevity and recycling efficiency for products (Franklin-Johnson et al. 2016), the assessment of circular economy strategies at the system level needs to include the growth patterns of the in-use stocks and develop indicators and policy targets based on the two mass balance equations presented above.

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SESSION 4:

EVALUATION OF ANTHROPOGENIC RESOURCES

AVAILABILITY ASSESSMENT OF ANTHROPOGENIC RESOURCES: FROM PROSPECTION TO PRODUCTION

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Introduction

The mining industry has a long tradition in assessing the availability and the recovery feasibility of resources from geogenic deposits. This allows for predictions of recoverable quantities under defined conditions. These quantities, however, are not fixed and depend on changes in science, technology, legislation and economic conditions (cf. McKelvey and Kleepe, 1976). Qualified persons or interdisciplinary teams do this challenging assessment task in order to help the industry to attract investments in exploration and mining projects. Various classifications have evolved over time, with the United Nations Framework Classification for Resources (UNFC) being the most comprehensive system (UNECE, 2010). This framework harmonizes the terminology and evaluation principles for different stakeholders and resource types, such as mineral and energy resources. Resource classifications serve for communication means only, i.e. they do not prescribe specific methods to characterize and evaluate mining projects. Winterstetter et al. (2015b) presented first UNFC applications to anthropogenic resources and in 2018 the scope of the UNFC was extended to anthropogenic resources extended (Kral et al., 2018a). The new Specifications (UNECE, 2018) allow to communicate the maturity level of recovery projects in a circular economy context, from the early stage of prospection to the final stage of production.

This article describes the availability assessment of anthropogenic resources and presents the application of UNFC to communicate the availability of materials to be mined from a historic landfill site in Belgium.

Methodology and case study

In the past, various authors developed general frameworks for availability assessment and applied them to case studies (cf. Fellner et al., 2015, Lederer et al., 2016, Winterstetter, 2016, Mueller et al., 2017, Kral et al., 2018b, Winterstetter et al., 2015a, Zuser and Rechberger, 2011). We divided the availability assessment into four phases, i.e.from prospection to potential production (Table 1).

To demonstrate the availability assessment in practice, we selected a historic landfill as potential material source and defined a landfill-mining project to produce secondary raw materials (cf. Table 1). Resource recovery under present conditions is contrasted to a future scenario with assumptions on decreasing sorting costs and increasing land prices, moving the project closer to the maturity level of production. The detailed case studies have been published by Winterstetter et al. (2018).

Table 1: Anthropogenic resource assessment applied to the Bornem landfill (cf. Winterstetter et al., 2018)

N°	**Phase**	**Approach**	
1	Prospection	The Public Waste Agency of Flanders (OVAM) developed the FLAMINCO tool (Behets et al., 2013) to map, screen and investigate old landfills for contamination risks and resource potential. Based on these criteria and the access to real-life data, we selected a former landfill site, located in Bornem covering about 5 ha and containing about 390’000 tons of municipal solid waste.	
2	Exploration	We estimated the landfill’s rough resource potential by gathering information on the type, location, size, depth, volume and rough composition. We examined the share of extractable materials and recoverable land as well as its contamination level as a function of different technology alternatives and project set-up options with their specific recovery efficiencies.	We classified the quantities under present and future conditions under UNFC (UNECE, 2018) as follows: • G-Axis: Depending on whether the level of confidence about the potentially extractable and usable share of materials and / or land is high, medium, low or whether knowledge on the recoverable quantities is practically not existing the deposit is graded with G1 to G4. • F-Axis: The technical and project feasibility is indicated by an existing and well-enforced legal framework and societal, institutional and organizational structures, by fully mature technologies applied and ongoing project activities (F1). One or several of those criteria, being unfulfilled, result in the lower categories F2 – F4. • E-Axis: A positive NPV implies that a project is economically viable (E1). If the NPV turns out to be negative, one has to judge, whether there are reasonable prospects for economic extraction in the foreseeable future (E2) or not (E3) by anticipating realistic changes of key economic parameters. We classified the recovery project under current conditions as “Non-commercial project” and under future conditions as “Potentially commercial project”. Detail are given in the results and discussion section.
3	Development of the recovery project	Using the Net Present Values (NPV), we evaluated the socioeconomic viability of the recovery project under present and future conditions, considering prices for secondary products and recovered land, investment and operating costs, costs for external treatment and disposal, avoided costs as well as possibly monetized social and environmental externalities and indirect financial effects.	
4	Production	Potential production under future conditions.	

Results and discussion

The availability of materials in the landfill “Bornem” is expressed by the maturity level in the life cycle of the recovery project (cf. Figure 1). The UNFC project life cycle starts after prospection with the exploration phase and the development of the recovery project towards the production of secondary raw materials. The “Bornem” project’s maturity level and the associated quantities are evaluated and classified for present and potential future conditions:

Present conditions: We classified the landfill-mining project as “Non-commercial project” (E3F3G2). First, on the G-axis the “Bornem” landfill-mining project is scored with G2. The quantities in the landfill are estimated with a medium level of confidence based on data from the test excavations, trial sorting and waste characterizations and the landfill’s logbook data. The applied technologies’ recovery efficiencies are estimated with sufficient detail for assessing the landfill’s material recovery potential. The land recovery potential is known since residues are re-landfilled off-site. Second, the field project status and technical feasibility (F-Axis) is classified with F3. Even though well-known technologies are applied and the institutional structure is already established with OVAM as committed partner, there are no activities on going other than test-excavations and trial sorting. The neighbors’ attitude towards the project is positive. However, the LFM project is still in the pre-feasibility stage with mainly planning activities and operations on a very small scale. As there is no legal framework for LFM, individual licenses from local authorities are needed to advance the project. Third, the socio-economic viability (E-Axis) is scored with E3, due to a negative Net Present Value of -17 Million € (-44 € / t excavated waste materials). Under the present conditions, about 336,600 t materials and 50,000 m² of land can be recovered and sold, while 34,600 t of materials need to be re-landfilled off-site (Winterstetter et al., 2018).

Future scenario: Changes in the key economic parameters “land prices” and “sorting costs” result in a positive economic evaluation result. Therefore, the landfill mining-project is classified as “Potentially commercial project” (E2F3G2). A combination of increasing local land prices from currently 150 €/m² up to 350 €/m² and parallel decreasing sorting costs could potentially be reached (Winterstetter et al., 2018).

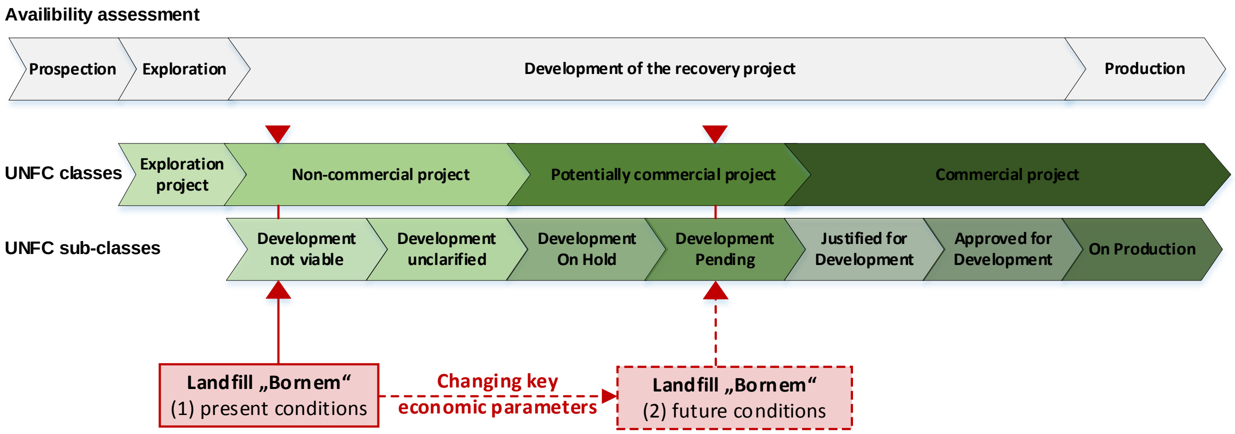

Figure 13 **Maturity level of the landfill-mining project “Bornem” under present (1) and future (2) conditions according to the UNFC (green colored boxes) and according to the phases of availability assessment (grey colored boxes).**

Conclusions

The United Nations Framework Classification for Resources (UNFC) can help to assess the availability of anthropogenic resources by classifying potential resource recovery projects with different levels of maturity, from prospection to potential production, under technical, socio-economic and project-planning aspects.

Acknowledgement

We thank our colleagues from the Christian Doppler Laboratory of Anthropogenic Resources (https://iwr.tuwien.ac.at/en/anthropogenic-resources), from the COST Action Mining the European Anthroposphere (www.minea-network.eu) and from the UNECE Expert Group on Resource Classification for fruitful discussions during project work, workshops and symposia.

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ECO-EFFICIENCY – A MEASURE TO DETERMINE OPTIMAL RECYCLING RATES?

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The official statistics of recycling rates are misleading

Recycling is an appropriate instrument to foster the paradigm shift to a so-called circular economy. But it is only an instrument and not a goal. Also recycling isn’t a never-ending story. After some loops of recycling the waste has to be assigned to the final sink.

The official statistics don’t tell the truth. For example, the published recycling rate of lightweight packing in Germany is about 80 %. But the reintegration-rate of secondary raw material – based on packaging waste –is much less: not really more than 20% - 25 %. The official recycling rate is measured at a certain point in the value chain “reprocessing waste to secondary raw material”, but not at the final end. After this measurement point further reconditioning steps are necessary to reintegrate the secondary raw material back into the business cycle.

Additionally there is no incentive tool to trigger high-quality secondary raw material

The technical maximum of a recycling rate is not compellingly the best solution

There are three interdependent influencing factors to determine the optimal recycling rate. The relevant factors are the ecological utility, the recycling costs and the recyclate revenues. In relation to the recycling rate these three factors are not constant – either absolute nor linear.

It is self-explanatory that the recycling process is associated with costs. Complying with only a low recycling rate the company only keeps an eye on so called “low hanging fruits” and therefore the recycling-costs are relatively low. But to comply with a high recycling rate the company must reap the “high hanging fruits” too. It can be assumed that in principle the recycling costs increase exponentially depending on the recycling rate. Of course recycling activities are useful for the ecological utility. But every recycling process leads to emissions and therefore impacts the environment. Step by step every additional benefit of an increasing recycling rate becomes smaller and smaller. Near to the technical maximum of recycling it might be that for example the benefit of a further increase of the recycling rate could be negative. Furthermore, secondary raw material based on “high hanging fruits” don’t generate the same price level on the market as secondary raw material produced from “low hanging fruits”

The interdependent interaction of these influence factors is shown below. (Fig 1):

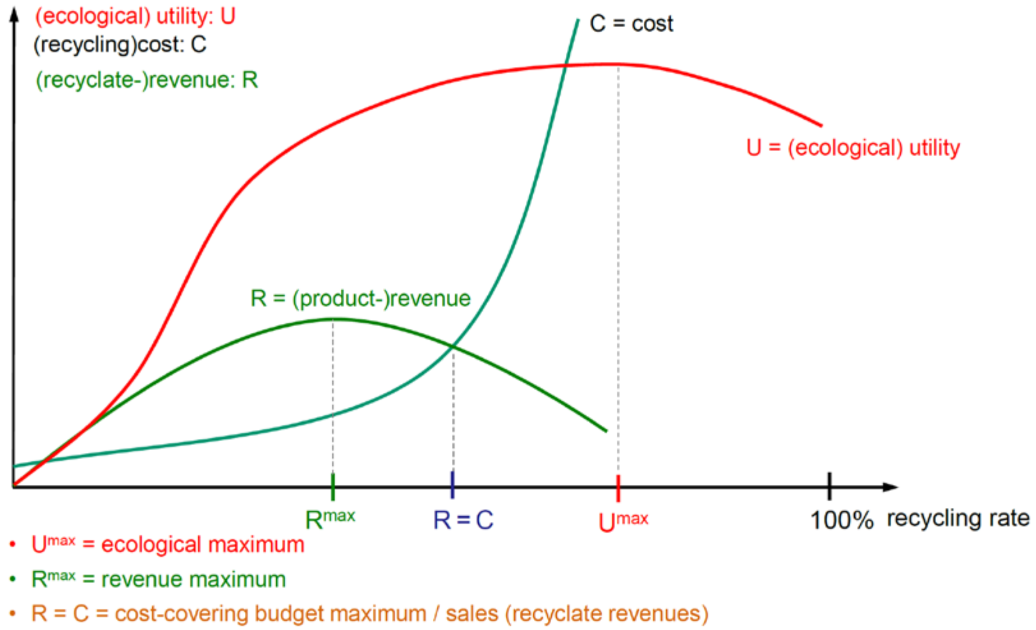

Figure 1 Recycling: Economic model

By an economic marginal analysis it is possible to identify the optimal recycling rate and to show the area of x-inefficieny (Fig 2)

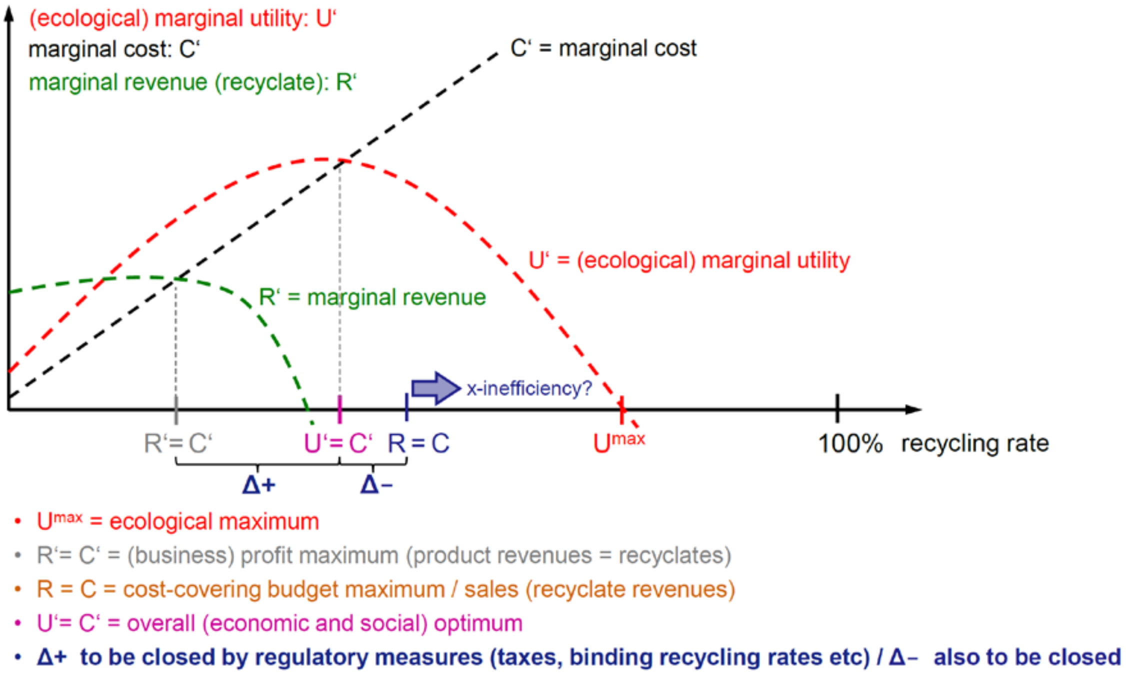

Figure 2Recycling: Economic marginal analysis in identify optimal recycling rate

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STATISTICAL ENTROPY – AN INDICATOR FOR RESOURCE SYSTEMS

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Introduction

In 1971 Nicholas Georgescu-Roegen introduced the term “low entropy materials” for valuable natural resources and “high entropy materials” for valueless waste and emissions. He explained the economy as a process which irreversibly transforms low entropy into high entropy materials by providing and using a flow of natural resources (Georgescu-Roegen 1971). Since then many others used the term entropy to describe the characteristics of the anthropogenic metabolism in a qualitative way. One of the first to make the entropy concept applicable to material systems was Szargut (1988), who developed a way to quantify exergy, a thermodynamic term introduced by Rant in 1956 to address available energy, for materials. Since entropy and exergy are directly coupled (the destruction of exergy causes entropy) this allowed to calculate exergy budgets for coupled energy/material systems and therefore indirectly consider entropy budgets. In this way exergy has been used by a growing community to evaluate and optimize technical processes and anthropogenic systems. Another way to employ entropy, Statistical Entropy Analysis (SEA), was developed by Rechberger and colleagues (Rechberger 1999, Rechberger & Brunner, 2002, Rechberger & Graedel 2002, Sobańtka et al. 2012, Laner et al. 2017). They used the statistical interpretation of entropy and made it applicable to results of Material Flow Analyses (MFA). The combination of MFA and SEA to analyse and evaluate systems can be seen as a straight forward application of the two Laws of Thermodynamics to material systems. MFA builds on the principle of mass conservation and SEA on the entropy law.

Statistical Entropy Analysis (SEA) and Material Flow Analysis (MFA)

Statistical Entropy (SE) derives from Information Theory (Shannon 1948) and is used to describe any kind of distribution of a set of features. Rechberger & Brunner (2002) showed that a process can be perceived as an entity that transform materials, e.g., wood into emissions and ash. This transformation can be described as a transition of the distributions of mass flow and concentration data (see Figure 1). In this way SE can be applied to MFA results and quantifies the power of a process (system) to concentrate or dilute substances. Concentrating of substances is seen as a positive process, since concentrates can be better controlled and are easier to handle, to recycle, to recover or to landfill. Dilution is to some extent a necessary process for all living organisms (hence also for the economy), however, strong dilution reduces the availability to recover a material and might result in environmental damages. While diluting is usually a rather simple process the opposite, concentrating, is difficult and requires technology, energy, and effort. As a

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working hypothesis, which so far has been unrefuted, one can say that all anthropogenic activities should be carried out in a way that entropy generation is minimized.

Figure 1 shows the basics of SEA. The inputs and outputs of a process can be described as a distribution of substance concentrations and masses among the single flows. These distributions can be quantified by SE, resulting in normalized entropies (H_{rel}). If the process increases H_{rel} then dilution takes place. The opposite case stands for concentration.

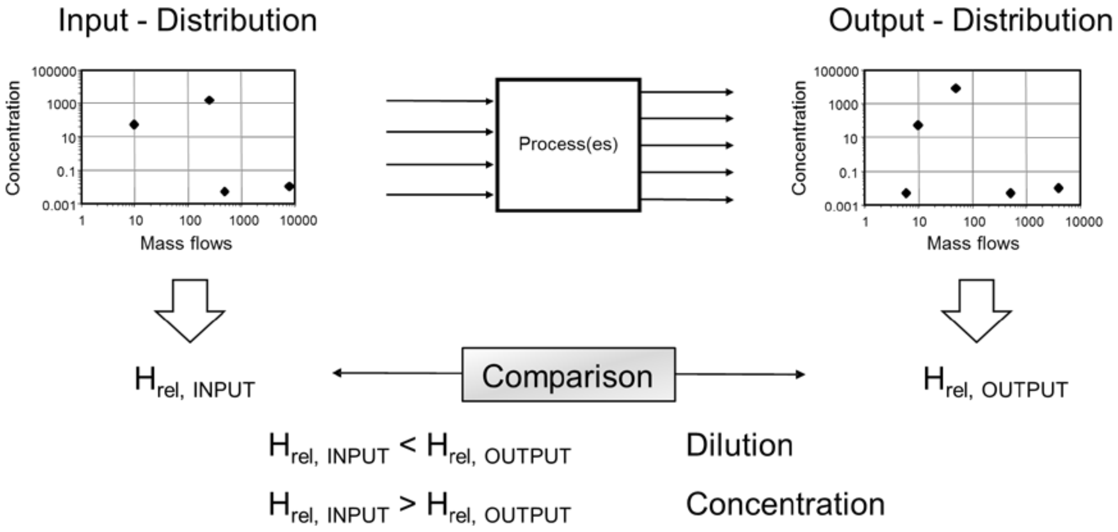

Figure 14 **Basics of Statistical Entropy Analysis (after Rechberger & Brunner 2002)**

Theoretical application of SEA to MFA results

In order to apply SE to a MFA result the MFA system has to be translated into a stage diagram (cf. Figure 2). This procedure follows strict rules (cf. Rechberger & Graedel 2002; Laner et al. 2017) and allows following a substance allong the system’s process chain.

