Life cycle-based health risk assessment of plastic waste

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Abstract

Purpose: The plastic crisis, has induced a number of jurisdictions to pose bans on use of plastic bags and enhance plastic recycling in the respective municipal waste management systems. However, landfilling remains the most common waste management practice in Greece. This study presents an innovative tool for integrated health risk assessment of plastic waste allowing the performance of a first-of-its-kind analysis of adverse health outcomes attributable to chronic exposure to persistent organic pollutants associated with plastic material use and disposal.

Methodology: Integration of all human exposure routes and pathways to the toxic compounds contained in plastic was done at the level of systemic internal dose using the intake fraction methodology. The level of homeostatic perturbation induced by the biologically effective dose at the target tissues was estimated using the INTEGRA platform.

Results: Landfilling is the worst plastic waste management strategy. At the same time, the investigated options for waste treatment coupled with energy and material recovery would result in very important benefits in terms of greenhouse gas emission reduction. Adverse effects on the endocrine system with cascade impacts on human reproduction, metabolic syndrome and, even, neurotoxicity after chronic exposure to the persistent organic chemicals found in plastic products and waste were estimated.

Conclusion: The coupled integrated exposure and life cycle assessment methodology developed in this study and translated into the INTEGRA LCA platform is a significant step towards the direction of comprehensive, precise and transparent estimation potential health risks associated with use, management and disposal of plastics in urban settings.

Keywords: plastic waste, human health risk, life cycle analysis, integrated assessment.

1 Introduction

Plastic waste management and the associated risks to human and ecosystem health are recognized as key issues in sustainable waste and resource management worldwide. Indeed, half of the plastics produced worldwide end up as waste. Three are the main treatment methods for plastic waste:

- Disposal (primarily landfilling) treating ca. 42% of total plastic waste.
- Energy recovery (primarily incineration) treating 34% of total.
- Recycling, treating 24% of total plastic waste.

The plastic crisis, has induced a number of jurisdictions to pose bans on use of plastic bags and enhance plastic recycling in the respective municipal waste management systems. Still to date, however, landfilling and illegally dumping waste remain the most common waste management practices in Greece in spite of enforced regulations aimed at increasing recycling, pre-selection of waste and energy and material recovery.

In the EU-27, mining and construction activities are responsible for 61% of overall waste generated per annum according to Eurostat (2012). Manufacturing is responsible for 11% of total waste, while utility supply (gas, water, electricity), sewage and waste management produce 10% of total waste. Households are responsible for 9%, the service sector for the 7% of total waste and agriculture, forestry and fishing for the remaining 2%. This picture is, however, vastly different when it comes to plastics. Here, manufacturing is the leading source of plastic waste (accounting for 31% on a yearly basis), followed by the service sector (23%), utilities and sewage and waste management (21%), households (14%) and finally mining and construction (6%) and agriculture, forestry and fishing (3%) (see figure 1).

The prevalence of manufacturing and service provision regarding plastic waste generation (together these two activity sectors account for more than 50% of the overall plastic waste production per annum) has repercussions on the ecosystem and human health risk posed by the plastic waste entering environmental systems. The chemical composition of plastic waste is variable; however, on the basis of the functionalities that plastics used in manufacturing and services

require, the latter have a higher probability of contamination by persistent organic pollutants (POPs) and potential endocrine disrupters.

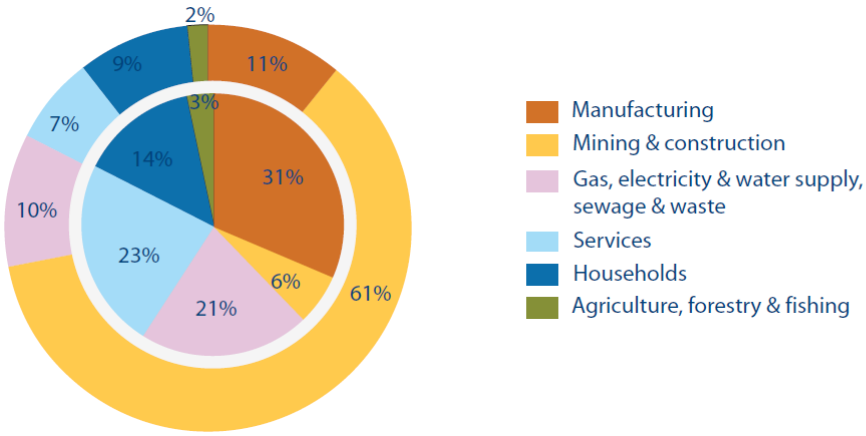

Figure 1: Total waste (outer circle) and plastic waste (inner circle) in the EU-27 (source: Eurostat, 2012).

