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Are the resource strategies for sustainable development sustainable? Downside of a zero waste society with circular resource flows

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ABSTRACT

The present study is a follow up study of Lee et al. (2014), which presented the mass flow of plastic and paper products in Europe with accompanying flows of three phthalates, i.e. DEHP, DBP, and BBP, in above mentioned products. This study aims to investigate how the resource strategies aiming at a sustainable and circular economy influence on the recirculation of micro-pollutants in the product cycle. In order to estimate the recirculating flow of hazardous chemicals in recycled material, the substance flow analysis of the three anti-androgenic phthalates, i.e. DEHP, DBP, and BBP, in the two Future Scenarios of the year 2020 has been performed: (1) all the EU waste legislations are fully implemented with the same demands for phthalates as in 2012 (Scenario A), (2) all the EU waste legislations are fully implemented and because of the efforts to reduce the use of phthalates, the production of virgin DEHP, DBP and BBP used for plastics and paper will be reduced up to 50% compared to the production numbers in 2012 (Scenario B). The result shows a possible, and unintended, downside of current resource strategies which mainly focus on increasing the recycling rate of wastes to foster the transition into a circular economy. If the resource strategies only focus on quantitative goals such as increasing recycling rates of wastes, a full implementation of the EU waste legislations in 2020 will increase unwanted recycling of micro-pollutants: as exemplified in the present study with 70%–300% increase of phthalates re-entering the product cycle compared to the year 2012.

1. Introduction

The concept "sustainable development" was popularized the first time in the Brundtland report stating that "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*" (Brundtland Commission, 1987). Sustainable development has been central for several plans, treaties and regulations within economic development, social development and environmental protection (UN, 2000; EC, 2005; Obama, 2009). One of the main management fields where this principle is widely applied is the field of resource strategy aiming at more resilient economies based on two types of material flows, *"biological nutrients, designed to re-enter the biosphere safely and build natural capital, and technical nutrients, which are designed to circulate at high quality without entering the biosphere"* (Ellen MacArthur Foundation, 2013). To this end, it is important to eliminate toxic chemicals which can impair reuse and return of resources to the biosphere (Ellen MacArthur Foundation, 2013). However, national resource action plans seem to focus only on increasing the "quantity" of reused and recycled resources and overlook the "quality" of resource flows re-entering to the product cycle (Lee et al., 2014).

Through technological development, materials used in products are more complex today; consequently, more and more chemical substances are being used. Therefore, with the material flow of recycling, some resources with low quality, e.g. products including impurities having adverse health effects, may undergo a recycling process and be included in recycled products with unpredictable and unforeseen health and safety problems; meaning that risk can also be "cycled" in a circular economy (Bilitewski and Grundmann, 2012). One of the examples is phthalate in plastics and paper. The production and use of both plastics and paper have been increasing for decades and 288 million tons of plastics and 399 tons of paper were produced worldwide in 2012 (PlasticsEurope, 2013; CEPI, 2013). Phthalates,

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Table 1
Material recycling, energy recovery and disposal rates of plastic and paper wastes applied in the Reference and the Future Scenarios A and B.

Product (Waste) categories (annual waste generation, Mt)	Reference Scenario (2012)[a]			Future Scenario A, B (2020)			Sources for recycling rates in 2020
	Material recycling	Energy recovery	Disposal	Material recycling	Energy recovery	Disposal	
Packaging (15.7)	35.0%	31.0%	34.0%	45.0%	52.4%	2.6%	PlasticsEurope (2013)
Construction & Demolition (1.4)	21.8%	37.6%	40.6%	70.0%	28.6%	1.4%	EC (2008b)
End-of-life vehicles (1.3)	11.4%	42.6%	46.0%	85.0%	14.3%	0.7%	EC (2000)
WEEE (1.2)	13.0%	42.0%	45.0%	75.0%	23.8%	1.2%	EU (2012)
Others (5.6)	8.0%	44.0%	48.0%	50.0%	47.6%	2.4%	EC (2008b)
Paper (77.4)	60.5%	–	–	70.0%	–	–	CEPI (2013)

[a] Details for the recycling, energy recovery and disposal rates in the Reference Scenario were provided in Lee et al. (2014).