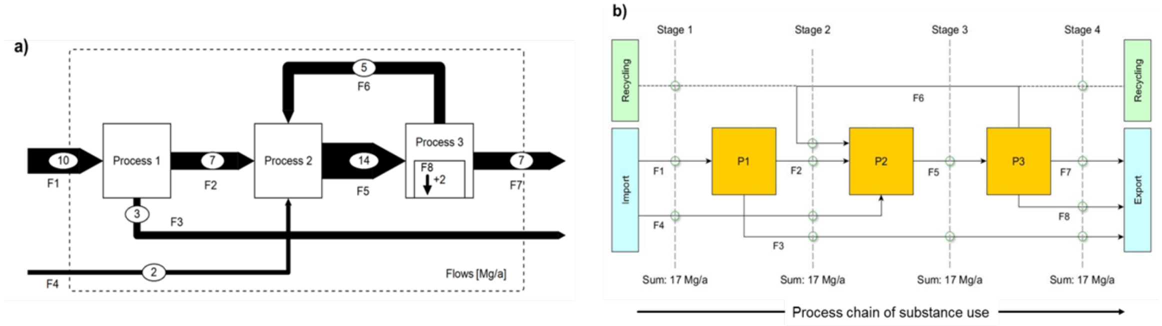

Figure 2 **Transformation of a MFA system (a) into a stage diagram (b) (after Rechberger & Graedel 2002 and Laner et al. 2017)**

The flows between the processes are organised in stages and the system as a whole can be considered as an entity transforming the throughput form stage to stage. Each stage is characterized by a specific distribution of mass flows and substance concentrations (cf. Figure 1) which can be quantified by SE.

Selected results: the Austrian budget of Phosphorus

The Austrian budget for Phosphorus (P) was analysed in detail by Zoboli and colleagues (2016ab) and resulted in a rather complex system consisting of 56 processes, 122 flows, and 8 stocks. The system has been meanwhile analysed over a period of 24 years beginning with year 1990, thereby generating profound system understanding, which resulted in the identification of 15 measures to optimize the system. The measures were implemented in the model of the status quo and a hypothetical target system (optimized system) was compiled. Figure 3 shows the entropy trends for the current state (2013) and the target system. The optimization measures are grouped into three categories, namely reduction of consumption (1) and emissions (2) as well as enhanced recycling (3). One can see that the overall entropy trends are ascending indicating that even in the target system P is used in a dissipative manner overall. However, inefficiencies and losses could be reduced significantly and the main fields of action are in wastewater treatment, waste management and to some extent in industry. The comparison between current state and target system shows that the entropy increases in the agriculture are to a large extent unavoidable and they have to be compensated as much as possible by optimizations at the end of the P cycle.

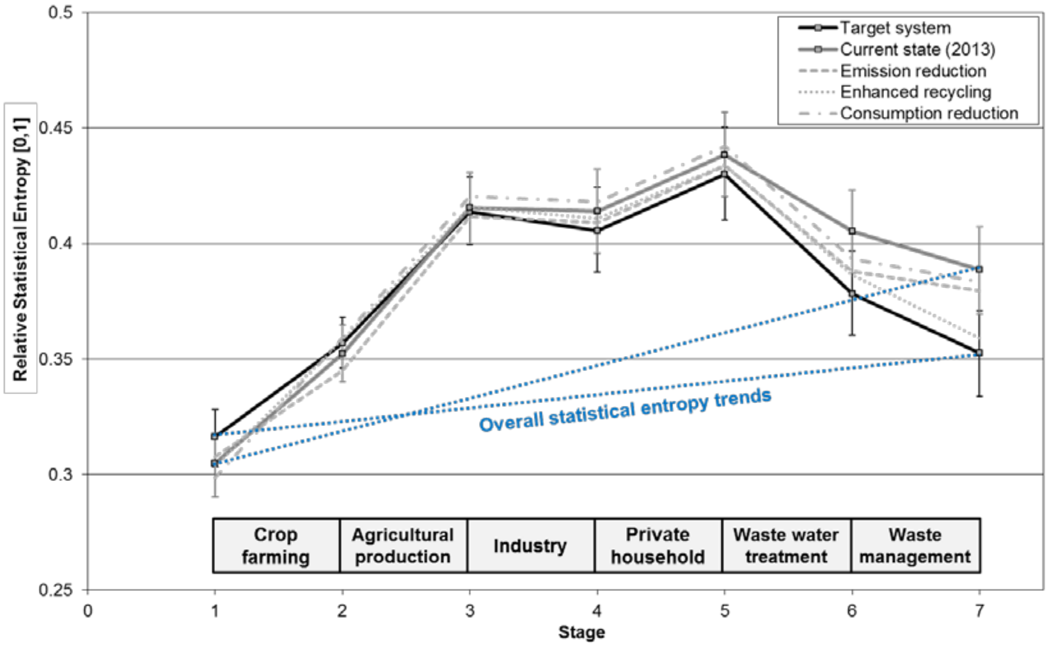

Figure 3 SEA of the Austrian Phosphorus household. The difference between the inclinations of the dotted lines (overall trends) indicates the potential for optimization (Laner et al. 2017).

One major advantage of applying SEA to MFA results is that one gets one single metric per stage, per process and per system, always indicating if dilution or concentration is dominating. However, SEA also allows for assessing the contribution of each single flow to the overall trend and so serves as a practical tool to analyse the relevance of single flows and specific measures of optimization. Generally the experience with the application of SEA shows that it enhances the system understanding, making clear which processes and flows are of particular relevance and it can also be used to decide about data quality requirements. For instance, the results displayed in Figure 3 show that the differences between current and target system are not significant for all stages indicating, that the MFA results suffer from uncertain basic data. This is a typical employment for Sensitivity Analysis to find out which data (uncertainties) have the largest impacts on the reliability of the final SEA results. In a following step it can then be checked how the identified data weaknesses could be resolved, which is valuable feedback to data producers and providers.

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POLICIES AND PRIORITIES FOR ESTABLISHING A CIRCULAR ECONOMY

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A policy mix is required to overcome the ‘Web of Constraints’

It is common to consider resource inefficiency to be the result of a collection of individual failures, including market externalities, split incentives, information failures, ‘irrational’ behaviour, and governance and regulatory inadequacies. However, Kemp & Dijk (2013) conclude that there exists a ‘web of constraints’ to resource efficiency - the direct and indirect relationships and dynamic interaction between institutions, organisations, societies and individuals, and the policies, norms and behaviours they set and exhibit. The specific form of the web of constraints depends on the focus (spatial, temporal, sectoral, etc.), and by its inherent nature, alters over time. A change to one aspect of the web of constraints may induce changes in another aspect (either towards or against the establishment of a circular economy). Over time, windows of opportunity for the development and implementation of radical technologies and practices, or the policy instruments to drive or facilitate them, may be opened (Kemp & Dijk, 2013). As such, strategic policy interventions may transform the web of constraints into a ‘web of drivers’ for a circular economy.

Due to the multi-aspect nature of resource use and its consequences, and the web of constraints constraining resource efficiency and the delivery of a circular economy, a ‘first-best optimum’ approach of applying a single policy instrument to counter the problem is insufficient. A policy instrument mix, applying ‘second-best’ theory and the Tinbergen Rule (i.e. for each policy objective, there must be at least one policy instrument), must be employed (Wilts et al, 2014a).

Figure 1 illustrates the concept of three ‘domains of change’ and corresponding ‘pillars of policy’, developed by Grubb *et al* (2014). Although originally developed in the context of climate change mitigation, the concept is applicable to other systemic environmental and resource use concerns. Each domain of change reflects a distinct sphere of economic decision-making and development. The first, satisficing, describes the tendency of individuals and organisations to base decisions on habit, assumptions and rules of thumb. Such phenomena link to behavioural and organisational economics, for which the first pillar of policy, standards & engagement, may be employed to produce ‘smarter choices’. Examples of such instruments related to resources include minimum performance or material requirement standards, the provision of information and instruments targeting behaviour change.

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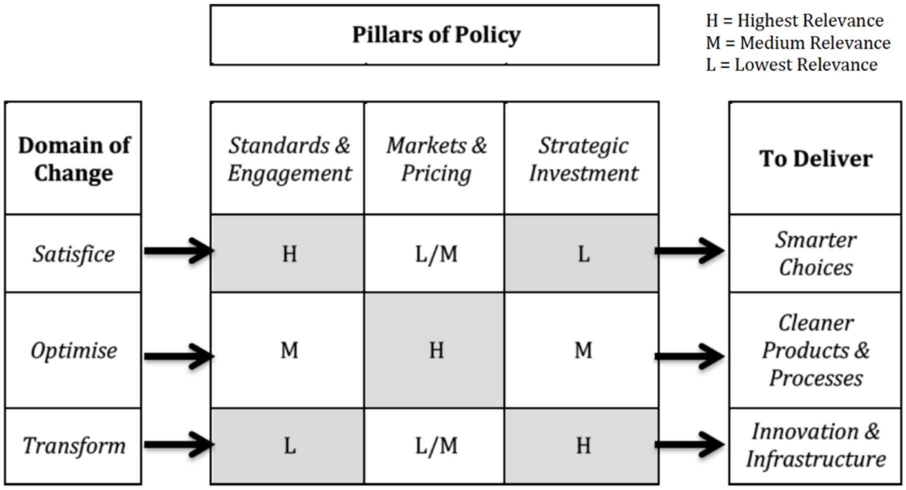
Figure 15 - Three Pillars of Policy and Domains of Change (Source: Grubb *et al*, 2014)



H = Highest Relevance
M = Medium Relevance
L = Lowest Relevance

	Pillars of Policy			
Domain of Change	*Standards & Engagement*	*Markets & Pricing*	*Strategic Investment*	**To Deliver**
Satisfice →	H	L/M	L	→ *Smarter Choices*
Optimise →	M	H	M	→ *Cleaner Products & Processes*
Transform →	L	L/M	H	→ *Innovation & Infrastructure*

The second domain, optimising, describes the ‘rational’ approach of actors making optimal choices on economic factors. This reflects traditional assumptions around market behaviour and corresponding theories of neoclassical and welfare economics. The second pillar of policy, markets & pricing, employs market-based instruments to deliver ‘cleaner (and more resource-efficient) products and processes’. Environmental taxation is a key example.

The final domain, transformation, encapsulates the ways in which complex systems develop over time under the influence of strategic choices made by large entities, particularly governments. The insights of evolutionary and institutional economics are employed in the third pillar of policy, in which strategic investment delivers ‘innovation and infrastructure’. Such instruments would include any that seek to encourage the development and deployment of niche or immature technologies or practices. Subsidies for the deployment of renewable energy, and R&D funding for new materials, would be key examples.

As Figure 1 illustrates, each of the pillars of policy have at least some influence on all three domains of change. A policy mix spanning all three pillars of policy is required to deliver the transformation to a circular economy.

The current European policy mix is insufficient for developing a circular economy

There are three broad reasons why this is the case. Firstly, there is a clear focus on the ‘output’ side of resource consumption, or the lower tiers of the waste hierarchy. Many of the more ambitious policy objectives and binding targets focus on the end-of-life of products and the prevention and handling of waste, with relatively little attention placed on the higher tiers of the waste hierarchy (e.g. prevention and re-use). Where such attention is paid, it is largely through aspirational, non-binding objectives and targets, voluntary mechanisms and information sharing.

The second reason is the varied ambition of the policy mix between member states. A clear indication of this is the substantial variation in resource productivity, ranging in 2017 from 8.5

tonnes domestic material consumption per capita in Italy, to 32.3 in Finland.[12] However, attributing resource use outcomes to policy initiatives is a highly complex exercise (Bahn-Walkowiak *et al*, 2014). Additionally, the outsourcing of primary material extraction is likely to be a significant factor in improvements in domestic resource productivity (Kemp *et al,* 2014).

Bahn-Walkowiak *et al* (2014) highlight some key weaknesses in the policy framework that may be found in many member states. A key example is the low level of environmental taxation, particularly on resources. In 2016, revenue from environmental taxes in the EU28 represented 2.4% total GDP, and 6.3% of total government revenues from compulsory levies. Of this, taxes on pollution and resources together represented just 3.4%.[12] This is exacerbated by the presence of environmentally harmful subsidies for resource-intensive activities (particularly in the form of non-taxation, discounts and exemptions for fossil fuel production and consumption). Various other common weaknesses may be highlighted, such as policy inaction, the use of qualitative rather than quantitative targets, insufficient policy coherence (including a lack of clarity regarding the division of institutional responsibility), and information deficits (Bahn-Walkowiak *et al*, 2014).

The third reason the EU policy landscape is insufficient to deliver a circular economy is the interaction between different policy strategies and instruments, and their component objectives, targets and operating mechanisms, within and between different levels of governance (from EU to city level). Such interactions may be synergistic or conflicting in nature. For example, recycling may reduce the consumption of primary raw materials. However, the promotion of renewables may require substantial increases in some materials, including critical raw materials and biomass, which in turn may have land use implications. Such conflicts occur laterally, but also over time.

The policy mix must be consistent, coherent and credible to be effective

As proposed by Rogge and Reichardt (2013), a policy mix must adhere to three core principles to be effective, cost-efficient and feasible:

Consistency - This principle may be defined as 'weak' (the absence of contradictions or conflicts within the policy mix), or 'strong' (the presence of complementarities, mutual support and synergies within the policy mix). Therefore, a priority action for the EU should be the introduction of new (or amendment of existing) instruments that generate synergies, and reduce negative interactions or side effects. Broadly, any instrument that internalises negative externalities, or reduces perverse subsidies, acts to improve the overall efficiency of market processes and is mutually supportive of other categories of policy instrument (in a well-designed mix) (Wilts *et al*, 2014a). As such, a focus should be the removal of environmentally harmful subsidies, and the wider application of effective environmental taxation instruments.

Coherence - This principle refers to the alignment of processes for the development, implementation and monitoring of policy instruments, within and between different levels of governance. Thus, there is a clear link between coherence and consistency, although coherent process alone is not a sufficient condition for consistent policy mix (Rogge and Reichardt, 2013). It is clear that no single actor is able to develop and implement a comprehensive policy mix that

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[12] EUROSTAT data.

tackles effectively tackles the web of constraints. As such, a priority action in the EU should be to ensure policy processes between actors within and between different levels of governance (i.e. EU, national, local/city), are at least not in contradiction and, where possible, are re-enforcing.

Credibility - The third principle is the perceived credibility of the policy mix, to provide confidence for long-term investment in resource-efficient and circular technologies and practices. Credibility is influenced by a range of factors, including political commitment, the presence of overarching strategies and targets, the operationalisation of these targets by the instrument mix, and the delegation of competences to independent agencies (Wilts *et al*, 2014a). Consistency and coherence are important considerations for credibility. Given the complexity of the transformation required, the development of long-term strategies and targets for achieving a resource efficient and circular economy is a key precondition to its achievement (Wilts et al, 2014b). As such, a priority action should be the development of long-term (post-2030), clear and credible strategy, with holistic, measurable targets, for the development of a circular economy in Europe.

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2 Poster

RE-USE: PRIORITY OPTION FOR THE CIRCULAR ECONOMY

THE REPANET - MARKET SURVEY 2017

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Introduction

RepaNet is an Austrian non-profit umbrella organization representing 28 social enterprises and other initiatives active in the field of re-use and repair. RepaNet aims to improve the framework conditions in the re-use sector and to create jobs for disadvantaged people. RepaNet is also the Austrian representative in the European RREUSE network.

Throughout various projects, RepaNet promotes waste prevention, re-use and the circular economy. In the project “BauKarussell”, re-usable parts of large buildings are removed before demolition and sold for the construction of new buildings. In another project, RepaNet supports and promotes the national network for repair initiatives, which help private households to extend the use-phase of their goods, especially through “repair cafés”.

RepaNet’s core activity is the representation of social re-use enterprises. These organizations collect used goods, prepare them for re-use and sell them in their shops (except for textiles, where only a small portion can be used in Austria). RepaNet members make up roughly 75% of the market for preparation for re-use in Austria. With their revenues, they cover the costs of social integration work places for disadvantaged people.

The following facts & figures are based on RepaNet's 2017 annual market survey.

Methods

The design of the annual market survey derives from RepaNet’s knowledge about the business activities of its members and its experience from past surveys that have been conducted since 2014.

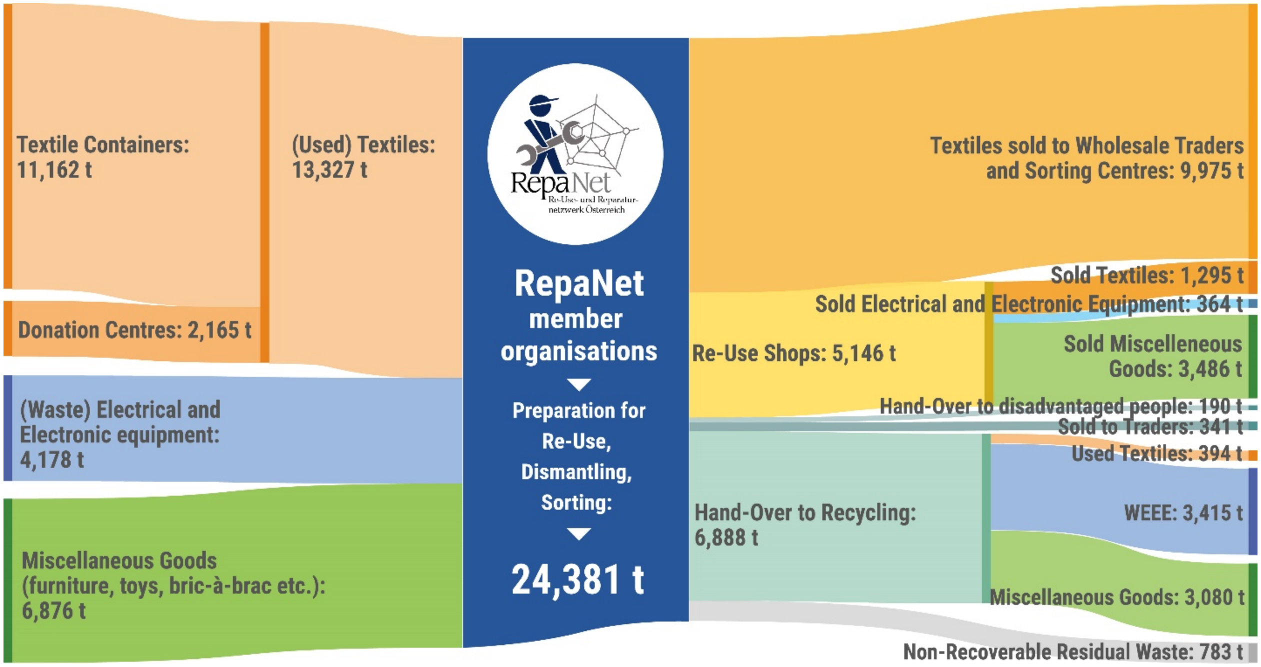
The members received the questionnaire via e-mail. The questions were designed so as to fit the different levels of accountancy and professionalism of the member organizations. RepaNet provided assistance in cases where the data was not readily available by generating qualified and conservative estimations (e.g. conversion from number of pieces to masses).

Environmental effects and potentials were calculated with external data. Only reliable and scientifically sound sources were used.

Results

24 members participated in the survey. In 2017, these organizations enabled the re-use of 10.664 t of goods (this corresponds to the amounts sold in shops and to traders, donations to people in need, as well as 50% of the exported wholesale textiles, which is the commonly accepted average re-use rate).

All in- and out-going mass flows are shown in the figure below.



The domestic sale of second-hand goods in the 99 shops of RepaNet members spread all over Austria is a crucial contribution to the circular economy. In 2017, the shops served about 1.6 million customers.

As seen in the figure above, the biggest stream are used textiles. They are predominantly collected in about 1,900 textile containers, and also outside the waste regime through direct donations. On the output-side, 11% are re-used domestically. The rest is exported by wholesalers.

(Waste) Electrical and Electronic Equipment ((W)EEE) and miscellaneous goods are also collected through donations as well as in 140 municipal waste collection centers and through 7,500 conducted pick-up services from private and commercial places. Two members limit their work with these materials to recycling. They were excluded from re-use figures and calculations. It is also worth mentioning that customer repairs and any kind of upcycling is not subsumed under the term “preparation for re-use” and therefore not included in the figures.

Non-recoverable residual waste accounts for only 4% of all outputs. This is due to the fact that in donation centres only functioning goods are accepted. Furthermore, the members service their textile containers on a regular basis. This keeps the waste ratio low.

However, not only is the amount of goods collected, treated and their whereabouts important, but also the people carrying out this work. Environmental protection creates jobs, and in the case of RepaNet, a big proportion of these jobs are transitional. They help disadvantaged people to gain a foothold in the job market. The table below shows the number of workplaces and their full-time equivalents.

Employment	In full-time equivalents	In workplaces
Total number of jobs in re-use and waste management	1.220	1.995
Thereof transitional jobs	815	1.519
Thereof permanent jobs for disabled persons	30	42

Calculations and comparisons

Job creation: An important number for comparison is the total full-time equivalent of jobs in re-use, which amounts to 958 FTEs. With the corresponding mass of goods collected just for the preparation for re-use, it can be derived that for every 1,000 t of goods 55 full-time jobs are created.

In comparison, the Austrian private and municipal waste management creates 9.6 jobs per 1,000 t of collected municipal waste from households and similar establishments (based on: Federal Waste Management Plan 2017).

This means that re-use creates over five times more jobs for the same mass of goods than recycling and waste treatment.