Currently, an estimated amount of more than 100.000 t of plastic waste, mostly micro-plastics, is floating in the world's oceans. On average nearly 80% of plastic in the marine environment is estimated to be coming from land. This is a great concern in particular since plastic and POPs concentrated on the surface of micro-plastics could enter the food chain. The potential environmental effects of this phenomenon are only beginning to be fully understood. With regard to plastic waste, a lot of studies have exemplified the adverse effects of low-biodegradability plastic material on the health and sustainability of natural ecosystems, disrupting the food web and inducing endocrine disruption and eventually gender alteration (feminization) in sensitive species such as fish. This effect in turn endangers biodiversity and ecosystem sustainability.

As yet, however, there is a much more limited number of studies focusing on the adverse human health effects of plastic products and waste, the ubiquitous nature of plastic material notwithstanding. Thus, in this study we have developed an innovative tool for integrated health risk assessment of plastic waste by focusing on the body burden of potentially hazardous compounds found in plastic materials and waste in the absence of dedicated toxicological studies so far. The INTEGRA LCA software couples the integrated external and internal exposure assessment capabilities of the INTEGRA computational platform (Sarigiannis et al, 2014) with life cycle impact assessment (Clift et al, 2000). The integrated software platform allowed us to perform a first-of-its-kind analysis of adverse health outcomes attributable to chronic exposure to persistent organic pollutants associated with plastic material use, treatment and disposal, covering the three major plastic waste strategies to date.

2 Methodology

2.1 Overall study design

In order to make a proper health risk assessment of plastic waste, it was felt quintessential to take into account the whole life cycle of plastics from their use as products in different types of economic activities until they are considered waste and they are treated as such. Thus, our study encompasses the plastics life cycle, yet, it focuses on specific chemical compounds that are commonly found in plastic and micro-plastic material and have been identified as potentially harmful for human and ecosystem health through different modes and mechanisms of action. Amongst them endocrine disruption is of high significance, especially given the downstream adverse effects that disruption of hormonal equilibria may have on the onset of type 2 diabetes, childhood obesity, reproductive capacity and even neurodevelopmental and neurodegenerative disorders. Thus, this study aims at assessing the environmental and health impact during the life cycle of plastics and micro-plastics identified in municipal waste streams, focusing on plasticizers such as bisphenol-A, bis(2-ethylhexyl)phthalate, di-(2-ethylhexyl)adipate and 1,2-Cyclohexane dicarboxylic acid diisononyl ester. These compounds are extensively used in the interior of cans, baby bottles, pacifiers and other plastic or plastic-coated products coming in contact with humans through the oral route of exposure [1], among several other applications in consumer products.

Towards this aim, the following steps were followed:

- Identification of exposure levels of these plasticizers either starting from biomonitoring data, or from

environmental releases during their entire lifecycle, based on data availability

- Evaluation of exposure levels under different waste management options, namely (a) landfilling, (b) incineration and (c) recycling.

2.2 Applied methodology

2.2.1 Integrated exposure assessment

The overall study aims at assessing the environmental and health impact during the life cycle of the selected compounds found in plastics. This lifecycle assessment includes the different industry categories (IC), use categories (UC) and main categories (MC), as well as the waste remaining in the environment life cycle stage, investigating the three major options related to plastic waste disposal, (recycling, incineration, landfill).

Due to the high persistency of the polymer matrix in the environment, emissions from polymer end products are expected to last during a long period. The total lifetime of plasticizer end products is therefore an important element in the estimation of the total emissions. The contribution of emissions from waste it might be significant, hence the efficiency of waste collection and waste management strategy (recycling, incineration, landfill) will therefore influence the overall emissions. Consumer exposure may occur via food and via contact with various use of end products. Exposure via food, water and air may occur because of emissions to the environment from all life cycle stages. Apparently, refined aggregate exposure assessment is data-intensive, requiring detailed information at every step of the source-to-dose pathway. Based on the needs described above, the computational platform INTEGRA [2] was used, that aims at bringing together all available information within a coherent methodological framework for assessing the source-to-dose continuum for the entire life cycle of substances covering an extensive chemical space. The major component of INTEGRA (*Figure* 2) is an integrative computational platform that comprises environmental fate, exposure and internal dose dynamically in time using a Markov chain Monte Carlo (MCMC) probabilistic analysis framework. The INTEGRA platform includes the following components:

