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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, doi: 10.1016/j.envint.2014.08.003) 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 (Biliterwski 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 (Plastics Europe et al., 2013; CEPI, 2013). Phthalates, 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 (Biliterwski 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” (Biliterwski 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

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 was modeled using STAN 2 (free download from www.stan2web.net). Two individual models were setup for plastic and paper, respectively. Input data for the model were derived from a literature review; specifically from investigation by PlasticsEurope et al. (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 et al., 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.

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

Product (Waste) categories (annual waste generation, Mt)	Reference Scenario (2012) ¹⁾			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 et al., 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

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

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 et al., 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, 2,650 tons DBP and 2,560 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).

Future Scenario A: Full implementation of the EU waste legislation with the same phthalate production as now

To estimate the flow of phthalates in the future circular resource flows, two scenarios for the year 2020 were developed in this study. The year 2020 was selected for the Future Scenario due to the fact that at this time all existing provisions should be fully implemented to meet the European strategy for sustainable growth, e.g. "Europe 2020" (EC, 2014). Scenario A is based on the assumption that all the EU waste legislations are fully implemented by 2020. It is also assumed that even under the similar trend of economic growth, there is no increase of the consumption and waste generation of plastic and paper products due to the effort of green economy and waste prevention. The production of virgin DEHP, DBP and BBP used for plastics and paper, and the distribution of phthalates among product categories was assumed the same as the production in 2012. For the material recycling rates of each plastic waste category, the targets in the EU waste legislations for different types of wastes were considered. As shown in Table 1, the recycling rates of plastic wastes from product categories were taken from relevant European directives: "Construction and demolition (C&D)" and "Others" from the Waste Framework Directive (EC, 2008b; Article 11.2), "End-of-life vehicles (ELV)" from End-of-life vehicles directive (EC, 2000; Article 7.2), "Waste from electric and electronic equipment (WEEE)" from the WEEE directive (EU, 2012; Annex V). For plastic "Packaging", the average recycling rate in 2012 already met the target in Packaging directive (EC, 1994; Article 6.1). Therefore, it was assumed that 45% of packaging waste will be recycled in 2020 based on the annual increase rate of material recycling in 2012, i.e. 3.3% (PlasticsEurope et al., 2013). Besides material recycling, it is assumed that 95.2% of the remaining plastic wastes will be used for energy recovery and only 4.8% will be landfilled in 2020 based on the study showing that the amount of waste used for energy recovery will be increased up to 118% by 2020 (BIO IS, 2011). For paper wastes, the average recycling rate in 2012 (60.5%) already met the recycling target of the Packaging directive 1994/62/EC (60%, Article 6.1). Therefore, it was assumed that 70% of paper will be recycled in 2020 based on the annual increase rate of material recycling between 1991 and 2012, i.e. 1.78% (CEPI, 2013).

Future Scenario B: Full implementation of the EU waste legislation with reduced phthalate production up to 50%

In Scenario B, it is assumed that because of the restriction under REACH and the efforts to reduce the use of phthalates, the production of virgin DEHP, DBP and BBP used for plastics and paper in 2020 will be reduced up to 50% of the year 2012, i.e. 45,264 tons DEHP, 1,325 tons DBP and 1,280 tons BBP. Regarding the consumption and waste generation of plastic and paper products, like the Scenario A, it is assumed that there is no increase due to the effort of green economy and waste prevention. The same distribution rates of phthalates in product categories, and the rates of plastic and paper wastes used for material recycling, energy recovery and disposal in Scenario A were applied to Scenario B. Therefore, the Scenario B illustrates one of the best cases: the amount of production and wastes of plastic and paper goods remains the same, but phthalate concentration in these products reduced by half, and the material recycling rate meets the EU regulations.

3. Results

Detailed information on the results of mass flow analysis of plastics and paper including phthalates in it is provided in Figure 1 to 3. As shown in Figure 1, based on the assumption that all the EU waste legislations are fully implemented, 12.9 million tons of plastic waste (51% of the total waste) is estimated to be collected for material recycling in 2020; of which 3.9 million tons (8.4% of total plastic demands) are recycled in Europe, i.e. almost doubled compared to 2012. Regarding paper, figure 2 shows that the rate of waste collected for recycling is estimated to increase from 72% in 2012 to 81% in 2020; of which 54.2 million tons are recycled in Europe, i.e. 16% of increase compared to 46.8 million tons in 2012.

Figure 1. The flows and stocks of plastics in Europe in the Reference (above) and the Future Scenario A and B (below). The figure presents the total system of the EU-27 + Norway + Switzerland (ton/year).

Figure 2. The flows of paper in Europe in the Reference (above) and the Future Scenario A and B (below). The figure presents the total system of 18 European countries (ton/year).

Figure 3 shows the results of the substance flow analysis of DEHP, DBP and BBP re-entering the product cycle with recycled plastics and paper. Detailed information on the flows of three phthalates in Future Scenario A and B is provided in Supplementary Table 1 and Supplementary Figure 1 to 4.

Figure 3. The results of substance flow analysis of DEHP, DBP and BBP re-entering the product cycle with recycled plastics and paper for the Reference Scenario (present, 2012), the Future Scenario A (shown as S(A): same phthalate production and full implementation of the EU waste legislation), and the Future Scenario B (shown as S(B): phthalate production reduced to 50% and full implementation of the EU waste legislation).

For each scenario, the left bars represents the annual demand of each phthalate and the middle bars represent the recycled phthalates in 'Total', which includes wastes exported outside Europe to be recycled. The right bars represent

recycled phthalates 'in the EU', which only include recycled wastes within Europe. Results of the Future Scenario A show that a full implementation of the EU waste legislation for plastics and paper in 2020 will result in an increase of the three phthalates re-entering to the product cycle in the range of 70%-310%. Result of the Future Scenario B show that even by reducing the phthalate production to 50% compared to the Reference Scenario in 2012, the amounts of DEHP and BBP re-entering the product cycle will still increase; approx. 110% and 40% respectively as a result of the increased recycle rate of plastic and paper. The recycling of DBP in Future Scenario B shows a slight decrease, i.e. approx. 15%, compared to the year 2012.

4. Discussion and Conclusion

In this study, the future flows of phthalates, known as anti-androgenic compounds, accompanied by recycled plastics and paper in Europe have been simulated to indicate the 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, this study strongly indicates that a full implementation of the EU waste legislations in 2020 will increase unwanted recycling of micro-pollutants as exemplified by phthalates in the present study. This implies that the problems regarding "risk cycle" in countries outside Europe, e.g. in Asia, might be more serious due to the continuous increase in phthalate production and resource use.

Based on the result of this study, we can raise a question towards the rejection of the proposal submitted to ECHA by the Danish government to restrict these phthalates for indoor use (ECHA, 2012). Was ECHA's perspective on the future risk precautionary enough when they concluded that the risk will be reduced when regulatory requirements are applied in the future? The result from this study shows the possible increase of the risk in the future with implementing EU regulations for green growth. In order to assess the impact of regulatory tools to human health and the environment, the aspect of "risk cycle" as shown in this study should have been considered. In addition, to foster the transition into a circular economy, making existing strategies and regulations for sustainable development work together is needed. In order to avoid an unintended "risk cycle" as the downside of a future circular economy, strengthening existing chemical regulations such as REACH to control the quality of recycled material flows is needed. Empowering "upcycling" of resources by guaranteeing clean resource flows, e.g. certification systems to guarantee the quality of recycled plastics can be an instrument supporting a transition into a circular regenerative economy.

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