Ecological benefit: The prolongation of a product's lifetime saves primary resources and prevents negative environmental impacts. This has been proven through Life-Cycle Assessments and similar studies. Such studies are rather complex and the outcome depends on various variables. Consequently, results are only partly applicable in other systems. However, by combining the results of several publications that complement each other, an approximate impression of magnitude can be attained (WRAP 2011, TemaNord 2016, University of Natural Resources and Life Sciences 2014, Bjurbäck 2015, The Restart Project s.a.).

The calculation reveals that RepaNet members and their customers saved roughly 19,700 t of CO_2-equivalents in the year 2017. According to the Austrian Environmental Agency, this corresponds to the annual emissions of 6.680 average Austrian cars. Taking into account the re-use abroad (i.e. 50% of the wholesale textiles), the prevented emissions rise to 72,800t of CO_2e; in other words: the annual emissions of 24.690 cars.

Furthermore, re-use saves a much larger quantity of primary resources than recycling or other recovery options. Therefore, it should be supported much more than it is today. Unfortunately, there is not yet a reliable calculation method to quantify this primary resource substitution ratio and make it comparable with other end-of-life solutions (see open questions below).

Examples of open questions for further scientific research:

- Recycling of 1 kg of material substitutes a maximum of 1 kg of primary raw material. Re-use of 1 kg of products through the prolongation of product lifetime substitutes a multiple quantity of primary raw material. Research exists only for a few specific product groups. To support better pro-re-use policies, public funding and regulations require reliable scientific evidence. Studies are needed to quantify the primary resource saving ratio of re-use in comparison to other end-of-life options. (Janez Potočnik, former EU Commissioner for the Environment said: “recycling is the worst of the good options”.)
- The European Commission released a revised version of the Circular Economy Package. It includes changes to the targets in the Waste Framework Directive. We advocate a separate re-use target. Quantifying re-use activities is challenging, due to the heterogeneity and informality of the sector. For example, only “preparation for re-use” is documented because this is classified as waste treatment under all relevant legislative burdens, including the obligation for documentation, whereas re-use activities outside the waste regime are waste prevention and therefore not documented (repair services, online secondhand platforms, flea markets etc.).
- In 2025, the separate collection of used textiles will be mandatory in the EU. Which consequences will this have? Will the demand for second-hand clothing be big enough? Will “fast fashion” influence the future textile recovery? What will happen with the non-re-usable material? Will there be advances in optical sorting at recycling plants? What will be the impact on social and charity organizations relying on textile collection?
- The EU favors Extended Producer Responsibility as a policy measure to make the economy more circular. Are EPR schemes the most efficient tool for all goods?

Contact

RepaNet would welcome research on the above-mentioned topics and everything else in the context of re-use, repair and the circular economy. We gladly provide information and the contact to stakeholders.

On our website, you find the RepaThek – probably the largest collection of publications about re-use, circular economy and related subjects in the German-speaking area. If you like us to feature your work, feel free to get in touch. New entries are mentioned in our newsletter that reaches over 3.000 subscribers.

For more information, visit: www.repanet.at

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“DOUBLE ETICS” IN INTERACTION WITH BIOCORROSION ON THE SURFACE ACRYLATE PLASTER

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Abstrakt

To find solutions for maintenance and repair of existing structures ETICS becomes the current another issue of improvement thermal insulation properties of external cladding, which needs to be answered necessarily till December 2020. Double thermal insulation technology can be achieved by jointly increasing of thermal insulation properties and by repairing surface porosity ETICS. The aim of the research is the analysis of alternative layers of insulation materials in plaster repair by technology "double thermal insulation" ETICS in terms of technology, humidity and temperature conditions in the layers. During the time, various faults appear in older thermal insulation systems, but they do not have to threaten the general function of the structure. The presence of microorganisms in building environments, which according to the analysis threatens the construction from the inside, is also possible (after Ivanova E., 2013). The most common visible thermal contact faults are cracks, springing-off and mechanical damage, microorganisms contamination and biological attack of ETICS layers. The cause of the biological attack of thermal insulation surfaces is not completely known. The research shows that acrylic plasters are more attacked. This material causes that the drying time of the surface of the plaster on the north and west sides is longer than the silicate plaster. The long-term wet surface of the plaster creates suitable conditions for biofilm formation. According to (after Švajhelka et al., JUN 2017), certain types of microorganisms on the surfaces of building materials produce mycotoxins and play their role within the so - SBS Building Syndrome, who is global problem. Micromycotes act by their physicochemical activities on building materials, including plasters, and degrade them. Elimination of micro-organisms is the most often used for chemical surface cleaning, but it has a short lifespan and it needs to be repeated regularly. The construction of double thermal insulation could be a lasting solution to this problem. The role of long-term research is to investigate the lifespan of the double structure in terms of bio-corrosion, with a new colonization of microorganisms on the surface or renewed colonization in the set of original and new thermal insulation. The output of the analysis is the proposal of a control mechanism for quality assurance of the substrate from the point of view of the destruction of microorganisms and the proposal of a methodical procedure for the quality verification of the realization of the preparation of the substrate for double insulation.

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Design of the experiment and the mechanism for assessing the quality of surface preparation

The quality control of the surface preparation in contact with the ETICS layer and the new thermal insulation can be determined in laboratory conditions. The research information we find is the basis for further research in this field and the processing of the basic methodology of the laboratory lifespan survey, which consists of:

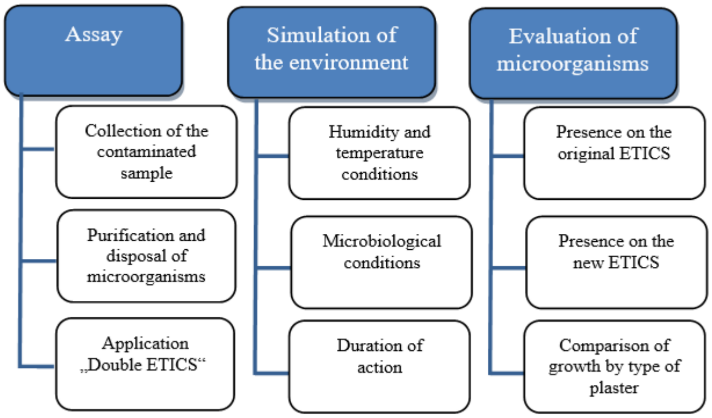

Figure 16 **Method for detecting the lifespan of "bio-corrosion" technology (author)**

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EVALUATION OF RESOURCE EFFECTIVENESS OF CIRCULAR ECONOMY STRATEGIES THROUGH MULTI-LEVEL STATISTICAL ENTROPY ANALYSIS

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Statistical Entropy Analysis of materials, components and products

In a circular economy (CE), materials, components and products should be kept at the highest level of functionality, while their loss and dilution should be avoided. Recycling, remanufacturing and reuse are examples of established CE strategies which aim to minimise the loss of materials and substances from anthropogenic metabolic systems. One method that assesses the performance of systems to concentrate or dilute substances is Statistical Entropy Analysis (SEA). The method has been applied on the substance level (elements and compounds), at different scales and on a variety of systems (Rechberger & Graedel, 2002; Rechberger & Brunner 2002; Sobańtka & Rechberger, 2013; Laner et al. 2017). Nevertheless, the current method does not allow for an integrated evaluation of recycling, reuse or remanufacturing systems, which consist of multiple materials and components. Through the extension of the method we are able to combine all three hierarchical levels consisting of the substance/material, component and product level. Additionally, we establish a baseline for resource effectiveness, which represents an ideal state of a CE system. In that ideal state, the dilution of substances/materials, components and products is avoided. Through a simple hypothetical case study we demonstrate how the baseline for resource effectiveness can be used to measure the distance of any system configuration to the ideal circular system state.

Simple MFA system

A simple Material Flow Analysis (MFA) system is developed to demonstrate the multi-level SEA method. It consists of four processes and represents a simplified production and end-of-life treatment system of an average car (Figure 1). The car composition data is aggregated on six material groups and four component groups (Table 1) as described by Modaresi et al., (2014a).

Table 2 **Average car composition, divided into four main component (vertical) and six material groups (horizontal) (based on an average US car, downscaled to global average) (Modaresi et al., 2014b).**

Group name	Standard steel (kg)	High strength steel (HSS) (kg)	Cast Iron (kg)	Wrought Al (kg)	Cast Al (kg)	Others (kg)	Total (kg)
Body and closures	222	182	0	8	0.3	45	457.3
Chassis and suspension	203	41	17	10	23	37	331
Powertrain	99	0	94	4	41	108	346
Interior and misc	61	0	0	12	2	173	248
Total (kg)	585	223	111	34	66.3	363	1382.3

The car composition data is employed to construct two different reuse scenarios, each with two recycling configurations (Figure 2).

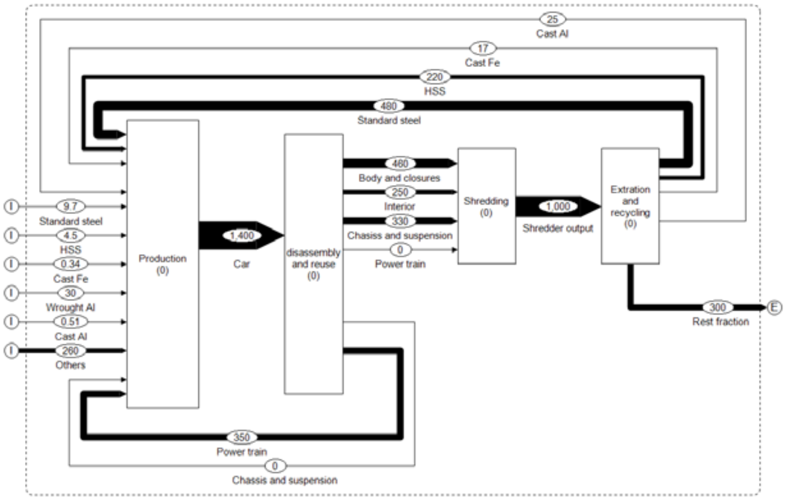
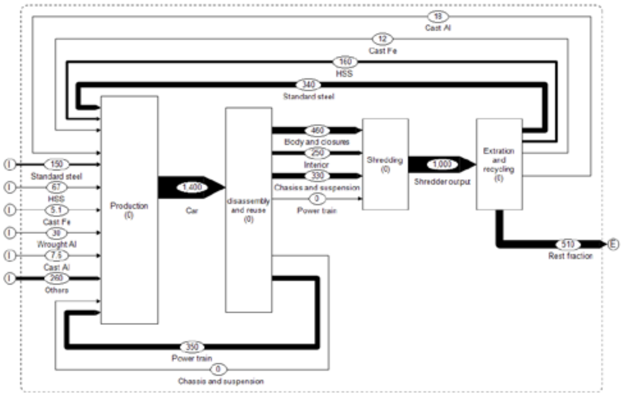


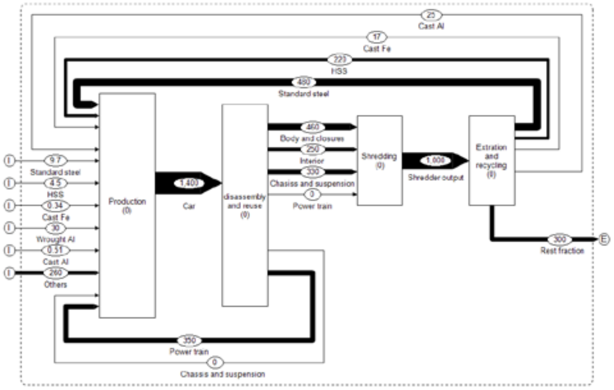
Figure 17 **Simple MFA system, consisting of a car production, disassembly and reuse, shredding, recycling processes (flows in kg/car).**

Low recycling level (70% of metals recycled)

High recycling level (98% of metals recycled)

Scenario 1: Reuse of one component group





Scenario 2: Reuse of none of the component groups

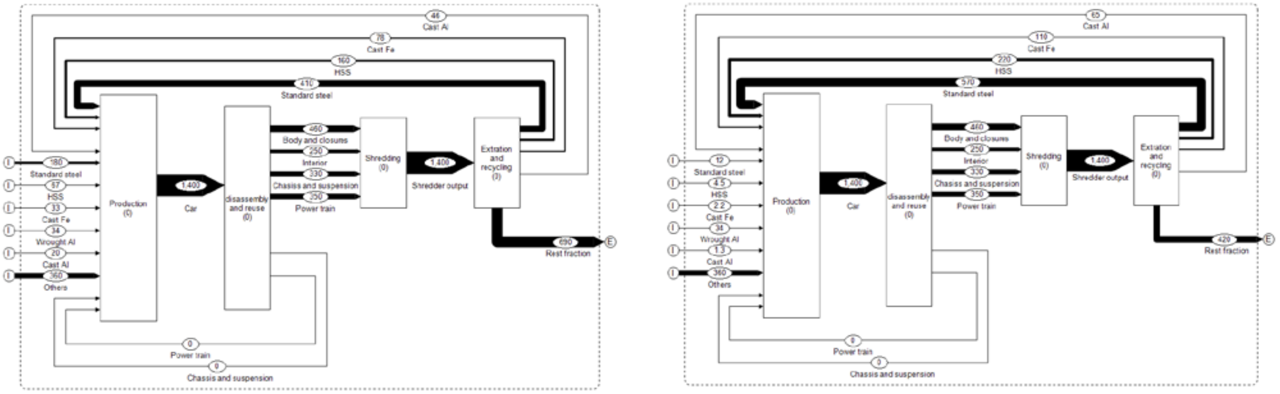


Figure 2 Two reuse scenarios with a higher and a lower level of recycling (low recycling level means 70%, high level recycling means 98% of metallic fraction of shredder output is recycled).

Method

The extended SEA method consists of two parts. First, the component SEA is calculated. Second, the component SEA is aggregated for the product. The component SEA calculation is similar to the original approach by Rechberger & Brunner (2002), with the difference that a component C_i consists of multiple substances *j* through their concentrations in the component *i*. In total, the sum of the substance concentrations $\sum c_{ij}$ adds up to one, resulting in the sum of substances $\sum X_{ij}$, which can fully describe the component *i*. The normalised mass fractions m_{ij} are calculated for the set *k* of induced material flows for the respective component by dividing each material flow rate by the sum of all induced substance flow rates $\sum\sum X_{ij}$ within the full set of material flows at a system stage (a stage representing a set of material flows between two processes) (1). Thereby, the normalised mass fractions take into account the relative contribution of each substance to the overall set of material flows at a system stage.

$$(1)\ \mathrm{m_{ij}} = \frac{\mathrm{M_{ij}}}{\sum\sum \mathrm{X_{ij}}}$$

$$(2)\ \mathrm{H_c}(\mathrm{c_{ij}}, \mathrm{m_{ij}}) = -\sum_{\mathrm{i=1}}^{\mathrm{k}} \mathrm{m_{ij}} \cdot \mathrm{c_{ij}} \cdot \mathrm{ld}(\mathrm{c_{ij}})$$

$$(3)\ \mathrm{H_{max,j}} = \mathrm{ld}\left(\sum \mathrm{m_j}\right)$$

$$(4)\ C_c = \frac{n}{N}$$

$$(5)\ C_m = \frac{m}{M_p}$$

$$(6)\ H_p(C_c, C_m) = -\sum_{i=1}^{k} C_m \cdot ld(C_c) \cdot \frac{H_c}{H_c + 1}$$

$$(7)\ H_{max,\mathrm{p}} = \frac{ld(C_c)}{2}$$

The statistical entropy value is calculated for a component according to Eq. 2 (ld refers to logarithmus dualis). It is further expressed as a dimensionless Relative Statistical Entropy (RSE) value, ranging between [0,1], as it is a ratio between H/H_{max}. The maximum statistical entropy value is calculated for each substance according to Eq. 3. For closed systems, the largest RSE value is reached, when a substance is diluted equally within a *k* set of flows. If a substance is fully concentrated in one flow, the RSE value is zero, representing the highest possible concentration.

For the calculation of the product entropy, the discrete component flows *n* are used to calculate the component concentration C_c. It is expressed as a discrete number of a component within a product over the overall number of components *N* in the product (4). Further, the component mass

m is standardised by calculating the mass concentration C_m of a component as a fraction of the overall product mass M_p (5). Both terms are combined in the product statistical entropy H_p. The previously calculated component entropy value H_c is included in the entropy term (6). The product entropy value H_p, together with the calculation of $H_{max,p}$ (7), locates the RSE value always in the interval of [0,1], while taking the value of zero or one for the extreme cases.

Results

The SEA results are plotted over their full life-cycle which starts and ends with the product stage (Figure 3). Any increase in the RSE indicates the dilution of substances/materials or components, while any decrease shows a concentrating behaviour of the system. It is important to note that any dilution requires concentrating processes afterwards. For the product and post-disassembly component stage, the relative statistical entropy (RSE) values are identical, as the material flows at these stages are identical for all system configurations. The first deviation for the two scenarios appears at the output flow from the shredder. The RSE is higher for the system with no component reuse, as all components enter the shredder and contribute to an overall larger material dilution. The resource effectiveness baseline as the ideal system state, represents the product which provides functionality and does not require any material inputs, neither does it induce the dilution of substances/materials and components. The system that performs closest to the resource effectiveness baseline is the system 1.2, with the reuse of one component group and a high recycling ratio for metals. Therefore, the worst performing system is the system 2.2, which lacks any reuse and has a low recycling level, requiring a high concentration of materials afterwards, which are again diluted into the functional product in the production stage. For this reason, the number of reused components and the shredder output stage largely determine the system performance. The presented methodology provides an evaluation perspective, which allows to compare systems that involve multiple CE strategies, and compare systems to a resource effectiveness baseline, representing an optimal CE state.

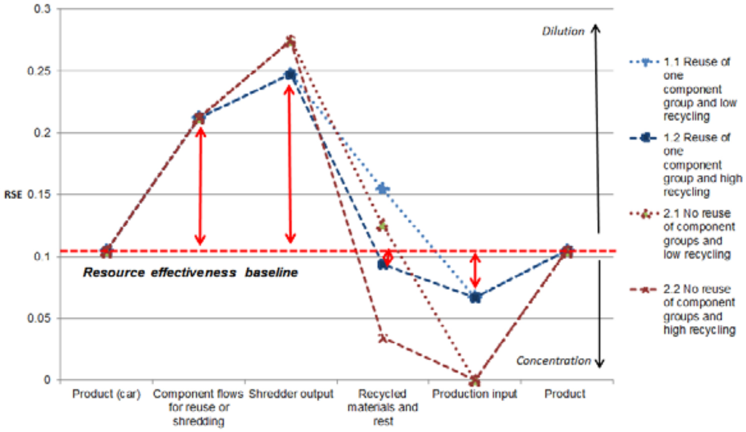


Figure 3 **Relative Statistical Entropy (RSE) for two reuse scenarios and two recycling configurations, with indicated distance to the Resource Effectiveness Baseline (red), and exemplary distances to the ideal state of scenario “1.2`Reuse of one component group and high recycling” (red arrows).**

Conclusion

In the short case example, we demonstrated that the extended SEA method not only allows to evaluate the degree of circularity in the context of different combinations of CE strategies, but is also able to identify stages with largest contributions to the deviation from the ideal CE state. Thereby, the extended SEA method can guide the choice of CE strategy combinations that minimise product, component and material losses and the distance to the ideal CE state.

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CIRCE2020 – EXPANDING THE CIRCULAR ECONOMY CONCEPT IN INDUSTRY AND PRODUCTION

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Introduction

The transition towards circular economy is particularly relevant for manufacturing businesses due to the outstanding use of primary resources in various production stages (European Commission 2015b). Recycling rates are still far from the targets set by the EU circular economy action plan (European Commission 2015a). One of the main reasons is that only few companies reuse or recycle by-products, and it is largely up to their independent initiatives. Therefore, shifting from single and sporadic company recycling interventions to an integrated redesign of industrial interactions needs an integrated environmental management approach in the manufacturing sector.

The Central Europe Programme project CIRCE2020, running from July 2017 to June 2020, aims to increase the reuse and recycling of waste and by-products produced in the manufacturing sector, in order to reduce waste and the consumption of primary raw materials. Achieving this goal requires a better understanding of waste and material flows, uniform framework conditions, innovative business models and quality standards for secondary raw materials. The goal of CIRCE2020 is to develop and apply an innovative waste governance model considering the entire cross-value chain. In addition, existing analytic tools, such as product environmental footprint (PEF), life cycle cost analysis and technology readiness rating will be adapted, in order to be applicable to waste and material flow processes.

Set up CIRCE2020

This newly developed approach will be tested and implemented in five Central European pilot regions: Province of Tyrol (Austria), Upper-middle Brenta Basin (Italy), Province of Wielkopolska (Poland), Tatabánya Industrial Park (Hungary) and Split-Dalmatia County (Croatia).

All five regions work in parallel with constant exchange on the three main steps: i) Status quo assessment, ii) Material flow, life cycle and life cycle cost analyses, and iii) Implementation of pilot actions, including several task (Figure 1).