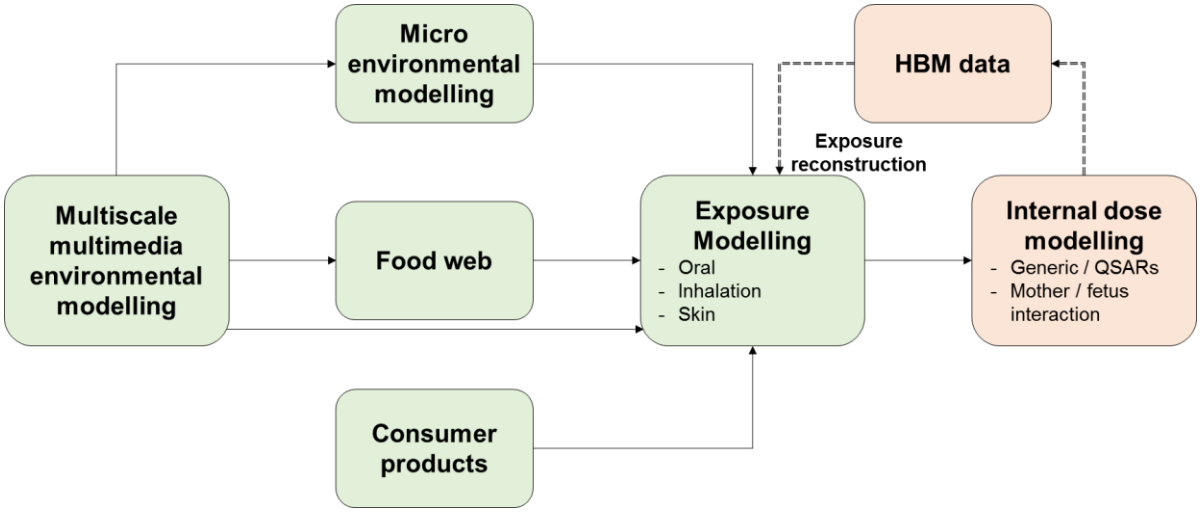

Figure 2. Conceptual representation of the INTEGRA methodological framework

1. Multimedia model to account for multi-scale (far field exposure) interactions affecting the environmental transport and fate of chemicals: The multimedia environmental modelling framework for INTEGRA, follows the ECHA guidance on information requirements and chemical safety assessment [3]. All different spatial scales (local, regional, continental and global), media exchange (air, soil, water, sediment and transfer to food items such as crops, meat, milk and fish) and environmental processes (emissions, advection, diffusion, and degradation) used in EUSES [4] were taken into account.

2. *Indoor micro-environmental modelling and detailed personal exposure assessment (near field exposure)*: In terms of indoor microenvironments, a two-zone model was developed [5], also accounting for partitioning among gaseous, particles and settled dust phase [6]. Exposure is explicitly described for each pathway and route of exposure, considering all the age and gender exposure modifiers, such as activity based inhalation rate, dietary patterns and intake rates per food item, amount of soil and dust ingested or hand-to-mouth behaviour.

