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Impacts and limitations of recycling

One distinction between highly developed and less developed nations is the availability and consumption of consumer goods. This difference results in a higher per capita solid waste generation rate and more stringent regulations to effect recycling in highly developed societies. Absent significant regulatory pressures, recycling in less developed countries is typically driven by market prices for recovered wastes and the relatively low prevailing labour rates for the collection and handling of wastes diverted from landfills. In highly prospering societies, the boundary conditions and motivations are different. Recycling is mainly driven by legal stipulations, often in place owing to legislative pressures from citizens who support environmental protection. The most prominent legal basis has been laid down by the waste hierarchy defined in the EU Waste Framework Directive. Right after waste avoidance and re-use, recycling has to be considered prior to other ways of waste recovery, and certainly before disposal.

No matter which societies we talk about, we must make sure to put the emphasis on recycling as described by Mahatma Gandhi: *'Waste is a resource in the wrong place'*. So, regardless of country, the priorities are similar, however, the approaches needed and opportunities available might be very different.

Owing to the level of consumption in prosperous societies, the quantity of waste and thereby the potential for recycling is much higher compared with less developed societies. In recent years recycling has become more important for strategic purposes, as for example to cover the needs for resources in the western world, and thereby reduce dependencies on raw material supplies from potentially politically unstable regions in the world. The recycling of secondary resources always competes with the use of primary ones, consequentially recycling efforts are higher if the availability of primary resources is limited or the price is high. This is the reason that, for instance, a high portion of aluminium and copper that might otherwise end up in the waste stream is already being recycled.

What does the picture look like if we ask (1) 'What is the impact of recycling?' or (2) 'Can we cover our resource needs by recycling?'

Question #1 pertains to both the direct and indirect benefits of recycling. Apart from providing material resources, industry saves energy and emissions by using secondary resources for the production of goods. According to a study from Fraunhofer and Interseroh (2008) CO_2 emissions can be reduced by 95% through aluminium recycling. According to the same study, for plastics like PET and PE, the reductions are 85% and 70%, respectively, and for steel and paper we can reduce CO_2 emissions associated with primary production by about 55%. Also, data shows that it is generally more advantageous to recycle combustible wastes instead of using such waste as fuel in a waste-to-energy plant, even if the plant's thermal efficiency is very high. The saving of energy demand by using of secondary resources in lieu of virgin raw materials is much higher for paper and plastic waste than the energy that could be provided by burning of these wastes (Fricke et al., 2008). So in that respect the impact is clearly there and the efficacy of recycling is further confirmed.

If we have to answer how much of the resources needed for production are provided by secondary materials, we see a very diverse picture in respect of regions and materials. Whereas in Germany, for example, secondary aluminium makes up about 60% of the resources needed in the aluminium industry (whereas it covers only about 30% of the worldwide need). Apart from the being in place of structured waste management practices, the recovery rate of materials is strongly dependent on the type of usage of the products made out of a specific material (for instance usage in the building sector versus usage as packaging) and the life-time of the respective products. The latter aspect leads to the fact that material used in products with a long life-time (such as products in the building sector) do not become waste for a long time and the respective materials are therefore not available as waste to be recovered. So if we come to answer Question #2 we see big differences between different materials, but in all cases it is apparent that society's demands for raw materials cannot be met fully by the supply of secondary materials, at least for the following reasons.

1. Many products that contain recyclable materials remain in use for protracted periods and thus the material is not available for recycling during the products' time-spans. Goods with a short life may have a product life of less than a year, whereas goods with a long life time might remain in the stocks for more than 50 years. For any one of these types of product we need different waste management approaches for collection and processing in order to enable efficient recycling and optimize the resource potential.
2. Waste collection and recycling systems are not 100% efficient; thus, not all recyclable wastes are captured in even the most modern regions.
3. A steadily increasing demand for new products necessitates a corresponding increase in consumption of raw materials (primary and secondary) in the manufacturing process. So, even if 100% of recyclable materials could be recovered from the waste stream, industry would still need to use virgin materials.

4. Losses of secondary material along each step of the supply chain of collection, processing and recycling further limit the available potential of secondary material for recycling. Losses are inevitable as any collection, processing or refining step cannot provide a 100% recovery rate (= yield) of recyclables. As recyclables must comply with certain quality criteria (= purity) there will always be a trade-off between achieving material quality standards for highest uses versus losing potential recyclable material owing to the processing needed for achieving these recycling material quality standards.

Even though recycling and production of secondary materials for industrial use cannot fully meet our resource needs, there are many benefits derived from recycling that justify continued efforts to divert wastes from disposal and even incineration.

A major challenge for the waste sector is the supply of recyclables that comply with material quality criteria set by consuming industries. Industry (and their consumers) value consistently high quality products that rely on consistently high-quality raw materials. If secondary materials comprise a significant fraction of the raw materials at a given plant, the quality standards are more stringent. Thus, collection of recyclables is an important first step in the recycling process; but as important is post-collection processing to remove contaminants to produce a material that comes close to mimicking the characteristics of a virgin raw material.

Complicating the supply chain for secondary materials is the rise in use of products (a) made from new or complex materials (such as alloys, carbon fibre composites, plastic additives and nano-particles), and/or (b) assembled in creative ways (such as multi-layer plastic films, wax-impregnated paper and new formulations of glue). This situation suggests that industries that produce consumer goods should include a place at the design table for those responsible for waste management to jointly develop 'eco-designs' for both products and packaging. This approach could preclude the need for waste managers to develop recycling solutions for emerging types of wastes with inherent and unintended characteristics that are 'resistant' to recycling. Ideally, this feedback loop can help industry develop products that enable the waste industry to process waste and generate recyclables with available technologies (e.g. to preclude the need for new investment by cash-strapped municipalities). In any event, waste managers should expect that new products and consumption patterns will require continuous advancements in waste management technology and practices, and manufacturers will be asked to continue seeking ways to make efficient use of both primary and waste-derived secondary raw materials.

As indicated above, complementary to using the material properties of waste there are options available to make use of the energy contained in waste. This approach should be followed whenever it is not possible to process organic recyclables to attain the quality needed using available technologies or if there is no current market for the combustible recyclables.

The articles published in this special issue of *Waste Management & Research*, which were presented at the last conference on Sustainable Development of Energy, Water and Environment Systems (SDEWES), held in Dubrovnik, Croatia, in 2013, address many aspects of sustainable waste handling and utilization/treatment mainly in connection with the energetic utilization of waste. The SDEWES Conference, sponsored by UNESCO, is a leading conference in the field of energy, sustainable development and environment in the region. The next SDEWES Conference will be held 20–27 September 2014, on a cruise ship sailing between Venice and Istanbul. It will be dedicated to the development and dissemination of knowledge on methods, policies and technologies for increasing the sustainability of development by de-coupling growth from natural resources. The aim is to help achieve a knowledge-based economy, taking into account its economic, environmental and social pillars, as well as methods for assessing and measuring sustainability of development, regarding energy, transport, water, environment and food production systems and their many combinations. More details regarding the conference can be found at: http://www.mediterranean2014.sdewes.org/.

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