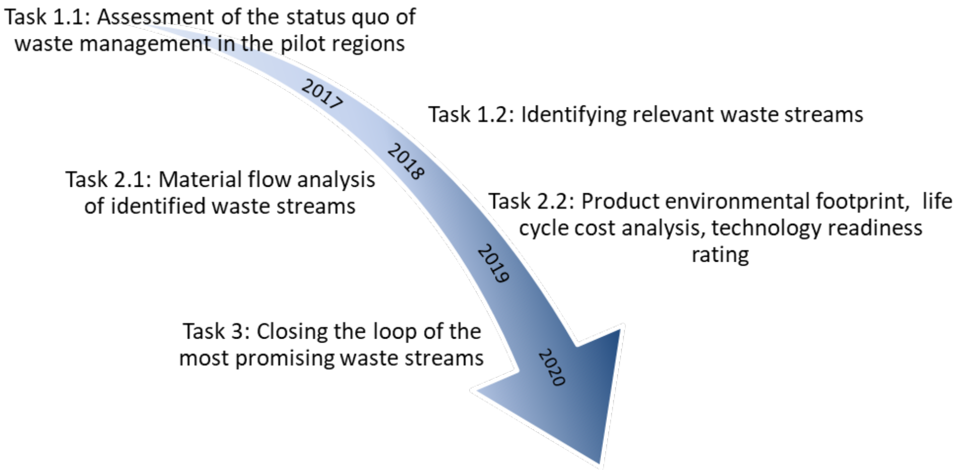

Figure 18: Tasks and their sequence of CIRCE2020.

For all tasks common guidelines will be established, so as to compare the results across the five pilot regions. Depending on regional constraints and conditions the pilot regions work independently, set their own focus and if needed adjust the commonly developed guidelines to their requirements.

The final Task 3 aims to implement the previously developed circular solutions. In order to close the loop of at least two waste streams, it is planned to establish an industrial symbiosis network. This network ideally includes companies representing various steps in the production chain, e.g. waste producers, waste collectors/processors, and waste recipients/consumers (Figure 2).

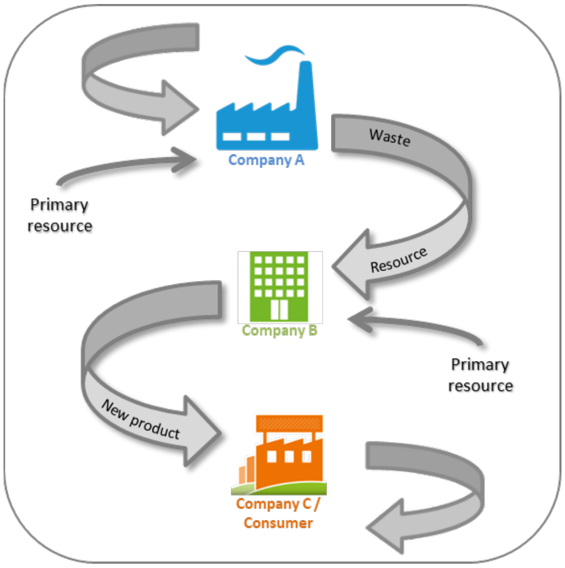

Figure 19: Schematic sketch of the planned industrial symbiosis network to close the loop.

Material flow analysis

For the pilot region Tyrol 10 waste streams were identified to be relevant, based on 27 stakeholder interviews, representing private companies, public administrations, business support associations and academia (see Table 1).

Table 3: Waste streams identified as relevant for the pilot region Tyrol.

	Waste streams	Waste introducing enterprises	Idea circular solution
1	Waste wood	Several companies	Activated carbon
2	Sheep wool, minor quality	Sheep Farmers, Breeding Associations	Fertilizing pellets
3	Non-saleable vegetables (rejects)	Farmers	Rejects retail / convenience food
4	Old bread	Bakers	Animal feed
5	Organic waste	Supermarkets, restaurant, hotels	Production of regional soil
6	Grease trap waste	Restaurant, hotels	Biogas/Biodiesel
7	Sewage sludge	Waste water treatment plants	Phosphate recycling
8	Filter cake	Paint producers	not yet defined
9	Sifted limestone (0-25mm)	Chemicals producers	Soil pH neutralizer
10	Calcium carbide production residue	Chemicals producers	Input for cement production

For these 10 waste streams material mass balances will be calculated regarding the origin of the waste production and its destination, and detailed analyses for the amount to be recovered, recycled, incinerated or deposited in landfill sites.

In combination with additional “semi-objective” criteria (see Table 2) these results will give a strong indication, which of these circular solutions are most promising and will be further elaborated regarding their product environmental footprint, life cycle costs, and technological readiness to be implemented.

Table 4: Criteria for the evaluation and selection of waste streams for further analyses.

Category	Criteria
Social / Moral	Is the newly created output product of moral and ethical relevance? Does the process of valorisation create jobs?
Environmental	Waste hierarchy indicator: Sum of the weighted waste management options for a specific waste stream based on the waste hierarchy as defined by the Directive 2008/98/EC (European Union 2008), which is (a) prevention; (b) preparing for re-use; (c) recycling; (d) other recovery, e.g. energy recovery; and (e) disposal.
Economic / Companies	Is a partner structure existing / established across the entire process chain (producer, collector / processor, distributor / consumer)? Is there a market/demand for the new output product, preferably regionally?
Technical	Is the concept/idea technically feasible within the project duration?

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DEMAND AND SUPPLY SCENARIOS TO SUPPORT CIRCULARITY IN THE COPPER CYCLE

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Background and aim of the study

Copper is widely used in modern society, finding application in traditional end-uses such as building and transportation, but it is also an essential material in emerging energy technologies (e.g., photovoltaics, wind turbines). Although Europe (i.e., EU-28) has considerable natural deposits of copper, this region strongly depends on imports to meet the domestic demand. Despite this, copper was not ranked as a “critical raw material” (EC, 2017) by the European Commission. However, the decrease of ore grade and the anticipated mine production peak (Vieira et al., 2012; Northey et al., 2014) could result in limitations to access essential materials for the European copper industry. In this view, end-of-life recycling can secure access to secondary copper forms and support the implementation of the Circular Economy in the EU-28. In addition, as copper recycling is generally less energy intensive than primary copper production, closing the elemental cycle through recycling would result in significant environmental benefits.

In this work, material flow analysis (MFA), scenario analysis and life cycle assessment (LCA) were combined to explore the possible evolution of copper demand in the EU-28, evaluate opportunities and barriers for improving recycling at end-of-life, and assess the potentials for energy savings and greenhouse gas (GHG) emissions reduction associated with copper recycling. For each scenario, we commented the results under the hypothetical creation of the Circular Economy in the EU-28 and measured the degree to which secondary copper supply could cover the expected domestic demand.

Main findings

Figure 1 displays the contemporary anthropogenic copper cycle in the EU-28. The results demonstrate that the EU Member States relies on imports of copper forms to meet the demand, with less than 20% of copper production being produced from domestic reserves. The cumulative anthropogenic reserve (or in-use stock) amounted to ~73 Tg Cu, which is about 1.5 times the known copper reserves in this region (~48 Tg Cu; USGS, 2017). Part of post-consumer scrap is recycled domestically, either sent to direct melting or secondary cathodes production. Part is net-exported, but the largest fraction of copper old scrap is not recovered and lost (Ciacci et al., 2017).

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The MFA model revealed that over the last five decades, the copper demand in the EU-28 has increased by 160%, should the future follow the dynamics of a “business-as-usual” world, the amount of copper apparently consumed will likely triple respect to current levels. This scenario implies severe constraints to a society based on secondary material sources. In contrast, a world that prioritises the Sustainable Development Goals would progressively decrease the copper demand. This positive situation would also significantly reduce the energy requirements and greenhouse gas emissions associated with the regional copper industry.

However, for most of the scenarios considered the current recycling performance seems not to be enough to tackle the challenge of ensuring access to essential resources to the European copper industry while preserving the natural capital and mitigating climate change. Fundamental constraints are likely to limit the implementation of the Circular Economy in modern material cycles, particularly whether the current models of resource production and consumption will dominate the world that is expecting us.

Acknowledgments

This project has received funding from the European Union’s Horizon 2020 Research and Innovation Programme under the Marie Sklodowska-Curie grant agreement No. 704633 (QUMEC). Disclaimer: Views expressed are those of the authors, and the Research Executive Agency (REA) of the European Commission is not responsible for any use that may be made of the information this work contains.

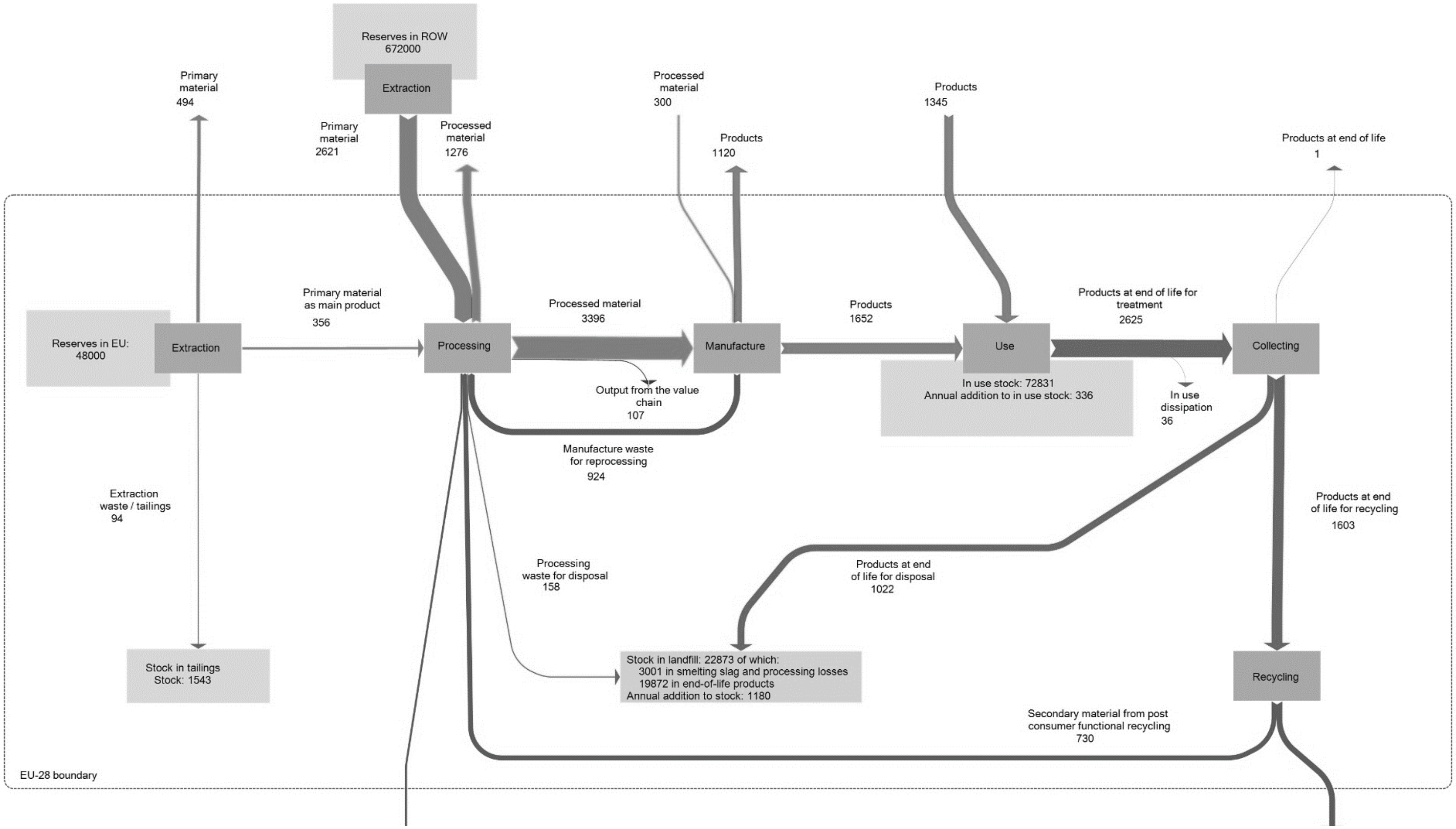

Figure 20 *The anthropogenic copper cycle in the EU-28 (year 2014). Values in Gg Cu. Reproduced from Passarini et al. (2018).*

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LABORATORY FOR APPLIED CIRCULAR ECONOMY

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Introduction

Circular Economy (CE) is the buzzword of today, promising an economy able to operate with limited resources by closing material cycles. Different strategies for the end-of-life of products are defined (see e.g. (Ellen MacArthur Foundation 2013)) and it is assumed, that an application of these strategies on a micro-level will lead to a net environmental benefit. But in reality, implementing these strategies alone will lead in many cases to a rebound effect due to the fact that recycling will not replace primary production on a 1:1 basis but rather increase the material on the market (e.g. (Zink and Geyer 2017), (Grosse 2010)). In addition to this shortcoming in scope of current understanding of CE, there is so far a clear lack in scientific literature on methodologies and indicators to assess CE strategies as well as the operationalisation of CE on a company level (Ghisellini, Cialani et al. 2016).

The in Autumn 2017 started Swiss project "Laboratory for Applied Circular Economy" (LACE) has as an objective to demonstrate that the principles of CE are indeed applicable to industrial production systems in an ecologically and economically sustainable way by consolidating practical knowledge for the transition towards such a circular economy. The project LACE is part of the Swiss National Research Programme 73 "Sustainable Economy" (NRP 73). The project is carried out at three Swiss research institutions, each one bringing its specific perspective into the topic – the University of St. Gallen (business perspective), the University of Lausanne (legal perspective) and Empa (environmental and technical perspectives). They will explore their research results concerning its applicability in close collaboration with eight private companies (see fig. 1), representing five different industrial sectors and ranging from small and medium enterprises (SMEs) to multinational cooperations.

Objectives of the LACE project

The main objective of the LACE project consists in introducing, consolidating and improving elements of a CE in companies that are representative for the Swiss economic tissue. The project aims at demonstrating under what circumstances circular business models can be implemented in an environmental and economical beneficial way.

Therefore, the LACE project aims at finding the boundary conditions within which a CE needs to operate in order to be sustainable. This work shall lead to concrete design criteria for products,

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services and business models. Further, the project will develop, in collaboration with the partner companies, possible pathways towards its implementation.

LACE aims at consolidating practical knowledge for the transition towards a CE. The final products will be business plans to show how to implement the principles of CE in the partner companies.

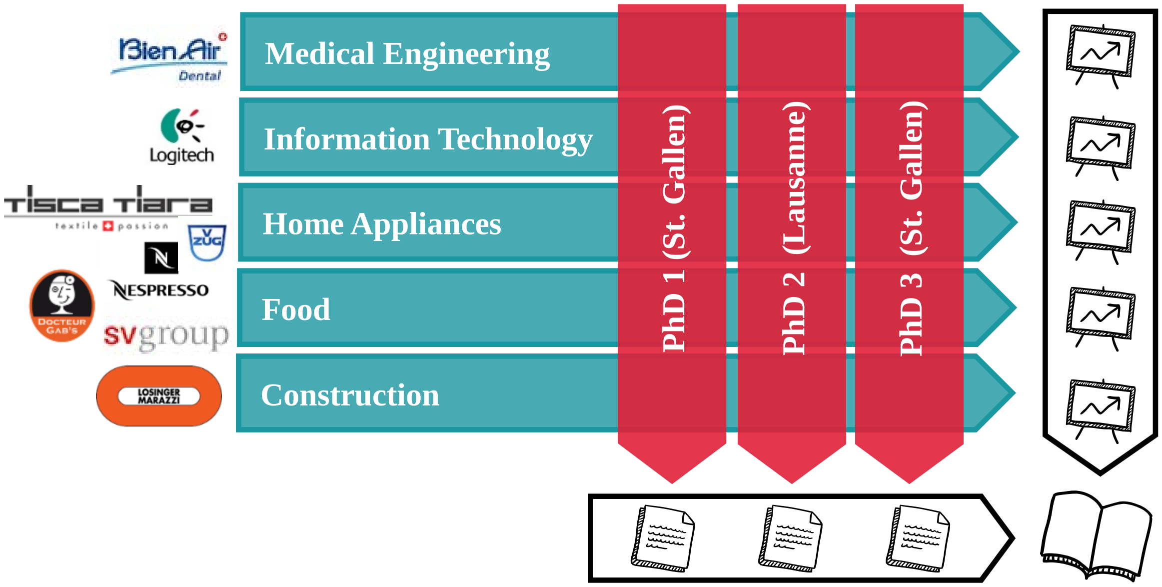

Figure 21: Structure of the LACE project

Project Overview

To reach these project goals, LACE will employ an inter- and transdisciplinary approach in close collaboration between science and industry. The core of the research will be carried out in the framework of three PhD thesis:

- Thesis #1 "Technical feasibility": The PhD Student at Empa looks at environmental and physical boundary conditions for a CE and will identify technical design criteria to respect these conditions. A MFA/LCA based tool will be designed to assess strategies in a CE on a product and company level.
- Thesis #2 "Legal complexity": The PhD candidate at University of Lausanne investigates legal barriers in the current Swiss legal framework for implementing CE. Further she will identify necessary changes in the legal framework in order to support and facilitate the implementation of CE strategies.
- Thesis #3 "Business profitability": The PhD student at University of St. Gallen will identify successful circular business model patterns and design a tool to design circular business model innovation. This tool will be designed to respect the physical and legal boundary conditions.

All three PhD thesis will cover their respective aspects in a general manner across all companies and sectors. The transdisciplinary collaboration between these PhD work and the companies in the different sectors will then highlight business opportunities for each sector, while each of these PhD thesis represents a consistent scientific work within a single discipline. To ensure that the scientific knowledge gained in these various fields as well as in the transdisciplinary work remains consistent and can be transferred to other industrial sectors, Sanu Durabilitas is responsible as knowledge transfer partner to coordinate and transfer these results (see fig. 2).

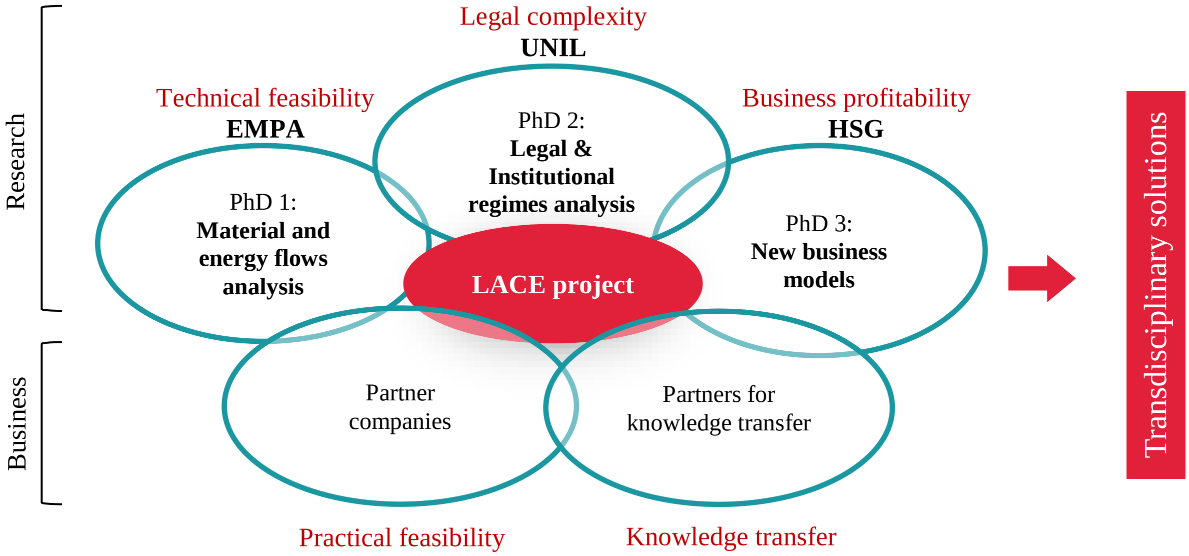

Figure 22: Relations and actors within LACE

The project LACE will run for a duration of four years, focussing on the following issues:

- Review of literature, methods and practical examples in CE
- Development of methodologies and tools
- Application in partner companies and refinement of methodologies and tools
- Finalisation of thesis work and knowledge transfer

Environmental and Engineering Aspects

A CE can only be considered environmentally sustainable, when it stays within the limits of the planet. Our planet is a finite entity and thus resources and energy are limited (e.g. (Kleidon 2012)). In addition, humanity is part of the ecosystem and relies on its functions and services (e.g.(Rockstrom, Steffen et al. 2009), (Running 2012)), thus it is in the very interest of humanity to stay within the ecological limits as well.

Therefore, in a first step of the PhD thesis #1, the boundary conditions for an environmental sustainability will be derived, in order to respect both physical and ecological limits. This analysis will focus on global resource availability, then these global budgets on resources are the basis for engineering guidelines. A material and energy flow analysis will be carried out for the three different resource types:

- energy (solar energy and its derivative forms, planetary motion, geothermal energy, fossil energy, nuclear energy),
- renewable resources (based on net primary production (NPP), such as wood, agricultural produce, cotton, leather, …),
- finite resources (minerals, metals, technical materials).