3. A generic PBTK model that captures satisfactorily life stage changes and physiological and metabolic efficiency

change over an individual's lifetime (from conception till 80 years of age): The generic PBTK model developed in INTEGRA is designed to describe in as much as possible detail the ADME processes occurring in the human body at different life stages, in order for it to be easily applicable to a broad variety of chemicals after proper parameterization. The model in its generic form includes the parent compound and up to three generations of potential metabolites [2]. Advanced QSAR models are used to estimate physicochemical and biochemical parameters of the model to expand its applicability domain to a large chemical space. All major human organs are included, as well as arterial, venous, and portal blood compartments. Xenobiotics and their metabolites are linked through the metabolizing tissues. This is mainly the liver, but also other sites of metabolism might be considered (intestine, brain, skin, placenta) based on the presence or not of the enzymes involved in the metabolism of the compound of interest. The mass balance equation for each compartment describes all appropriate parameters carrying biological significance, such as absorption, metabolism, elimination, and protein binding. In practice, in each tissue three mass balance equations are written, for (a) red blood cells, (b) plasma and interstitial tissue and (c) cells, allowing the application of the model to both flow limited, as well as membrane-limited compounds. Specific organs were further divided in sub-compartments: liver is divided in up to 5 compartments to better describe the distribution of enzymes, and brain is divided in four sub-compartments, namely, main brain, globus palidus, cerebellum and pituitary, to better describe the permeability differences among the different brain regions. The model describes mother fetus interactions by modelling the intra-placental properties that govern the transfer of xenobiotics and their metabolites from the mother to the fetus as it grows. The anthropometric parameters of the models are time dependent, to provide a lifetime internal dose assessment, as well as to describe the continuously changing physiology of the mother and the developing fetus. The model include the diffusion flow from uterus to placenta and vice-versa during pregnancy [7]. Excretion via lactation is described as an output from the mammary tissue compartment through a partitioning process between mammary tissue and milk, and milk withdrawal by suckling, as described for PCBs in rats [8] and further adopted for humans [9]. The model includes also a detailed description for the three main routes of exposure. Inhalation considers absorption of gases and deposition fractions of particles across the different human respiratory tract regions based on particles size distribution. Absorption through the oral route is governed by the absorption rates of stomach and intestine. To better describe dermal absorption, skin has been modeled as a two layer structure, including stratum corneum that has been described as a "bricks and mortar" structure [10] and viable epidermis (also accounting for metabolism), where the geometry of all layer microstructure has been explicitly described [11].

4. Inverse modelling module for exposure reconstruction and human biomonitoring (HBM) data assimilation: The PBTK model is geared with reverse modeling algorithms to reconstruct exposure from human biomonitoring (HBM) data. Assimilation of human biomonitoring data and their translation into intake distribution amounts to a computational inversion problem, where the objective is to identify the specific input distributions that best explain the observed outputs while minimizing the residual error. Inputs involve spatial and temporal information on micro-environmental media concentrations of xenobiotics and corresponding information on human activities, food intake patterns or consumer product use that result in intakes; outputs are the observed biomonitoring levels. More in detail, a computational framework was developed based on Bayesian Markov Chain Monte Carlo (MCMC) combined with the generic Physiological Based Pharmacokinetic (PBTK) model aiming at performing accurate exposure reconstruction. Differential Evolution (DE) and MCMC algorithms have been combined to this problem for the first time. The PBTK model has been combined with the Bayesian MCMC [12,13] and DEMC [14] techniques in order to simulate and calculate the exposure value that fits best the observed HBM data.

2.2.2 Data collection

Bisphenol A (BPA) is an organic compound with two phenol functional groups. Four companies manufacture bisphenol-A [15], for use primarily in the production of polycarbonate plastics and epoxy resins. Polycarbonate plastics have many applications including use in some food and drink packaging, e.g., water and infant bottles, compact discs, impact-resistant safety equipment, and medical devices. Epoxy resins are used as lacquers to coat metal products such as food cans, bottle tops, and water supply pipes. Some dental sealants and composites may also contribute to BPA exposure. The total amount of bisphenol-A manufactured within the EU for 2005/2006 was 1,100,000 tonnes/year. BPA has been considered a weak environmental estrogen, based on traditional bioassays, as it binds to the estrogen receptor alpha and beta (ERα and ERβ) [16,17] with affinity, which is about 10.000 to 100.000-fold weaker than that of 17β-estradiol. Exposure to low doses of biphenol A has been demonstrated to produce disruptive effects in endocrine organs including the androgen or estrogen responsive tissues, immune system, thyroid hormone function, and developing nervous system. The current toxicological threshold for BPA is set at 4 μg/kg_bw/d [18].