diesters of ortho-phthalic acid, have been used as, e.g. plasticizers, stabilizers, lubricants, dispersants, and binders, and widely applied to make plastics, paints and inks with the annual global demand reaching nearly 6 million tons (Lee et al., 2014; ECPI, 2013). As adverse health effects such as effects on liver, kidney and the reproductive system, have been reported, some of these phthalates such as Di(2-ethylhexyl) phthalate (DEHP), Di-n-butyl phthalate (DBP), and Benzyl-butyl phthalate (BBP) are classified as presumed human reproductive toxicants (EC, 2008a) and restricted on the use in products, e.g. toys and childcare articles, cosmetics, and food contact materials (EC, 2006, 2009, 2011). As part of the efforts to foster the transition into a circular economy, plastics wastes and paper have been recycled, e.g. in Europe 26% of plastic wastes and 60% of consumed paper were sent for material recycling in 2012 (Lee et al., 2014). However, when plastics and papers are recycled, phthalates in these plastic and paper products can also re-enter to the product cycle. As there is no specific guidance for assessing the risk potential of contaminants in recycled materials (Lee et al., 2014), products made from recycled plastics and paper might contain some of the above mentioned phthalates as unwanted impurities. Thereby, they can become additional exposure sources threatening human health (Gärtner et al., 2009; Keresztes et al., 2013). If societies increase the amount and rate of recycled materials without considering the quality and use of recycled materials, there is a risk of increased human health impacts in a future circular economy (Bilitewski and Grundmann, 2012).

This paper is a follow up study of Lee et al. (2014) which presented the mass flow of plastics and paper in Europe with the most recent data available (for the year 2012) and accompanying flow of three phthalates, i.e. DEHP, DBP and BBP, in plastic and paper products. In order to investigate how the resource strategies aiming at a sustainable and circular economy can influence on the "risk cycle" (Bilitewski and Grundmann, 2012), the substance flow analysis of the above mentioned phthalates in the two Future Scenarios of the year 2020 has been performed: (1) all the EU waste legislations are fully implemented with the same demands for phthalates as in 2012 (Scenario A), (2) all the EU waste legislations are fully implemented and because of the efforts to reduce the use of phthalates, the production of virgin DEHP, DBP and BBP used for plastics and paper will be reduced up to 50% compared to the production numbers in 2012 (Scenario B). Based on the comparison of the two Future Scenarios with the Reference Scenario presenting the current situation (Lee et al., 2014), the possible downside of present resource strategies and the ways to improve material flows to be sustainable are discussed.

2. Materials and methods

2.1. Circular resource flow modeling

Based on the circular resource flow model developed by Lee et al. (2014), the mass (quantity) and substance (quality) of future plastic and paper products were modeled using STAN 2 (free download from www.stan2web.net). Two individual models were set up for plastic and paper . Input data for the model were derived from a literature review; specifically from investigation by PlasticsEurope (2013), CEPI (2013) and BIO IS (2011). The circular resource flow model includes two layers: goods (materials in terms of plastics and paper) and substances (in terms of micro-pollutants DEHP, DBP, and BBP in plastics and paper). The functional unit is tons of raw materials per year. The system boundary of the circular plastic flow model comprises the EU-27 plus Norway and Switzerland based on the available data on European statistics on plastics (PlasticsEurope, 2013). Plastic products are categorized according to five applications, i.e. 'packaging', 'building and construction', 'automotive industry', 'electrical and electronics', and 'other uses' including agriculture, furniture, toys, and sport. The system boundary of the circular paper flow model comprises 18 European countries, i.e. the members of the Confederation of European Paper Industries (CEPI) representing 95% of the European pulp and paper production (CEPI, 2013). For an in depth presentation of the mass and substance flow models in plastic and paper, the reader is referred to Lee et al. (2014). The recycling, energy recovery and landfill rates taken into account in Reference Scenario and Future Scenario A and B are illustrated in Table 1.

2.2. The Reference Scenario: Reflecting the present situation in Europe

The Reference Scenario is the scenario described in Lee et al. (2014) showing the present flows of products (plastics and paper) and substances (DEHP, DBP and BBP) in Europe using the most recent available data. In 2012, 45.9 million tons of plastics were produced in Europe: 39.4% for packaging, 20.3% for building and construction, 8.2% for automotive, 5.5% for electrical and electronics and 26.6% for other applications (PlasticsEurope, 2013). After use, 25.2 million tons of plastic wastes were collected and used as follows: recycled within Europe (2.0 million tons), exported outside Europe (3.3 million tons), incinerated with energy recovery (9.6 million tons), and landfilled (10.4 million tons). Regarding paper, after 77.4 million tons were consumed, 55.7 million tons of wastes were collected of which 46.8 million tons were recycled. For phthalates, Lee et al. (2014) estimated 90,528 tons DEHP, 2650 tons DBP and 2560 tons of BBP were produced in Europe for the year 2012. The information on the distribution of these phthalates in plastic and paper products was provided in 'Supporting information Table 1' in Lee et al. (2014).