Based on the relative availability of different resources, a list of preferable materials and forms of energy can be derived. Further physical considerations yield additional engineering guidelines, such as concerning entropy production. Besides these general engineering guidelines applicable across all industries, particular guidelines for specific sectors can be derived wherever need be.

As second step within thesis #1, indicators and tools will then be developed in order to measure the progress towards a CE. The indicators will be based on the boundary conditions identified. To quantify the indicators, a tool will be developed based on MFA and LCA methodologies.

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NATURE TO SUPPORT CIRCULAR ECONOMY – INDUSTRIAL SYMBIOSIS IN FOOD MANUFACTURING

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** defended PhD thesis on 9th July 2018 at the Faculty of Economics in Subotica, University of Novi Sad, Serbia*

> *Look deep into nature, and then you will understand everything better.*
>
> Albert Einstein

Introduction

In contrast to linear economics and linear business model as a dominant model of unsustainable industrial systems, circular economics and circular business model aim to avoid pollution and environmental degradation by turning waste into a resource. Within individual production (manufacturing) processes, raw materials are taken and two basic outputs are generated: 1.products with the purpose to be sold and 2.waste to be disposed of. Due to the latter, industrial system should learn from nature and use nature as a model because nature creates no waste. In natural ecosystems, through the food webs, interconnection of uses of both organisms and their waste is established. Therefore, individual manufacturing processes should be transformed into an industrial ecosystems. Why ecosystems? Ecosystems provide the best available example of sustainability: energy and materials are extracted, metabolized and transferred by organisms and across their communities, in a cyclical manner. Why industrial ecosystems? In such a system the consumption of energy and materials is optimized, waste generation is minimized and the effluents of one process are inputs for another process. Industrial ecosystem is the place where industrial symbiosis occur. Industrial symbiosis consider cooperation among companies in managing resources, particularly by-products, such that the waste of one firm become the input for another. This closed loop pattern is the basic pillar of the concept of the circular economy and circular business model. Why industrial symbiosis? Industrial symbiosis is a self-organizing business strategy among companies that are willing to cooperate in order to improve their economic and environmental performances. Through symbiotic exchanges companies can save on treatment or disposal and possibly can earn by selling by-products and waste e.g. improve economic performances. Also, industrial symbiosis is a form of inter-organizational environmental management or network environmental management practice allowing companies participating in symbiotic transactions to improve environmental performances – less waste to landfill, less non-renewable energy sources used, reduction of emissions, etc.

Why industrial symbiosis in food manufacturing industry? Food industry generates high amounts of solid waste and by-products. From an industrial symbiosis perspective, the outputs - by -

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products and waste in food industry are relevant. The large amounts of waste produced by the food industry are a great loss of valuable materials, on the one side, and serious management problems, on the other side. Valorization of by-products and waste from food industry impacts not only environmental performance but also company’s economic efficiency. For example, where waste is unavoidable, industrial symbiosis helps eliminating the cost of landfilling by finding new homes for waste streams. By-products and waste originating from food manufacturing (processing) as well as recovered valuable components from the food production residuals can be transformed into, for example, fine-chemicals or natural macromolecules and can be valorised in sectors like the pharmaceutical or chemical industry or in food industry itself.

Research Question: How could look like an industrial ecosystem as an industrial food web consisting of 1. food manufacturing companies and 2. companies from the same or other sectors that are using residuals (by-products and waste) from food processing as inputs?

Methods

Model of industrial ecosystem (industrial food web) development was based on the literature review in the field of valorization of food manufacturing residues, companies’ web sites and field research.

Results

Model presents the flows of food production residues generated in the food manufacturing stage of the food supply chain and their industrial uses. Selected by-products and waste streams show that applying industrial symbiosis for recovering residues from food processing leads to their usage as a material and/or energy inputs within the same company (internal symbiosis) or by another company (external symbiosis), in the same industry or related industry. Besides manufacture of food products, model includes manufacturing of beverages as well. Numbers indicated before the names of the food and beverage manufacturing groups or classes are in accordance with NACE Rev.2, statistical classification of economic activities in the European Community.

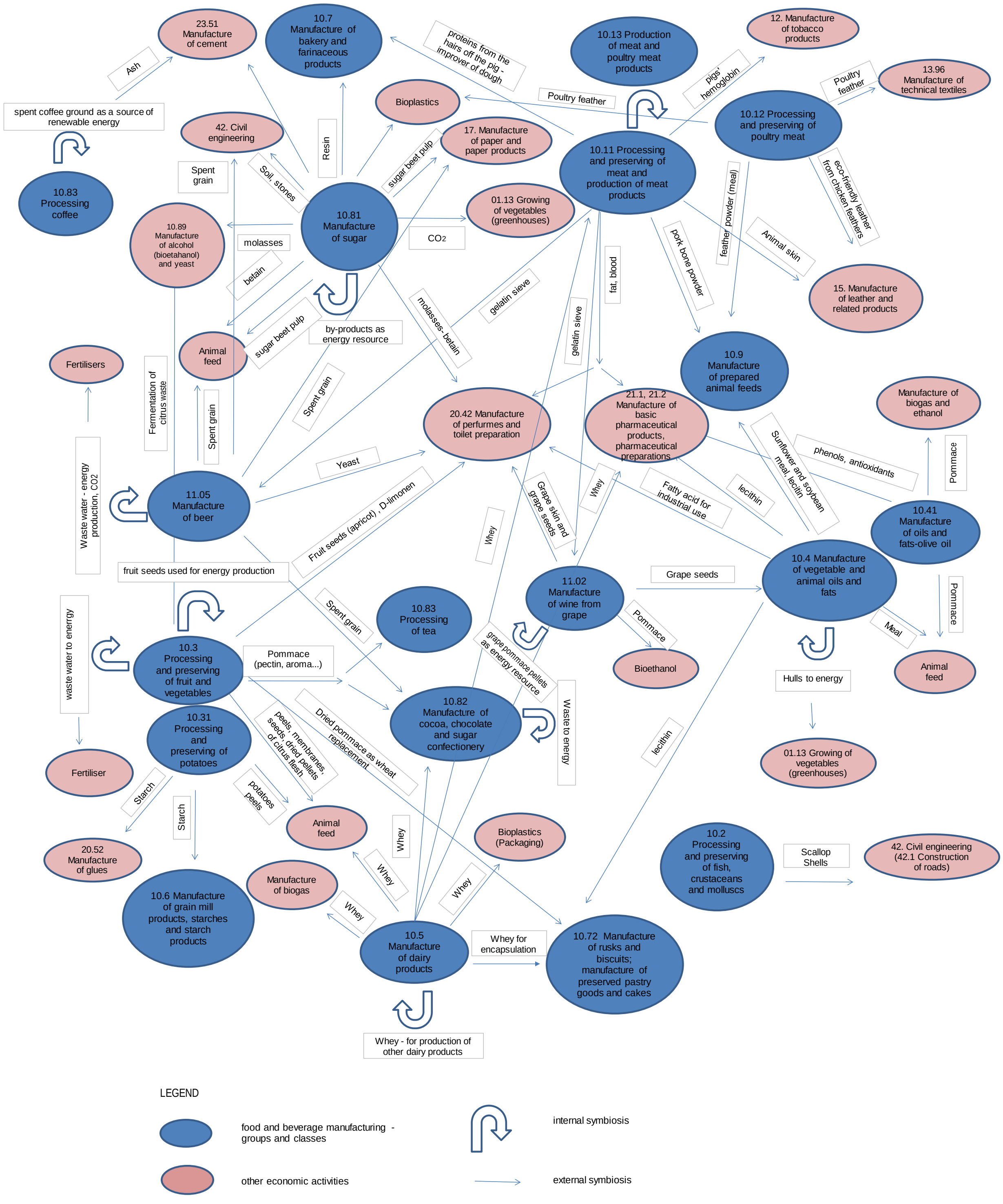

Figure 23 **Industrial ecosystem (industrial food web) – food and beverage manufacturing and other sectors**

Conclusions

There is a significant resource potential in the food manufacturing residues. Industrial symbiosis helps to easier close certain material loops through internal and extrenal use of waste and by-products as a raw material and energy sources, within food manufacturing companies or with the companies from the same or related sectors. Industrial symbiosis may have a significant potential to improve company’s competitiveness at the same time – reduce cost and/or increase revenue. Optimisation of cooperation between companies within and outside food manufacturing sector and the maximization of resource utilization means growing internal efficiencies. Industrial symbiosis can be of a crucial importance for sustainable transition to sustainability and circular economy, above all economically sustainable sustainability.

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PHOSPHORUS CRITICALITY: CLOSING THE LOOP OF PHOSPHORUS FLOW

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Introduction

Phosphorus is an essential chemical element for all form of life. The Agri-food system is by far the first consumer of phosphorus with 82% for agricultural fertilization, 7% as animal feed additives, and 1-2 % as food additive. (Schröder et al. 2010).The global demand for nutrient and fertilizers are growing as fast as the world population’s growth. As Phosphate rock is a finite resource, the nature is not able to regenerate its stock as fast as our consumption rate and we did not find yet a substitute for this resource as we did for the oil substituted by renewable energy. Following the current linear economic paradigm, the depletion of Phosphate rock is a major threat to the ability to meet a basic need of fast growing world population, which is nutrition. In addition,the European Union listed phosphate rock as a critical material in its report about critical raw material (European Comission 2014) and one of the priority sectors to implement the principles of the circular economy package adopted by the European commission (EC) (European Comission 2017) (Abdulai et al. 2015)

The Wastewater Ordinance 2004 has regulated the quantity of phosphorus in the discharged wastewater, depending on the capacity of WWTP. The ordiance (AbwV) of 17 June 2004 stipulates that total phosphorus (PTot) at the point of discharge into water bodies is limited to 2 mg/L for waste water treatment plants (WWTP) category 4 (10,001-100,000 population equivalents) and limited to 1 mg/L for WWTP category 5 (>100,000 population equivalents

These aspects of phosphorus criticality, the EU dependency on imports, and the environmental regulation altogether are forming the cornerstone of interdisciplinary research approaches to promote the technological innovation for phosphorus recovery and to reuse the end-product in the agriculture or industry.

Research goal

As raw material criticality patterns are highly dynamic and a standardized method may lead to wrong decision making (Achzet und Helbig 2013), this paper aims first to develop a methodology to assessment criticality of phosphorus through its value chain and define the bottleneck of Phosphorus supply. It includes the entire life cycle of Phosphorus from exploration, extraction, processing, use and recycling.

Methodology

We chose as method the Criticality of the function through the value chain of Phosphorus with the following steps:

1. Selection of the key crossroad of different transformation processes through the value chain (We referred to them as Functions). We used the flow of traded Phosphorus commodities on the global market for the year 2016, which are Phosphate Rock (PR), white Phosphorus (P_4) and Phosphoric Acid (H_3PO_4) marked as orange boxes in figure 1.
2. Definition of the parameters and indicators that reflect the supply risk. The Parameters are Geological, Environmental, Socio-political and Technical.
3. Aggregation and equal weighting the indicators for the calculation of Supply risk for each function, taking into consideration the time horizon; short term (0-5 years) and mid to long term (above 5 years).

This method would give an outlook of the dynamic of change of natural resources, and accumulation of the anthropogenic resources.

Results

- The factors that may affect Phosphorus criticality in different stage of its value chain are mainly:
- For Phosphate Rock: Short-term factors are the socio political factors and environmental factors. The long-term factors are the geological and technical factors.

For White Phosphorus and Phosphoric Acid: the long term factors are technical and environmental factors; there is a decline in the future of producing technical Phosphoric acid from P_4 and producing it from Phosphoric acid the thermal process.

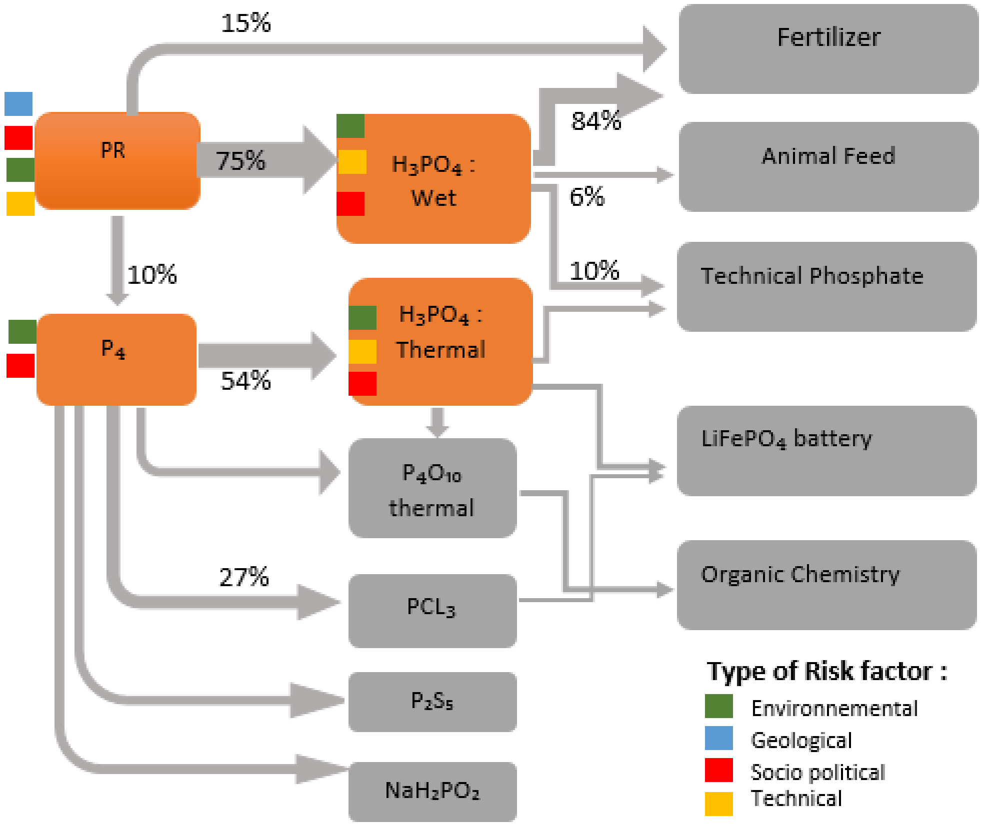

Figure 1: Global Phosphorus market: Flows and risk factors according to Traded quantities in 2016 from the data base of the Internation Trade Center (www. intracen.org)

Conclusion

The market of Phosphate Rock (PR) and Phosphorus products is highly concentrated. For (PR) three countries control 75 % of the reserves (Morocco, China and Algeria) and 81 % of the production (China, Morocco and the USA). 75% of PR is used to produce Phosphoric acid, which is currently in competition of the market of White Phosphorus and projected to grow 2% per year due to the advancement of technology to produce highly pure technical Phosphorus.

Therefore, the long-term factors such as geological, environmental and technical factors are the main supply risks for the global market

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CARBON IN GLOBAL WASTE AND WASTEWATER FLOWS - ITS POTENTIAL AS ENERGY SOURCE UNDER ALTERNATIVE FUTURE WASTE MANAGEMENT REGIMES

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1 Introduction

The concept of a circular economy has emerged as a strategy to cope with uncontrollable and unsustainable consumption rates of today’s society (Haas Willi et al. 2015) . In that context, sustainable waste and wastewater management systems play a significant role in contributing to reduce air and water pollution as well as to decarbonization of the energy system through reducing, reusing, recycling and recovering part of the energy embodied in waste materials and wastewater (Corsten et al. 2013). Regarding wastewater, different case studies have shown that anaerobic digestion with biogas utilization could offset the energy consumption in the wastewater treatment process (McCarty, Bae, and Kim 2011; Stillwell, Hoppock, and Webber 2010). Different waste and wastewater management pathways and policies would have different social, environmental and economic impacts. While in the developed world the focus of the management systems have moved towards resource efficiency, developing countries are still facing problems to cope with the large volumes of waste and wastewater generated (Manaf, Samah, and Zukki 2009). This has been attributed to financial, technical and institutional problems at the local and national levels (Pokhrel and Viraraghavan 2005). However, if an economy grows accompanied by enforcement of environmental policies focused on the circularity of the system, climate, health and other environmental impacts caused by poor waste and wastewater management systems could be tackled simultaneously (Ghisellini, Cialani, and Ulgiati 2016). Therefore, an examination of the current state and an exploration of future waste and wastewater management alternatives is needed in order to identify an adequate strategy to achieve the maximum benefits for a growing economy. Accordingly, the overarching goal of this study is to investigate the maximum potential contribution of the global waste and wastewater sectors to the decarbonization of the global energy system, as well as to quantify potential limitations on energy recovery from these sources introduced by possible future waste and wastewater policies. The analysis rests on detailed country-/region- specific estimations of the carbon content in current waste flows with simulations of future carbon flows for a range of different waste and wastewater management regimes.

2 Maximum energy potential from waste and wastewater

The analysis of the estimation of maximum energy potential from waste and wastewater (before conversion to electricity or heat) shows (Fig.1) that current energy recovered from waste and wastewater management is around 13EJ at a global level, which corresponds to 2 % of the total primary energy demand in 2010. 63 % of the total energy recovery originates from waste incineration and 37 % from biogas generation. OECD countries have a share of 81 % of total energy recovered from waste and wastewater at the global level (79% incineration and 21 % biogas). In general, OECD countries have been improving waste and wastewater treatment systems as a key element of achieving sustainable resource management, of which energy recovery is an essential part.

With the 'maximum technically feasible phase-in of waste and wastewater management' (MFR) energy generation would be ~ 5 times higher compared to the CLE scenario reaching 66 EJ by 2040, which would correspond to 9 % of the total primary energy demand (~ 740 EJ) projected by IEA (International Energy Agency 2017) in 2040. 81 % of the energy would be recovered from waste incineration and 19% from biogas. These shares are the result of exhausting the corresponding recycling capacity before sending material to incineration, reducing the waste going to landfills and upgrading/improving wastewater treatment systems with energy recovery. Most of the biogas is generated from solid waste (99 %) while the contribution from wastewater is particularly low (1%). Wastewater must undergo pre-treatment before entering the anaerobic treatment, which removes organics by 35 % - 40%, reducing the capacity of biogas generation (Cakir and Stenstrom 2005). Furthermore, a certain fraction (depending on temperature, pressure, salinity) of the methane formed remains in the water as dissolved methane, which diminishes even further the potential for biogas generation (Liu et al. 2014) – a situation which explains the lower share of energy recovered from wastewater.

Moreover, if on top of the technical improvement, policies aimed at reducing food and plastic waste are implemented and plastic recycling rates are maintained at current levels and the remaining plastic material is sent to incineration (MFR+PCY+PLA), energy generation will reach the same level as the MFR strategy alone (66 EJ). Biogas would be reduced by 23 %, falling from 13 EJ to 10 EJ in 2040. Energy available from incineration will increase from 53 EJ to 55 EJ in the same year. Sending the excess of plastic waste into energy recovery compensates for the reduction of plastic generation and increases energy from incineration by ~5%. Although the concept of waste recovery includes energy recovery, this latter process results in less decarbonization and environmental benefits than material recovery since virgin material is still demanded (Hopewell, Dvorak, and Kosior 2009). However, with the current situation of excess supply in the plastic recycling market (e.g., China's ban on importing recycling plastic after being the leading world's importing country (Velis 2014)) and assuming the success of the plastic waste reduction policy, the 'best' way to recover/reuse plastic waste is to convert it to energy through incineration.

However, it is preferable to exhaust the maximum recycling rates before sending material to incineration. Therefore, assuming an ideal market for recyclables on top of food and plastic reduction policies (MFR+PCY+REC), the potential of energy generation is reduced by 6% in 2040 compared to the MFR and to the MFR+PCY+PLA, resulting in 62 EJ of the energy gains. Hence, the prevention of food and plastic waste generation would not drastically affect the maximum energy recovery potential, but instead have positive impacts towards other sustainability factors. 84 % of the total energy recovered would be from waste incineration and 16% from biogas.

Finally, the optimal waste and wastewater management scenario for improving the so-called circular economy would be to follow the scenario MFR+PCY+REC+IMP, where the implementation of food and plastic waste reduction policies succeed, the maximum recycling rates of the different waste streams (including plastic) are reached and where waste and wastewater treatment technology improvements increase energy generation and energy recovery efficiency. Once the recycling capacity is exhausted, remaining materials are allowed to enter incineration plants. Organic waste is digested and wastewater is anaerobically treated to produce biogas. The maximum energy potential from waste and wastewater sectors would then be 64 EJ by 2040 which is 9% of the total primary energy demanded in 2040 as projected by IEA (New Policies scenario 2017). By comparing the CLE to the MFR + PCY + REC + IMP we observe that there exists and estimated additional potential for recovering energy equivalent to 50 EJ per year. In other terms, it means that only 20 % of the maximum capacity to generate energy from solid waste and wastewater would be exploited if current technology and infrastructure are maintained in the future. The success of policies simulated in the improved technology scenario requires waste prevention, reuse, recycling and energy generation, resulting in multiple climate, environmental and social co-benefits.