Europe is a significant producer as well exporter of bis(2-ethylhexyl)phthalate (DEHP). The amount of global produced volume of DEHP is more than 2,000,000 tonnes/year [19] while in Europe was produced 595,000 tonnes/year in 1997 [20]. However, recent information from REACH shows that the used in EU of DEHP doesn't exceed the levels of 100,000 tonnes/year in 2015. DEHP is one of the most common used plasticizers of phthalate in EU corresponding to

51% of the total consumption. The three main product groups are PVC, non-PVC polymers and non-polymers. In particular, the 97% of DEHP is used as plasticizer for PVC and more than the 3 quarters of the annual production is used for indoor applications [21]. Additionally, it has been detected in many foods such milk, cheese, meat, eggs, baby food, cereal, products etc. as well as it is used in clothing (footwear, outwear and rainwear), soft plastic toys and infants supplies (pacifiers, teethers, and nipples) while DEHP is used in building materials including cables, coated fabric, roofing materials, car under-coating [22]. Human can be exposed to DEHP through migration, leaching or evaporation into indoor air and atmosphere. DEHP is rapidly metabolized to more than 30 metabolites which are eliminated in urine. MEHP is the putative toxic metabolite of DEHP. The toxicity of DEHP relates to adverse effects on the androgen responsive tissues of rodents, while high doses of DEHP have suppressed estradiol production in female rats [23]. The TDI for DEHP is 50 µg/kg_bw/d [24].

Di-2-ethylhexyl adipate (DEHA) is imported as well as manufactured in Europe. According to ECHA the amount of DEHA used by the industry ranges between 1,000 and 10,000 tonnes/year [25]. DEHA is widely used as plasticizers in the flexibly vinyl industry and in flexible polyvinyl chloride (PVC) food firm. DEHA is mainly used in the processing of synthetic rubber, plasticizing polyvinyl butyric, cellulose acetate butyrate, polystyrene and dammar wax and in cosmetics. However, because of DEHA is used in lieu of DEHP, it is indisputable detected in daily and common products and application such as in flooring, wall coverings, cladding and roofing, film and sheet, automotive, tubes, coated fabrics, inks and waxes, food packaging and toys. Hence, human can be exposed to DEHA thought multiple routes of exposure. DEHA was tested for carcinogenicity by oral administration in experiments in rodents and the results shown that it were produced liver adenomas and carcinomas [26]. For DEHA a TDI of 30 µg/kg_bw/d [27].

1,2-Cyclohexane dicarboxylic acid diisononyl ester (DINCH) is manufactured by BASF Corporation and is a clear colorless plasticizer that was developed for use in applications that are sensitive based on exposure and toxicological issues. DINCH is suitable for use with PVC and other polar polymers. The major applications of Hexamoll DINCH are use in food packaging, wire and cable, automotive, plastisols, and other related applications. Due to steadily growing demand since its market launch in 2002, DINCH has become an established plasticizer in food packaging, medical devices and toys. During the last few years there was also an increasing demand in the flooring and wall covering industry. Overall production volume of DINCH is 200.000 tn/year. Although DINCH is considered safer than older phthalates, based on data obtained *in vitro*, a biological disruptive effect of MINCH – a metabolite of the plasticizer DINCH- on metabolism in mammals has been observed [28]. The current tolerable daily intake is 1mg/kg_bw/d [29].

3 Results and discussion

3.1 Exposure trends during the plasticizers lifecycle

Biological monitoring results show that the levels of all organic EDCs in the European population tend to decline, except for DiNP, which is the substitute of DEHP in plastics. The trends of the major metabolites of DEHP and DiNP (MEHP and MiNP respectively) are illustrated in Figure 3.

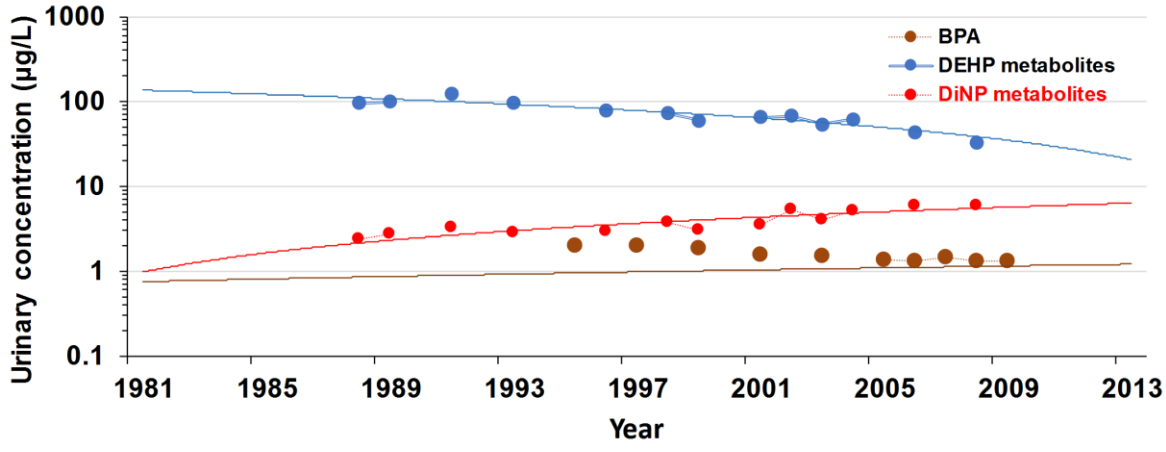

Figure 3. Temporal trends of characteristic plasticisers urinary concentrations in EU

MEHP follows a consistently decreasing trend over the last fifteen years, while MiNP levels in human biological samples keep increasing. In 1999 DEHP represented 42% of phthalates use in Western Europe compared to only 35% for DINP and DIDP. The use of other phthalates, and in particular DiNP, has constantly increased since 1994, whilst DEHP represents nowadays (2008 figures) only ca. 18% of the overall consumption of plasticizers. In contrast DINP,

DIDP and DPHP amount together to ca. 65% [30]. For BPA, the trend is not clear, due to its ubiquitous present; exposure has been decreased only for specific consumer exposure scenarios such as baby bottles, after the ban of the manufacture of baby bottles with BPA, adopted in January 2011 (EU Directive (2011/8/EU). However, biomonitoring comprises a key tool for the assessment of exposure to plasticizers (among other compounds), since it encompasses the integral of exposure from all sources, pathways and routes, during the life cycle of the compounds of interest.

3.2 Bisphenol-A

Bisphenol-A is characterised by low environmental concentrations, as a result of the limited environmental emissions. In Greece, BPA concentration in urban PM has been estimated equal to 0.06 ng/m^3 [31], which is in a very good accordance with the predictions of the multimedia model incorporated in INTEGRA. Exposure to BPA mainly occurs through exposure to specific consumer products.

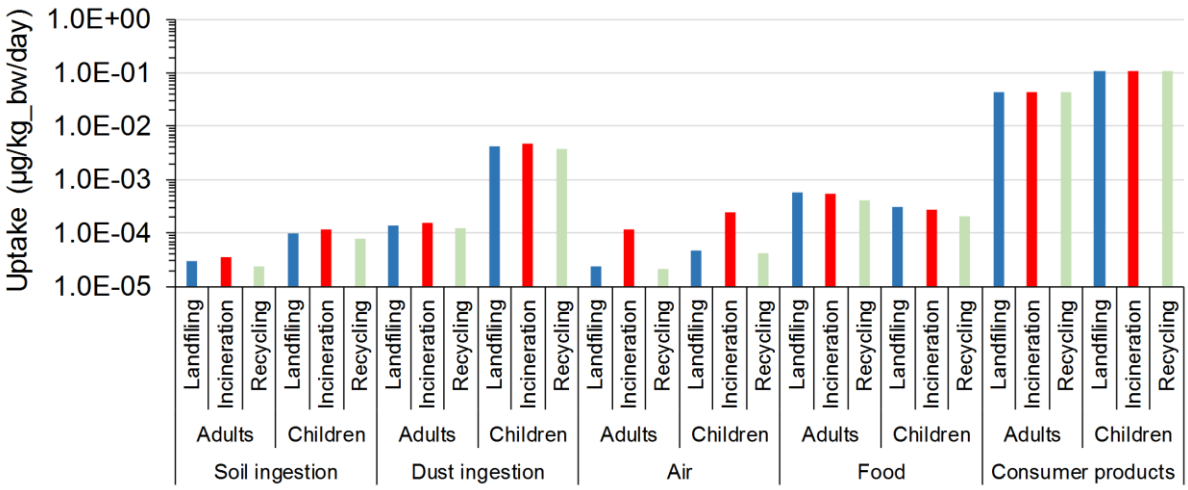

Figure 4. Contribution of various pathways to BPA exposure for adults and children under various waste management options

As expected, children are exposed to higher amounts of BPA, and the mean urinary concentration in Greece have been identified equal to 1.2 and 2.1 µg/g creatinine for adults and children respectively [32]. Using the exposure reconstruction module of the INTEGRA platform, the respective external exposure levels correspond to 0.06 and 0.156 µg/kg_bw/d, which is far below the temporary tolerable daily intake (t-TDI) of 4 µg/kg_bw/d set by EFSA. Contribution of the various pathways to overall BPA exposure for adults and children is plotted in Figure 4. Among the various waste management options, incineration contributes to a higher amount of exposure through air for the local population, due to the higher emissions occurring from the incinerator. Similarly, exposure to dust is also slightly higher. On the contrary, landfilling contributes to slightly higher exposure through food (and drinking water) from the leachates ending up to the ground underwater and eventually to drinking water.