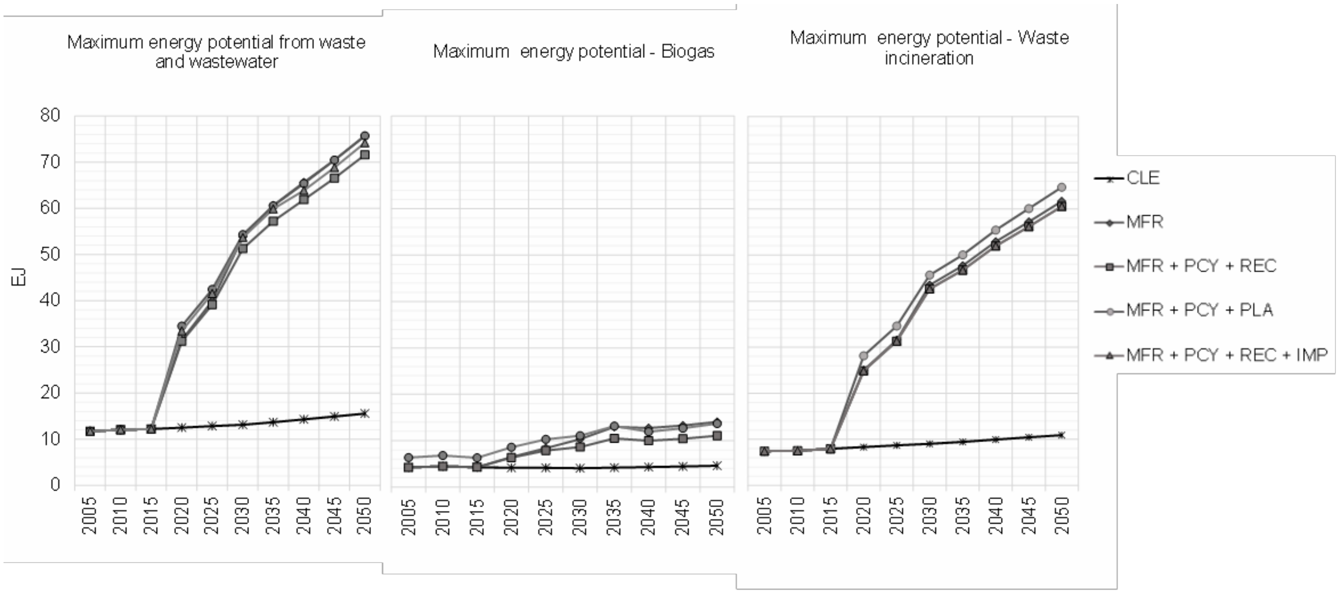

Figure 1. Maximum global energy recovery potential from waste and wastewater treatment by scenario

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SUSTAINABILITY-ORIENTED CRITICALITY ASSESSMENT FOR METALS AND LOW-CARBON TECHNOLOGIES

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Motivation

The global agenda of Sustainable Development Goals and the Paris Agreement leads to a world in which access to materials and technology is ever more important. A global net zero greenhouse gas emission target necessitates so-called low-carbon technologies in all industry sectors, many of which are highly reliant on critical metals. Critical raw materials are of highest concern, due to their high supply risk and high vulnerability to supply restrictions, their environmental or societal impacts. If we want to reach climate goals and development goals, we need to manage the risks and interactions of critical metals.

Method

Assessments developed at the Resource Lab working group quantify the criticality of metals, including for example 11 indicators for supply risk and 17 for social implications. Fig. 1 shows the framework for upply risk indicators in four risk categories for supply reduction, demand increase, concentration or political risks (Kolotzek et al., 2018). The indicators are often used in criticality assessments, are quantifiable and relevant for supply risk assessments for industry and academia.

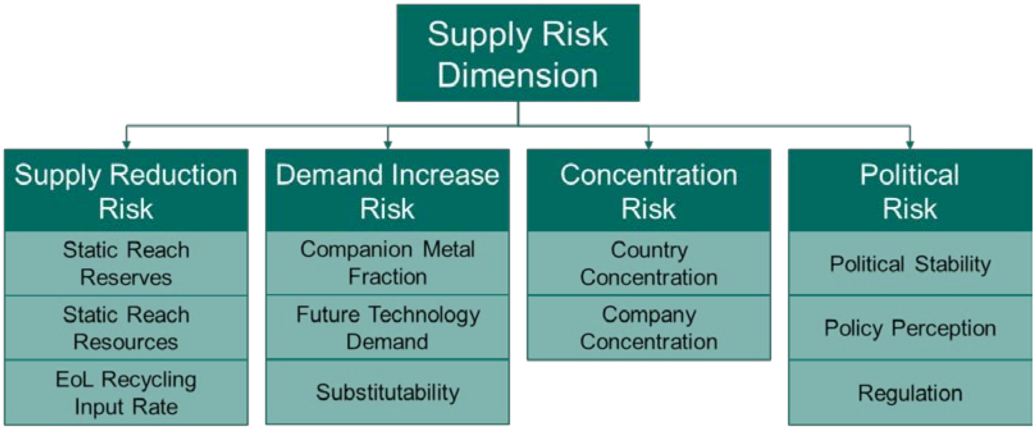

Figure 24 Eleven supply risk assessment indicators (after Kolotzek et al., 2018)

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The framework for social risk assessment follows the guidelines for Social Life Cycle Assessment of the UNDP. From their five stakeholder categories, suitable indicators are identified for the local community, society and worker stakeholders. Fig. 2 shows the social risk assessment indicators by Kolotzek et al. (2018).

Figure 25 **Seventeen social risk assessment indicators (after Kolotzek et al., 2018)**

Both the indicators for the supply risk assessment and the social risk assessment are weighted by in total 50 experts from industry and academia following an Analytic Hierarchy Process (AHP).

Case study results

Multiple case studies on elemental and technology level include a range of more than 30 raw materials and a period of more than 20 years. Supply risk, environmental risks and social assessment have been applied to a case study in the electronic industry for capacitor technologies, comparing capacitors made out of aluminium, niobium or tantalum (Kolotzek et al. 2018). For this purpose, a circle diagram featuring both numerical (on a 0-100 score) as well optic (on a colour gradient from blue to red) criticality information, and additionally the weighting of each indicator and risk category through their respective angle in the circle. Normalized supply risk and social risk scores are aggregated from the detailed outside annulus to the inner circle. Fig. 3 shows the results of the capacitor technologies case study. Niobium shows the lowest social risk, tantalum shows the highest supply risk among the three evaluated metals.

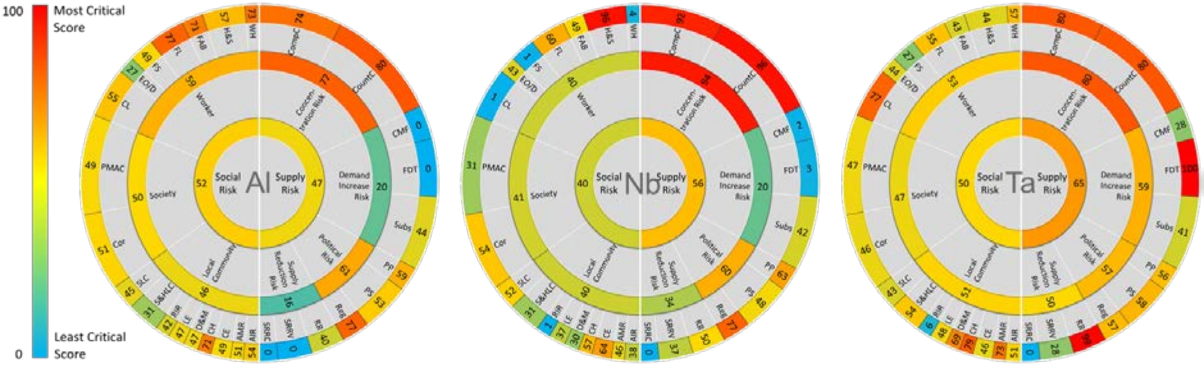

Figure 26 **Supply risk and social risk assessment of aluminium, niobium and tantalum (after Kolotzek et al., 2018)**

In different case studies, the Resource Lab has evaluated the supply risks of two thin-film photovoltaic technologies CdTe and CIGS (Helbig et al., 2016) as well as six lithium-ion battery technologies LCO-C, LMO-C, NCA-C, NMC-C, LFP-C and LFP-LTO (Helbig et al., 2018). In these case studies, in particular the problem of aggregating single element supply risks scores to a technology level with multiple contained elements was assessed. Four different possibilities are evaluated: the mean of all contained functional elements, aggregation by mass share, by cost share and a maximum supply risk approach. Fig. 4 shows the results for the assessment of photovoltaic technologies, in which CIGS has a higher supply risk for all four aggregation perspectives (Helbig et al., 2016).

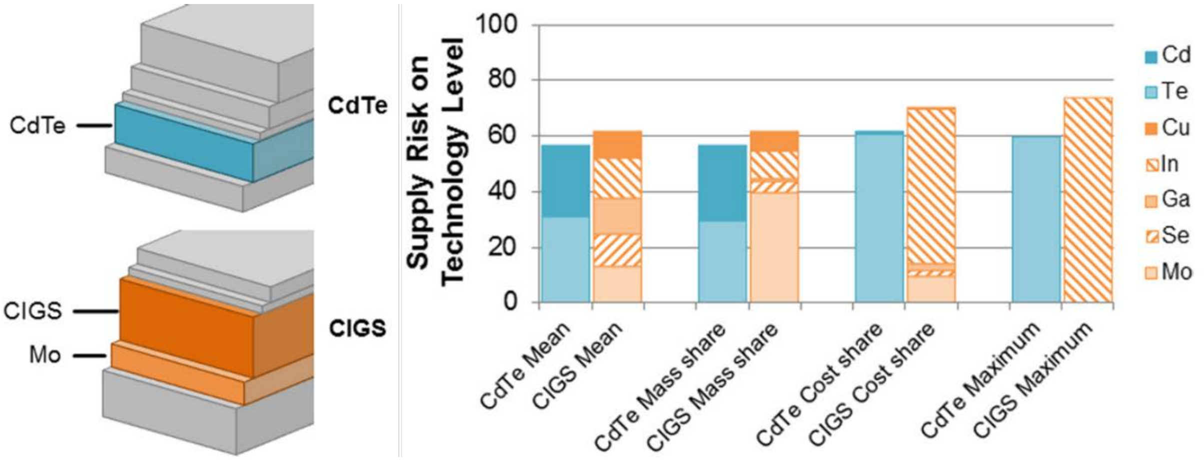

Figure 27 **Supply risks of cadmium-telluride (CdTe) and copper-indium-gallium-diselenide (CIGS) thin-film photovoltaic technologies based on their contained functional elements (Helbig et al., 2016)**

Fig. 5 shows the results for the assessment of lithium-ion battery technologies. Higher contents of lithium or cobalt increase the supply risk score of a technology. Current battery technology developments often decrease the cobalt content for cost and supply risk reasons. However, this very often comes with a higher lithium content in the battery, which has almost the same supply risk score. Therefore, differences between the six evaluated technologies are marginal, with maybe slight supply risk advantages for the LFP-LTO technology in the perspectives arithmetic mean and mass share weighting.

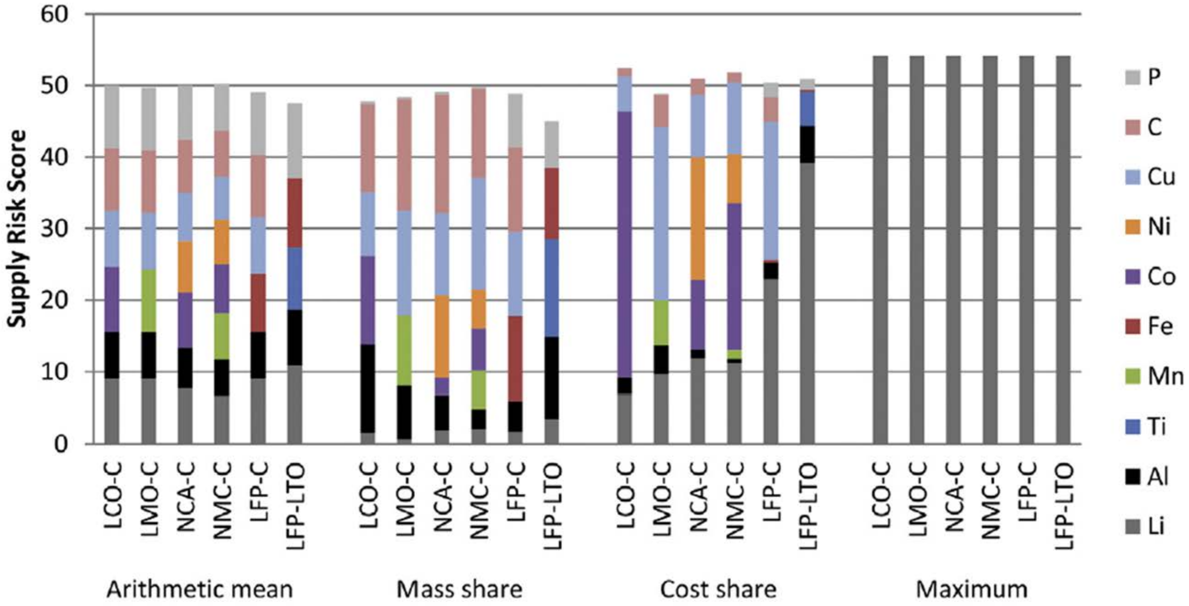

Figure 28 **Supply risks of lithium-ion battery technologies with the cathode materials LCO, LMO, NCA, NMC and LFP as well as the anode materials graphite (C) and LTO (Helbig et al., 2018)**

Conclusion

The work is a framework for a sustainability-oriented criticality assessment for metals and minerals, including supply risks and social risks assessment. The risks can be managed through supply chain management, substitution, exploration, recycling or increasing product lifetime. These results can be compared with circular economy indicators based on material stocks and flows as well as dissipative losses. It is necessary to assess material requirements for critical metals in low-carbon technologies already at an early stage. Regular updates to criticality assessments help to identify emerging risks and criticality-reducing measures have to be implemented. Finally, the impact of changing metal stocks and flows on the Sustainable Development Goals and climate goals have to be monitored. Further research is needed on the vulnerability of metals and products to supply disruptions and on the importance of indicators for disruptions based on events.

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BAUKARUSSELL – SOCIAL URBAN MINING

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Introduction

The Recycling Construction Material Regulation and the Austrian standard ON B 3151 define the national legal frame for the dismantling of buildings as a standard method for demolition (BMLFUWW, 2015). Depending on the size of the buildings a pollution investigation and a concept for dismantling and demolition are required. Within the second document also reuse-able materials and products should be listed if found in the object. At present hardly any of the authors has the knowledge to decide upon the property "reuse-able". The project consortium BauKarussell (Caritas Wien, DRZ VHS Wien, RepaNet, Romm/Mischek ZT und pulswerk) aims to develop that knowledge and has made its first experiences in two operational pilot activities. The results show that reuse in the large scale building sector is feasible. The earlier in the process of planning reuse is integrated the more likely it is to realise the potential (see (Meissner et al., 2018)). The project is supported from the government of Vienna, the Federal Ministry of economy and the Foundation for waste prevention of Austrian packaging systems.

Project approach

BauKarussell is the first Austrian cooperation that addresses reuse in buildings at large scale. Together with property developers the consortium removes distinctive materials and products to make them available for new buildings. The operational work is performed by transit employees from social enterprises. These former unemployed people gain work, training and support to find their way back to the labour market. In parallel the consortium develops internal structures to finally found a legal entity.

Project results

Within two operational pilot objects BauKarussell at least achieved 450.300 kg Waste Prevention due to reuse. Furthermore 74.000 kg material was collected separate and handed over for recycling of materials. Finally 171.000 kg of impurities that impede the recycling of construction and demolition waste were removed. The revenues and the cost saving due to the reuse of material allowed the social enterprises to perform app. 7.600 working hours. Within the operational work the consortium defined a procedure to develop an appropriate procedure to incorporate reuse and circular economy into the sector of dismantling and demolition (see figure 1 and following paragraph). The consortium actually negotiates with many property developers.

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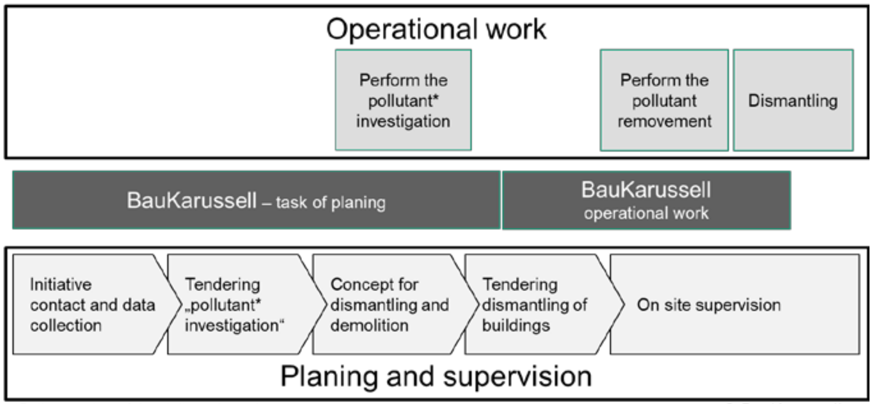

*Pollutant = harmful and disruptive substances

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Figure 29 **Integration of the concept of circular economy in the sector of dismantling and demolition (after (Meissner et al., 2018))**

In the first step basic data and information regarding the building area collected. Base on that the tender for the pollutant investigation is worked out. This functional tender allows to choose the best offer for the project developer. The results of the pollutant investigation provide the data to work out a proper concept for dismantling and demolition (as required in the Recycling Construction Material Regulation). In that concept BauKarussell considers reuse and potential for high quality material recycling. For material with reuse potential the search for customers start. Focussing on reuse and high quality recycling reduces the costs for waste disposal. BauKarussell then prepares the tender for the dismantling and demolition. Again the tender defines tasks and masses in detail to support an effective decision upon the best offer. In case distinctive materials will be removed by BauKarussell the tender will also include positions for minor costs. Parallel to the tendering process BauKarussell can start operational work on behalf of the project developer. On site supervision secures that the operational work follows the requirements defined.

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THE INTERRELATION OF INFRASTRUCTURE EXPANSION AND WASTE GENERATION ON THE ISLAND OF SAMOTHRAKI, GREECE.

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Introduction

With our case study we show how the gradual shift of a locally shaped economy towards an import-based economy increasingly poses challenges for the community of a small Greek island. Land use change, new kinds and the expansion of the local buildings and infrastructure but also changes in consumer behavior lead since the 1960s not only to an increase in import dependency but also to a gradual decline in the circularity of the local economy. Our study focuses on the construction sector and shows how one specific infrastructure project in the 1960s paved the way for unprecedented infrastructure expansion and consequently increasing amounts and new qualities of construction and demolition waste (CDW).

Samothraki, located in the north-eastern Aegean Sea, is with 178 km^2 and 2.840 inhabitants a fairly small island. It’s outstanding natural features (Biel and Tan 2014), the initiative of some highly engaged local citizens in collaboration with researchers, lead to a transdisciplinary process that fosters a sustainability transition and aims at including the island into the world network of UNESCO Biosphere Reserves (Fischer-Kowalski et al. 2011; Petridis et al. 2017). The size and natural features of the island determine the limitations in local waste treatment possibilities and the import of growing quantities and diversities of commodities becomes increasingly a problem. The construction of a new port in the late 1960s marked the beginning for a new area of infrastructure expansion, unprecedented on the island. Old infrastructure got replaced by new one and larger infrastructure projects became possible. From the 1960s onwards, traditional stone houses were increasingly abandoned or replaced by brick/concrete or reinforced concrete houses, the road network was asphalted and successively extended, another port was built, the main port enlarged, hotels and other civil infrastructure and a military basis were built. Consequently, the new types of CDW are a relatively new phenomenon on the island and its uncoordinated and often random and illegal disposal will increasingly put the island community in the need for action. So far, no attempt has been made to estimate quantities and qualities of CDW and potentials for recycling and reuse, an important prerequisite for any strategy aiming at increasing the circularity of the local economy (Haas et al. 2015).

Methods

For this study a bottom-up dynamic stock modelling approach (Müller 2006; Tanikawa et al. 2015; Stephan and Athanassiadis 2018) was chosen in order to assess material flows associated with built infrastructure dynamics from 1970 to 2016 (Figure 1). Official census and construction licenses data were combined with survey data and on-the-ground measurements and estimations. A leaching model was applied for the assessment of the maintenance of houses (Džubur and Laner 2017). A one-at-a-time sensitivity analysis was carried out in order to address uncertainties.