3.3 DEHP

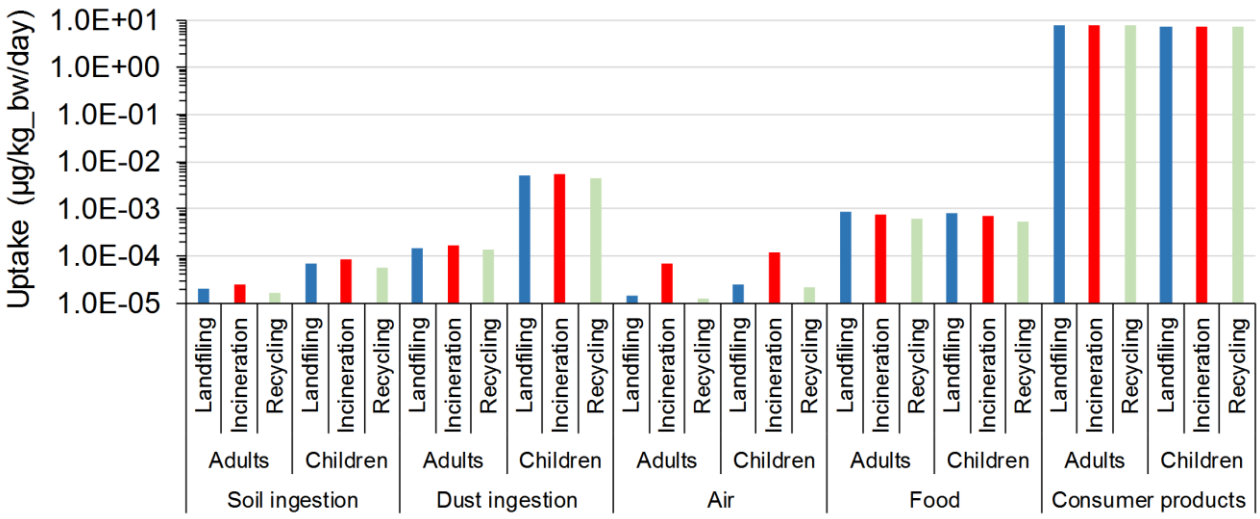

Figure 5. Contribution of various pathways to DEHP exposure for adults and children under various waste management options

Although DEHP is produced in lower volumes compared to BPA, overall exposure is significantly higher. The measured urinary levels of MEHP, the major metabolite of DEHP have been identified as 7.6 and 2.8 μg/g creatinine for adults and children respectively [32]. Similarly to BPA, contribution of DEHP exposure originates from consumer exposure (mainly use of PVC flooring and use of various plastic toys and equipment, as well as food conduct materials), however, these exposure levels (10 μg/kg_bw/d are in the same order of magnitude with the respective TDI (Figure 5). Among the various waste management options, incineration contributes to a higher amount of exposure through air and dust for the local population, as a result of the higher emissions in air from the incinerator.