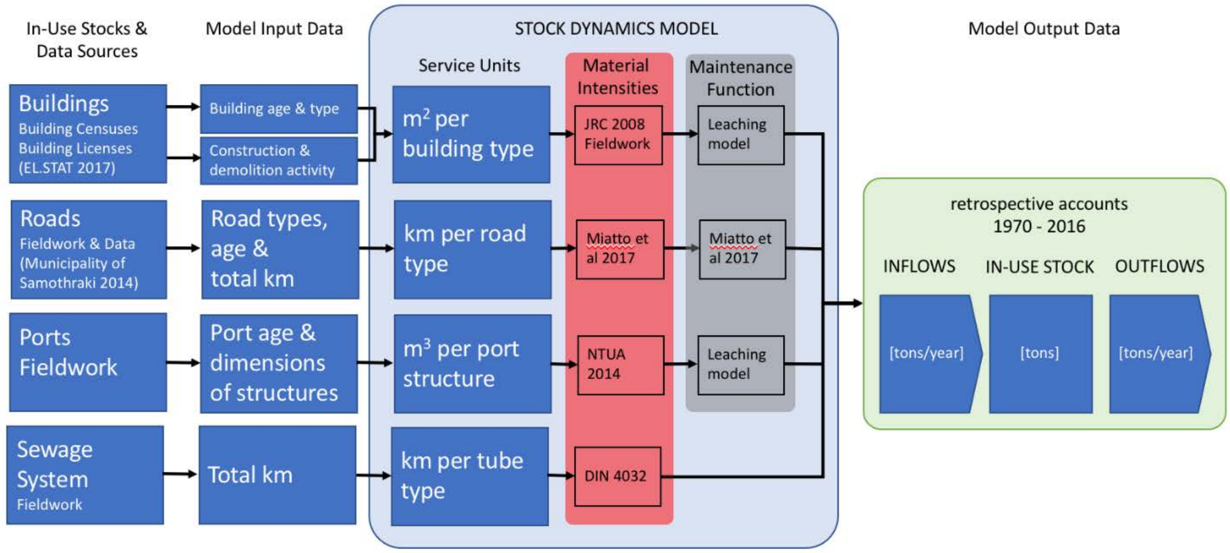

Figure 30: Conceptual graph of the bottom-up dynamic stock modelling approach applied in this study.

Results

The results indicate that from 1971 to 2016 the mass of local infrastructure doubled (Figure 2a). Material demand shifted from mainly for construction of buildings and roads to mainly for maintenance of the road network, while maintenance requirement for buildings constantly increased (Figure 2b). In the 1970s generation of construction and demolition waste (CDW) was mainly determined by the abandonment and demolition of traditional stone houses and the maintenance of a relatively short road network with an annual material output of approximately 5Mt/yr. After 2000, the annual material output of CDW increased 3-fold and originates mainly from maintenance of the road network and increasingly from brick/concrete buildings (Figure 3c).

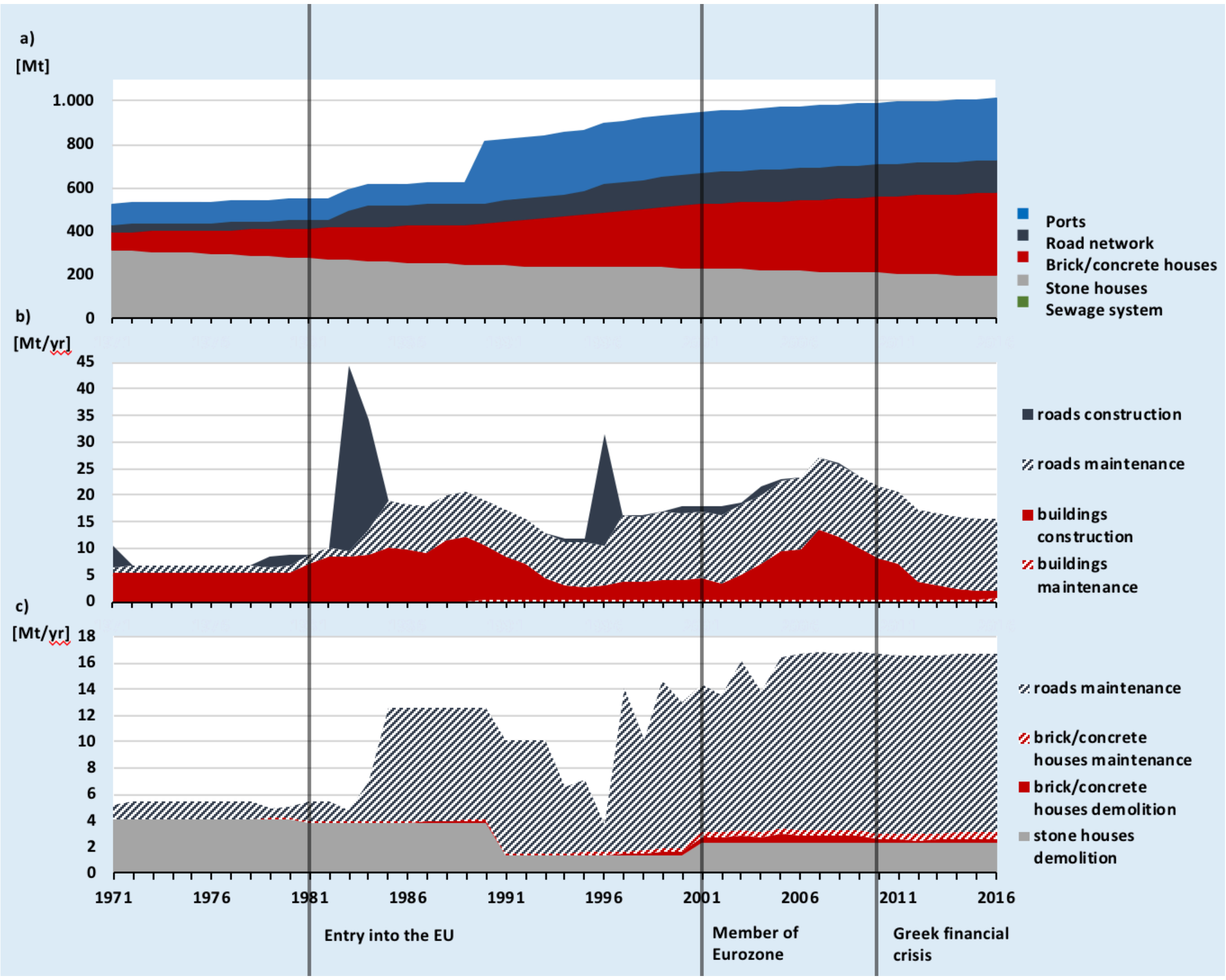

Figure 31: Development of in-use stock, annual material requirement and output from 1971 to 2016; a) Mass of the 5 categories of in-use stocks (sewage system, stone houses, brick/concrete houses, road network and ports); b) Annual material requirement for construction and maintenance of buildings and roads; c) Annual material output (CDW) from demolition and maintenance of buildings and roads.

Since the 1990s almost all the materials for construction and maintenance are imported and due to high costs for export, they stay on the island after use. Except some recycling of a minor fraction of the asphalt layer in the maintenance process of roads, no indication on recycling or reuse of CDW has been found. It becomes therefore evident that Samothraki will not reach the targets of the EU waste framework directive (2008/98/EC) of 70% recovery and recycling of CDW until 2020. Nor are there any strategies in place in order to increase the circularity of materials associated with construction, maintenance and demolition of buildings and infrastructure. For future waste management strategies, the island community requires an integrated assessment of CDW avoidance, recycling and recovery potentials. This study marks the first step in this direction.

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MANAGING CARBON INTO A CIRCULAR ECONOMY

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Any form of natural carbonaceous compounds will fall into the so called Ternary Diagram. Nature lives from perpetuated decomposing & re-synthesizing carbohydrates. Carbon thereby is Nature’s favorite storage for chemical energy. But today’s Energy Recovery just liquidates Carbon and destroys it into CO_2 to atmospheric Carbon stock as if it was a one-way package. Reuse of CO_2 requires lots of transformation energy or enzymes plus unconsumed Carbon or Hydrogen making Carbon Circularity via CO_2 broadly unaffordable. As of today the world incinerates 17% of waste ligated Carbon at an η_{el} of 11% plus scantily usable 70% thermal Anergy, both lost if not used. The rest of urban household waste is landfilled where to flaring might be applied at 60% maximum. Without non rotting plastics among the latter, total MSW CO_2 emissions are about 8.5Gt/yr.

Catalytic physical Carbon Capture from anoxic bio- and/or thermo- chemically decomposed household waste by steam reformed pyrolysis of carbonaceous residues keeps 75% Chemical Energy content stored for later Carbon-neutral on-demand use – For example for Hydrogen Fuel Cell Utility by Water Gas Shift [WGS] reforming which yields 4 times the η_{el} of an incineration. – 0.8kWhel/capita is equivalent to 23% (EU) and 50% (CN) of total households’ electricity consumption and would be an ideal back-up potential for New Renewable Electricity. Energy Storage is needed for energy on demand as well as for economic use of excess power-generation. Happens Recycled Carbon is a good match for both:

As mentioned WGS on demand can provide Hydrogen Fuel Cell Utility for New Renewable Electricity [NRE] - Grid Back-up. Alternatively available excess grid electricity can either be used to smelt Carbide for Acetylene Chemistry or to split CO_2 with stored Carbon into 2CO molecules to optimize Synthesis Chemistry stoichiometry for desired products. Available extra Hydrogen from electrolysis can alternatively further uplift Carbon Recovery from decomposed biomass to 100% .

Catalytic physical Carbon Capture for Acetylene based Ethylene supply would allow to keep 50% of feedstock ligated Carbon stored in new virgin plastic. The share of Carbon contained in plastics represents less half that ratio in total MSW Carbon. Therefore no fossil Carbon from waste would get disposed as soon as plastic went back to Carbon Recycling as part of typical trash mixes incinerated or landfilled today. Hence plastics could become renewable materials at contemporary arms’ length cost. Urban household waste represents just 20% of total organic residue potential not re-useable as compost in agriculture. Nature’s binary nexus of Carbon and Water for any life matter made from those two by solar energy stored in such created compounds allows catalytic physical recovery of Carbon to unlock its resurrection at End of Life-Cycle across versatile platforms for Energy-Storage, Renewable synthetic matter or Hydrogen Economy.

Since sustainability is about Carbon Efficiency including to make a best efforts’ use of Terrestrial Carbon before letting it disappear to atmosphere Carbon Circularity is a big relief on the 2°C Carbon Budget. Recycling Terrestrial Carbon from residues is financially self-sufficient at arms’ length prices for fossil substitute commodities and just costs 67-75% CAPEX of crude oil Find, Development & Exploration [FDE] cost per barrel substituted oil. This saves the need for Petro-Dollar disbursements financing arms & weapons driving flows of refugees nowadays. In contrary the moneys kept within local closed loop economies spur new quality employments, secure monetary value and increase local purchase power. According to a study from Economica Institute the fiscal return on the private investments would be 14% per annum at Austria’s employment overheads and tax scheme before any profit taxes from operations.

OPTIMIZING PLASTICS RESOURCE EFFICIENCY WHILE PREVENTING “CONTAMINANT CYCLING”

Melanie Haupt, Stefanie Hellweg, Joanna Houska, Zhanyun Wang

Recycling of used materials including plastics can save resources such as energy and virgin materials. However, if hazardous chemicals contained in some used materials are not eliminated in the recycling process, or if hazardous chemicals unintentionally enter the recycling process, the recycled materials and products may be contaminated and lead to undesired human exposure.

This poster presents a new project that aims to: (1) quantify current levels of contaminants in selected plastic fractions, (2) model the material flows and associated chemical pollutant flows of recycled plastics and thus identify sources of contaminants, (3) model plastic flows in future scenarios and quantify potential pollutant enrichments in secondary plastic products, (4) model the current and future levels of exposure to selected hazardous chemicals via plastics and associated risk, (5) model environmental impacts of the current and future recycling system, (6) develop strategies to exploit the resource potential of plastics without risks to human health and (7) inform decision makers about priority pollutants, exposure pathways and suitable recycling strategies.

INNOVATIVE UPCYCLING OF POLYPROPYLENE POST CONSUMER WASTE

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Introduction

In the last years the global production of plastic increased very fast. 2015 the global plastic production was 322 million tons in one year. 2016 the value increased to 335 million tons in one year. After polyethylene (PE, 29.8 %), polypropylene (PP, 19.3 %) is the second most important polymer on European plastic demand. It is used for different applications like food packaging, automotive parts, plastic pipes, injection-moulded building parts, chill-rolled and blow-moulded films, fibers etc. [1]. On principle, there are three different categories of recycling of plastic waste. The primary recycling is the re-introduction of single polymer waste material to the extrusion cycle to produce product with the same quality. The secondary recycling process, so called mechanical recycling can only be performed for single polymer waste. The last recycling type is the tertiary or chemical recycling. It is a collective term for advanced processes to depolymerize plastic waste to recover base chemicals for the chemical industry [2, 3]. Recycling rates of PP are increasing since years, but converting PP-waste into a valuable resource is still a challenge and needs a lot of research on this topic from different perspectives.

Figure 32: left: the global plastic production and the different plastic sorts; right: the production of PP an the different applications of them [1]

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About 27.1 million (EU27 + CH + NO) tons of plastic post-consumer waste ended up in plastic waste upstream in 2017. 41.6 % were used for energy recovery, 31.1 % have been recycled and 27.3 % went to landfill. However, 2017, it was the first time, that more plastic waste was recycled than landfilled [1].

Modification of Polypropylene via reactive extrusion

To produce PP with a high melt strength and strain hardening long chain branching (LCB) is a suitable industrial post reactor process. In addition, the molar mass can be increased and the molar mass distribution is broadened [4]. The process of peroxide-induced degradation of PP is mostly carried out in an extruder, which is one type of the so-called reactive extrusion. Not only controlled degradation of PP can be realized, but also modified PP materials with predesigned chain structures and enhanced physicochemical properties can be effectively and economically prepared by this method. On principle, the mechanism of LCB is a combination of radical induced activation of PP, partial chain scission and recombination. The recombination is preferred at temperatures below the melting point of PP. In Figure 2 a reaction scheme is given.

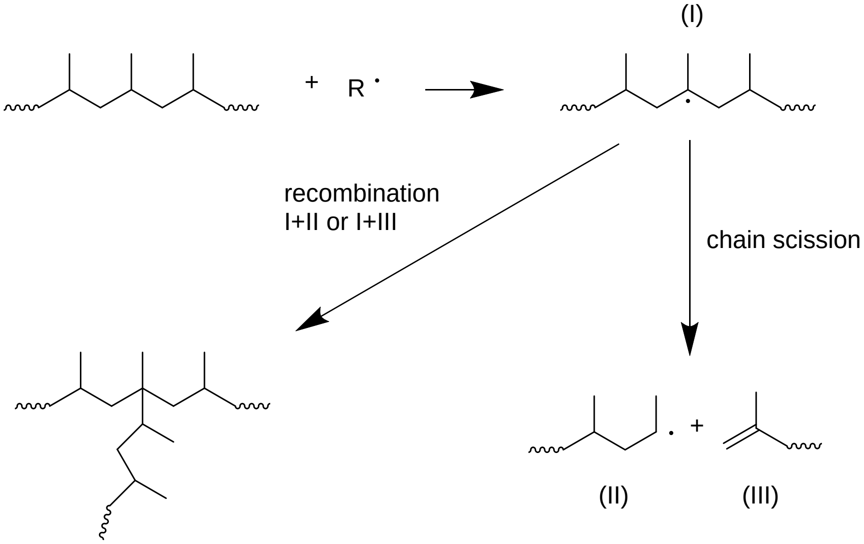

Figure 33: Reaction scheme of the LCB formation [5]

In our studies, induction of LCB was used as an innovative upcycling process for PP [5, 6 7]. As post-consumer waste is highly contaminated, the influence of impurities on the structure and properties in melt and solid state is of particular importance. Compared with virgin material, PP from post-consumer waste may contains impurities like polyethylene (PE) or polystyrene (PS).

We started the studies with a model mixture of PP and PE with a ratio of 90:10 and investigated the influence of the mechanical properties of this mixture. The same study was repeated with real post-consumer material from household plastic waste. In both cases, the melt properties could be improved but the mechanical properties showed mixed results, especially in the case of the post-consumer PP [5].

Additional to this study with an impurity of PE, a second study was investigated with PS as impurity. We also started with a mixture of PP and PS with a ratio of 90:10 and increased the content of PS stepwise to a final ratio of 75:25. It is turned out, not surprisingly, that the elongation at brake is decreased with the increase of PS ratio. This is shown in Figure 3. However, the values of the quasi-static tensile tests and investigations on the impact behaviour still exceeded those of high impact styrene.

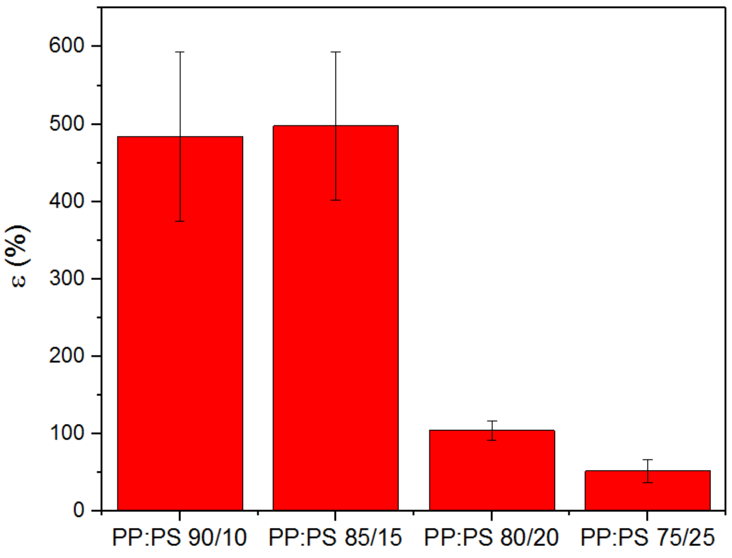

Figure 3: Tensile test of PP with different ratios of PS

Furthermore we concentrated on single polymer PP post-consumer waste and continued the investigation on the influence of different PP types with different molar masses. The investigation contains four different PP types with higher molar masses, like those used for water pipe systems, and injection moulding PP with low molar mass. The yield of LCB of the higher molar mass PP is lower compared to the PP type with low molar mass [7]. The constitutive study of these four different PP types was the compounding of two PP types via LCB. For this investigation we started with a model mixture PP1:PP2 with a ratio 50:50, where PP1 represents a high molecular mass type and PP2 a low molecular mass type.

As a result, and especially concerning waste of high consumption, as packaging materials, knowledge improvement about recycling will enhance the efficiency of the waste management in view of a reduction of the waste disposal volume and the production of high quality component parts containing recycled material.

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A REVIEW OF CIRCULAR ECONOMY INDICATORS FROM THE MICRO TO THE MACRO LEVEL

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Abstract

The Circular Economy (CE) has been proposed as a sustainable alternative to the take-make-dispose linear economy model. In light of growing interest in a transition to a more circular economy, governmental administrations and practitioners have been promoting CE by developing CE strategies and policies.

CE research at different levels has become prolific in the past twenty years or so (Ghisellini et al., 2016). While the term CE has been extensively described in different spatial scopes, the divergence in understanding of CE leads to a lack of broadly accepted definitions and measuring metrics of CE so far.

Some efforts have been made to develop an evaluative approach to a CE at different levels in order to monitor the CE performance. These CE indicators can simplify complex information to be more manageable in order to effectively communicate with stakeholders, support policy and decision-making, and help achieve CE targets and outcomes (Geng et al., 2012).

Consistent set of indicators to measure different dimensions of CE are crucial for designing policy measures and contribute to increased knowledge about the qualities and quantities of circular performance. Several reviews have been published focusing on particular scales of analysis, such as product level indicators (Linder et al. 2017) and micro level with brief review on multi-level (Elia et al., 2017). Following growing awareness of CE transition, a large amount of CE indicators have been proposed recently. However, a more comprehensive review on CE indicators is still lacking, in particular covering all scales from material, product, business to region, national to global scale.

To fill this gap, this research presents a comprehensive overview of CE indicators that have been applied or proposed. This research addresses several questions: How do different indicators reveal different conceptualisations of CE? What dimensions of the CE are included and excluded in current indicators? How a can progress towards the CE be measured? What are the barriers and challenges of measuring CE?

The review is based on an extensive search of the academic and grey literature from more than 40 studies, and analysis based on the procedures described by Hagen-Zanker and Mallett (2013). The main analysis structure focuses on identifying the purpose, spatial level, time interval, focusing dimensions, basic principles, and calculation methods for each indicator or indicator set.

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The findings suggest that the breadth of indicators show the diverse and contested understandings of the CE concept. There are five main dimensions including resources, energy, environment, economic value, social benefit, and innovation. Among them, measuring resource circularity is the core of CE, whilst many indicator sets are more broadly linked to the other dimensions. Most of the indicators exclude the dimensions of social benefit and innovation. Moreover, a single indicator is limited in its ability to show the resource circularity and multidimensional nature of the CE concept. Therefore, CE indicators can be considered in a systematic analysis along the whole value chain, and take resource circularity as a priority. Lack of primary data leads to the challenges for examining the relationship between the circularity of different resource and other dimensions.

Finally, since research about CE indicators for measuring the application level of CE strategies is still in an infancy stage, some recommendations were offered for improving better measurement of CE performance. That is, further development of CE indicators is needs especially for measuring CE of different singular resource; ensuring CE based on different resources' circularity prior to other dimension of benefits; application to the whole value chain of resources with policy relevance; how to represent trade-offs; data availability and easy communication should also be considered in practice.

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CREATION OF A NETWORK FOR CIRCULAR ECONOMY
– HOW TO CLOSE THE LOOP OF SELECTED MATERIALS? –

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Background

The background to the project is the increasing shortage of raw materials and the effort to decouple economic growth from the extraction of primary raw materials and thus reduce dependence on volatile markets. In line with the vision of a circular economy, as adopted by the EU Commission's "Circular Economy Action Plan", the closure of material cycles and cascade use for selected material flows is to be achieved together with partners from the entire value chain and thus increasing the added value of raw materials.

The focus is on the recycling of sewage sludge for phosphorus recovery and the promotion of the use of mineral secondary raw materials from construction waste in building and civil engineering.

The amendments of the German sewage sludge regulation (AbfklärV) and fertilizer regulation (DüMV) contain new requirements, including for phosphorus recovery. These determine an adaptation of existing recycling paths and thus present the industry with great challenges. The development and implementation of concepts for phosphorus recycling and the thermal disposal of contaminated fractions will be advanced with this project.

The construction industry is one of the most resource-intensive economic sectors in Germany and responsible for 54% of the total waste volume. The high demand for resources and the enormous land consumption through primary raw material extraction demand a change of thinking. The rise of volume of complex input streams for treatment, while waste disposal capacities are becoming scarcer require an intensification of the circulation of mineral raw materials.

Methodology

The research project is carried out by the Department of Energy Raw Materials Technology (TEER) and the Chair of Operations Management (OM) - both RWTH Aachen University and the Institute for Infrastructure Treatment, Water, Resources and Environment (IWARU) of Münster University of Applied Sciences in cooperation with the Bergischer Abfallwirtschaftsverband (BAV).

The first step is to identify material flows that have high potential in terms of circular value creation or are of particular practical relevance. In specially organised events by the grouping relevant players along the value chain from industry, politics, the public sector and research are brought together. The aim is to identify opportunities and challenges for closing the cycle of the identified material flows and to sensitize the actors involved. Together, solution strategies are discussed and concrete measures derived. These include, for example, targeted research activities, suggestions for adaptation of regulations or an intensified exchange between the actors involved. Depending on the measures derived, which are specific to the material flow, the further procedure is determined. The objective here is to ensure the highest possible permeability of the results in practice

Outlook

The objective of this research project is to close the loop for material flows as holistically as possible. Against the background of the accumulation of pollutants in the material cycle, however, this is not feasible for selected materials. These substances must be discharged through energy utilization or landfill.

For sewage sludge, on the one hand the focus is testing of phosphorus recycling processes and design of appropriate recycling paths. On the other hand, cooperation is being established between waste water treatment associations and the waste management industry in order to ensure area-wide thermal treatment of the sludge while eliminating pollutants. In addition, the fertilizer industry is also being sensitized for the market launch of phosphorus recyclates.

There is a need for research in the field of mineral waste especially in the development of high-quality utilization of mineral fine fractions and the crushed sand produced during processing. Research into efficient plant and process technology in the treatment of mineral construction waste is also crucial for the competitiveness of secondary raw building materials.

Closing material cycles makes a decisive contribution to conserving resources and protecting the environment. The decisive factor for the success of closing the loop is a cohesive approach by all actors along the value chain.

In order to sustainably increase value added of raw materials against the background of ecological, economic and social aspects, further material flows should be examined according to the procedure described in the “Methodology” section. The complexity of each individual material flow requires a separate procedure with appropriate measures.

INNOVATIVE CIRCULAR SOLUTIONS AND SERVICES FOR NEW BUSINESS OPPORTUNITIES IN THE EU HOUSING SECTOR

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Abstract

The housing sector is responsible for more than 50% of global resource extraction, about 50% of world energy consumption, 1/3 of water consumption and furthermore generates about 1/3 of all produced waste. A new, circular approach is needed to enable better decision-making on the selection of innovative architectural solutions for all phases of a building's life cycle. The current building sectors’ business model must be redesigned to include the application of new and improved methods, solutions and innovative services, and advance a positive transition from a linear economy to a circular economy.

We will present the circular interventions carried out on a centenary building located in Vienna in the framework of the HOUSEFUL project. HOUSEFUL is an EU-funded initiative with the objective to develop and demonstrate integrated circular services, focusing on the optimal management of resources throughout the life cycle of new or existing buildings. The demonstration will include technologies to circulate all process flows while reducing the overall energy demand. These technologies will be offered as integrated services to produce treated rain and waste-water for internal reuse, the generation of renewable energy from biogas, compost production combined with urban gardening and for the use of nutrients in a greenhouse. The design of more efficient processes, such as green walls, innovative conservatories, building-integrated solar thermal and photovoltaic panels will improve building energy efficiency. All process flows will be intensely monitored to ensure safety and collect data for further replication cases. The solutions will also include the use of sustainable and upcycled materials and the implementation will be based on the principles of reversibility and de-constructability. The final services of the building will be elaborated in co-creation workshops with a multitude of stakeholders. Additional service-oriented modelling facilitates replication for the transition to the circular housing sector.

Keywords: circular economy, service-driven business models, nature-based solutions, innovative use of secondary resources, technological innovation, resource and energy efficiency.

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Challenge

The transition from a linear to a circular business economy is being implemented at an industrial scale in Europe. Many referenced case studies and innovative projects are focused on the innovative design of products, smart production lines in industry and energy efficient processes. However, this transition has not yet taken place at all levels of the housing sector (energy, water, waste and materials). Most of the time the circularity only focuses on one of these levels. For that reason, a new circular thinking approach is required to enable better decision-making on the selection of circular solutions at the different, or various levels for all the different stages of a building’s life cycle to attain optimal building functionality and maximise the reuse of resources in a co-creation process [1].

Meeting the challenges outlined in Fig.1 requires the redesign of current housing business model, creating new method for the evaluation of the circularity level in the housing sector while co-creating new solutions and services for its improvement. The transition from a linear to a circular business model in this sector will contribute massively to establishing a low-carbon urban economy in future “green” cities, and the reduction of waste and GHG emissions, recognising the COP21 objectives and the goals proposed by the 2030 Agenda for Sustainable Development (United Nations, 2015).

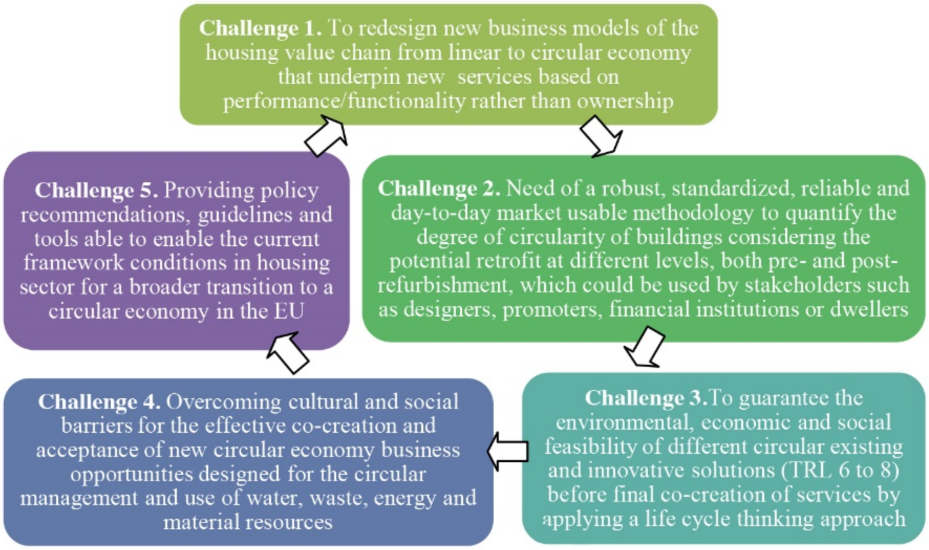

Figure 34 Main HOUSEFUL challenges addressed for a circular housing sector

The main goal of the HOUSEFUL project is to develop and demonstrate an integrated systemic “service” composed of different circular technical solutions in the current housing value chain. The HOUSEFUL service will aim at the circular management and efficient use of water, waste, energy and material resources for all the stages of European building’s life cycle and will be presented as an on-line “Software as a Service (SaaS)”, enabling the replication of proposed circular solutions at EU level: renting, leasing, customer service, capacity building service, and various combination thereof.

The integrated HOUSEFUL service and proposed technical solutions will be demonstrated at a large scale in four representative European residential buildings (frontrunner buildings) characterised by variations in climate, social and legislative/organisational conditions, as follows:

1. “DEMO 1” in Sabadell, Spain - a building constructed in the 1960s to be refurbished for social housing
2. “DEMO 2” in Terrassa, Spain - a to-be refurbished social housing estate built in the 1970s
3. “DEMO 3” in Vienna, Austria - a centenary building designated for both private and commercial use; and
4. “DEMO 4” in Vienna, Austria - a new social housing building constructed in 2017.

The buildings were selected with regard to their spatial and geographical distribution which would guarantee the collection of data on the feasibility and replication of solutions across differences in social, cultural and current practices on housing, differences in national regulation regarding construction and refurbishment, and common European building archetypes. Further considerations related to variations in scale and number of dwellers per building, climate-oriented differences in characteristic and typologies of residential buildings, and common challenges shared by construction companies, related professionals and regional/national housing agencies. The frontrunners will accordingly act as references for replication activities of proposed solutions with a further ten so-called “Follower” buildings to be identified during the first year of the project execution.

Expected HOUSEFUL impact

The HOUSEFUL solutions pursue the specify objectives for a more circular housing sector: the design of new efficient processes and procedures for the construction/refurbishment and demolition phases, leading to net reduction in the use of resources, minimising the waste destined to landfills (reduction from current 40% to 10% in 10 years as realistic scenario) and selecting/using sustainable materials for improving the energy efficiency of buildings. The new technologies will be offered as new circular services for the production of treated water for internal reuse (i.e. for toilets recharge and irrigation), the generation of renewable energy at residential level from biogas for own consumption (i.e. CHP or heat) and the compost production for gardening purposes for self and neighbours. In detail, the following technical objectives are foreseen: the recovery of >95% of food waste at home level by the successful separation of kitchen waste at source, grinding and valorisation as biogas; the recycling of >90% of rainwater, greywater and blackwater for production of reclaimed water and biogas; high quality biogas production from grinded bio-waste and blackwater and efficient valorisation (>90% conversion yield) as renewable heat and/or power at home level to be able to endure the winter with own heating system; high quality compost production from digestate produced from the joint valorisation of bio-waste and blackwater; reducing the non-renewable primary energy consumption of buildings up to 50%

related to the national regulations requirement by integrating the existing and proposed passive and active solutions, contributing to the achievement of Nearly Zero Energy Buildings (NZEB).

From a point of view of economic benefits, HOUSEFUL will provide new opportunities for (social) housing sector by offering new solutions with circularity principles having in mind the reuse of materials, resources and increasing the energy efficiency of buildings by passive and active planning. The uptake of recycled construction materials by other industries boosts industrial symbiosis at local/regional level. The cost saving of all HOUSEFUL solutions, based on a preliminary evaluation, will be: 10% (on average) saving costs in the long run of using treated waste-water and recovering of energy at building level with respect of external energy and tap water costs; 80% (on average) saving costs of using treated waste-water and recovering of energy at building level with respect of all external costs (including externalised costs such as investment in infrastructure cost); 70% (on average) savings from current fees applied to citizens for the treatment costs of waste-water and waste management of bio-waste.

From a point of view of social benefits, HOUSEFUL will create different circular economy business models for EU markets for the waste, water, energy and material flows and will be designed in such way that renting, leasing, customer services and capacity building services are promoted over ownership. Since the responsibility of the service/product/technology lay on the provider and not on the costumers the quality of the services is higher and much more in demand [2].

From a point of view of environmental benefits, HOUSEFUL will tackle the energy efficiency of existing and newly constructed buildings in two different ways: by using a µCHP to provide end-users with heat and power produced from waste-water and bio-waste and by planning and designing the use of more energy efficient products and services in the preventive, corrective and replacement phases of selected residential buildings. With these solutions, we estimate a reduction of up to 60% of CO_2 emissions, contributing to the efforts to limit the global temperature rise to 1.5 ºC, as provided for in the COP21 Paris Agreement.

The optimal use of the water, bio-waste and materials cycles within the building will reduce by up to 40% waste ending in landfill, allow for the recovery of up to 95% of food waste and the recycling of >90% of WW (grey and black water) for water reuse (e.g. irrigation, toilets), improving the energy efficiency of buildings of up to 30%. The 40% reduction in wastes disposed in landfill will significantly reduce the risk of hazardous substance released into the environment (e.g. bituminous mixtures, solvents, paints) strongly harmful to the environment and human health.

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IMPROVING CIRCULARITY OF BUILDUING COMPONENTS – A CASE STUDY ON THE ENVIRONMENTAL PERFORMANCE OF FAÇADE SYSTEMS OF PREFABRICATED TIMBER BUILDINGS

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Introduction

Construction and demolition waste have been designated a priority waste stream by the European Union, due to increasing amounts and high potential for increasing re-use and recycling levels (European Commission 2017). Design for renovation, design for re-use, and design for recycling are important concepts in this context, where the largest gains in resource efficiency are typically associated with measures enabling longer product lifetimes (Thomsen et al. 2009). Because the market share of pre-fabricated houses has been growing steadily in Austria (in 2015 around one third of newly erected houses were pre-fabricated, Interconnection Consulting 2017), measures to improve circularity in the pre-fabricated building sector are urgently needed.

The goal of the present study was to assess the environmental impact of three alternative façade systems for a pre-fabricated timber wall. Therefore, a conventional composite façade system (made up of expanded polystyrene, fibres, plaster) was compared to two versions of a ventilated façade (which is optimized for higher durability, lower maintenance and easier disassembly).

Methods

Life Cycle Assessment (LCA) was used to evaluate the environmental impact of a conventional cladding system (glued expanded polystyrene with plastering, version A) and a newly developed ventilated façade (in two variations, respectively with mineral cladding and plastering (version B.1) or planking (version B.2)). One square meter of a prefabricated single family house wall over a lifespan of 60 years (with replacement of the conventional version after 30 years) was assessed. Both systems had, by design, the same thermal conductivity. The LCA does not include erection, use, dismantling/demolition, because these phases are considered to be the same independent of the façade alternative. For the same reason, identical parts of the wall are neglected in the assessment. Four different End-of-Life (EoL) treatment scenarios, defined based on current legal standards and technologies, were considered in the evaluation:

- *Status Quo*: Represent the most likely treatment options for different waste streams currently in Austria.

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- Recycling (*REC*): maximum recycling of wastes, re-use of mineral wool.
- Energetic Biomass Use (*EBU*): Untreated wood waste is directed to thermal utilization, mineral wool is re-used.
- Waste-to-Energy Plant (*WtE*): All combustible material is treated in a state-of-the-art WtE plant, the mineral fraction landfilled

Data for all relevant energy and material flows were gathered. The material demand (incl. upstream losses) was derived from primary data provided by a company specialized in high quality pre-fabricated dwelling buildings, which are customized to a high degree. Additional data on material and energy flows was extracted from common LCA databases (such as ecoinvent v3.3, Ecoinvent Association 2017) and specific ones for building materials (e.g. ÖKOBAUDAT, BBR 2018). Two impact categories were considered in the LCA. The global warming potential (GWP) over 100 years and the cumulative energy demand (CED) of non-renewables.

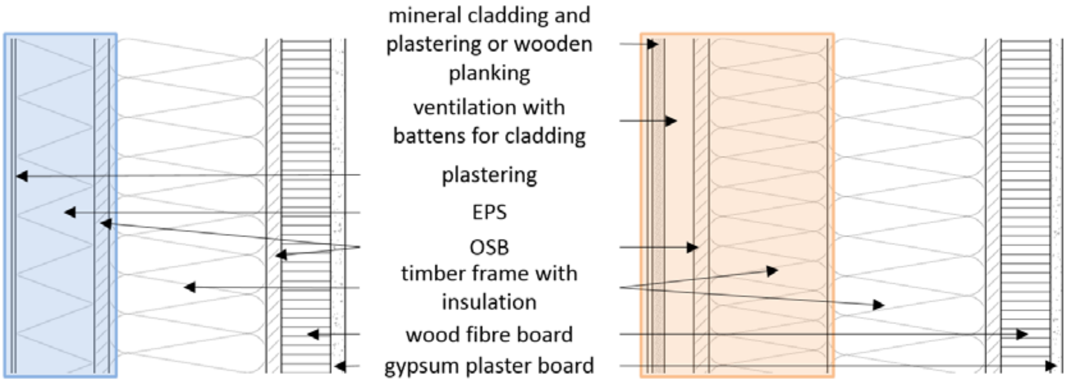

Figure 35 **Compared wall systems, in LCA considered parts highlighted, left: construction with composite façade (version A), right: ventilated facade (versions B.1 and B.2)**

Results and discussion

The material intensity of the ventilated façade (B.1 and B.2) was substantially higher than the material intensity of the conventional façade (A) (see Figure 36, left). This was due to the broader wood frame with an additional layer of mineral wool insulation (cf. Figure 1). However, despite the higher mass, the ventilated system performed better in terms of both impact categories, GWP and CED (cf. Figure 36, middle and right). The different composition and the possibility to separate the fractions by dismantling enabled better treatment and more efficient recycling. The lowest impacts were achieved for the ventilated façade with wood planking (B.2). This is due to the relatively low impact of wood use given GWP and CED, because wood is a renewable energy source and binds CO_2. This results in low impacts of wood production and thermal utilization, because only impacts related to harvesting, handling, conditioning, and transport are considered.

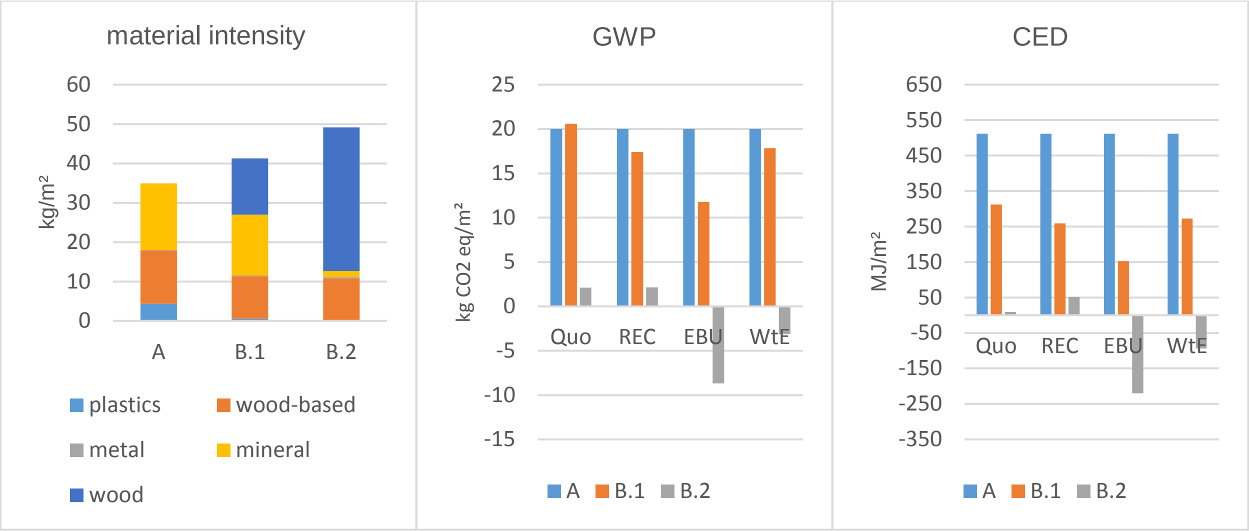

Figure 36 **Reults: left: Material input for assessed cladding systems, middle and right: LCA indicators Global Warming Potential (GWP) and Cumulated Energy Demand (CED) of different disposal options for assessed cladding systems**

Conclusion

The present study showed that despite a higher material demand, the ventilated façade system performed better than the conventional composite façade in terms of GWP and CED. The high mass share of wood and the improved disassembly options allow higher quality utilization of building waste materials. Hence, due to optimized design, more material (and waste) can mean less environmental impact.

Acknowledgments:

The presented research was carried out as part of the project “OpAF, Optimierung der Abfallvermeidung im Fertighausbau” which was funded by the VKS within the program “Abfallvermeidungs-Förderung der SVS für Verpackungen”.

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