3.4 DEHA

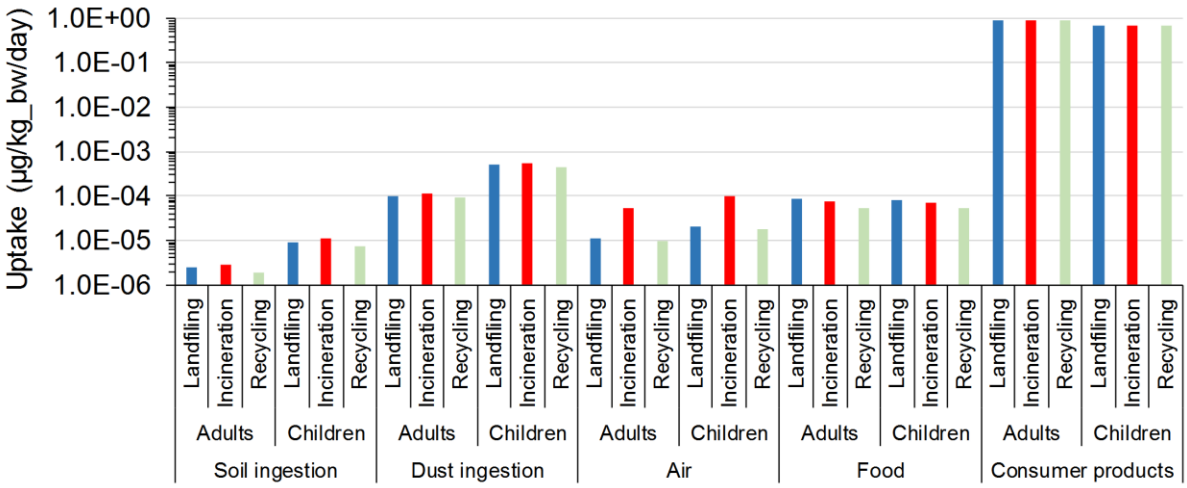

Figure 6. Contribution of various pathways to DEHA exposure for adults and children under various waste management options

DEHA is considered one of the major DEHP substitutes. Based on the LCA and considering its broad applications, the estimated daily intake is in the range of 1 μg/kg_bw/d (Figure 6). In Europe, the estimated intake for children based on biomonitoring data, has been estimated within the same range.

3.5 DINCH

DINCH is another of the DEHP substitutes. Based on the respective LCA, the predicted exposure estimates of DINCH are close to 0.7 μg/kg_bw/d; this value is close to the dose (0.5 μg/kg_bw/d) estimated from biomonitoring data collected in daycare centers in Germany [33]. Contribution from consumer applications is similar, but four to five orders of magnitude higher that the rest of the contributing pathways (Figure 7).

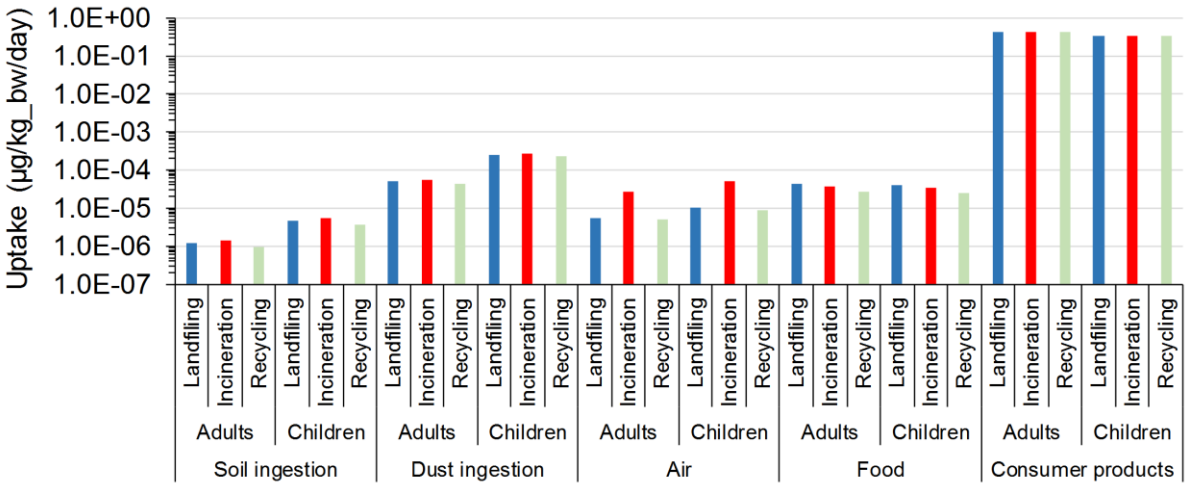

Figure 7. Contribution of various pathways to DINCH exposure for adults and children under various waste management options

3.6 Intake and internal dose

A very important finding of this study is the higher bodyweight normalized exposure to children, which is mainly driven by non-dietary ingestion of soil and dust. This is of further importance for the population living near to waste management sites due to the higher contamination of these media. In addition, exposure through the inhalation pathway results in higher internal dose (for the same bodyweight normalized dose), due to the lack of the first pass metabolism that occurs in ingestion. These effects are clearly demonstrated in the internal dose estimates presented in Figure 8. However, the overall exposure to plasticizers was estimated to be low, and for this reason, they were excluded from further analysis related to children neurodevelopment.

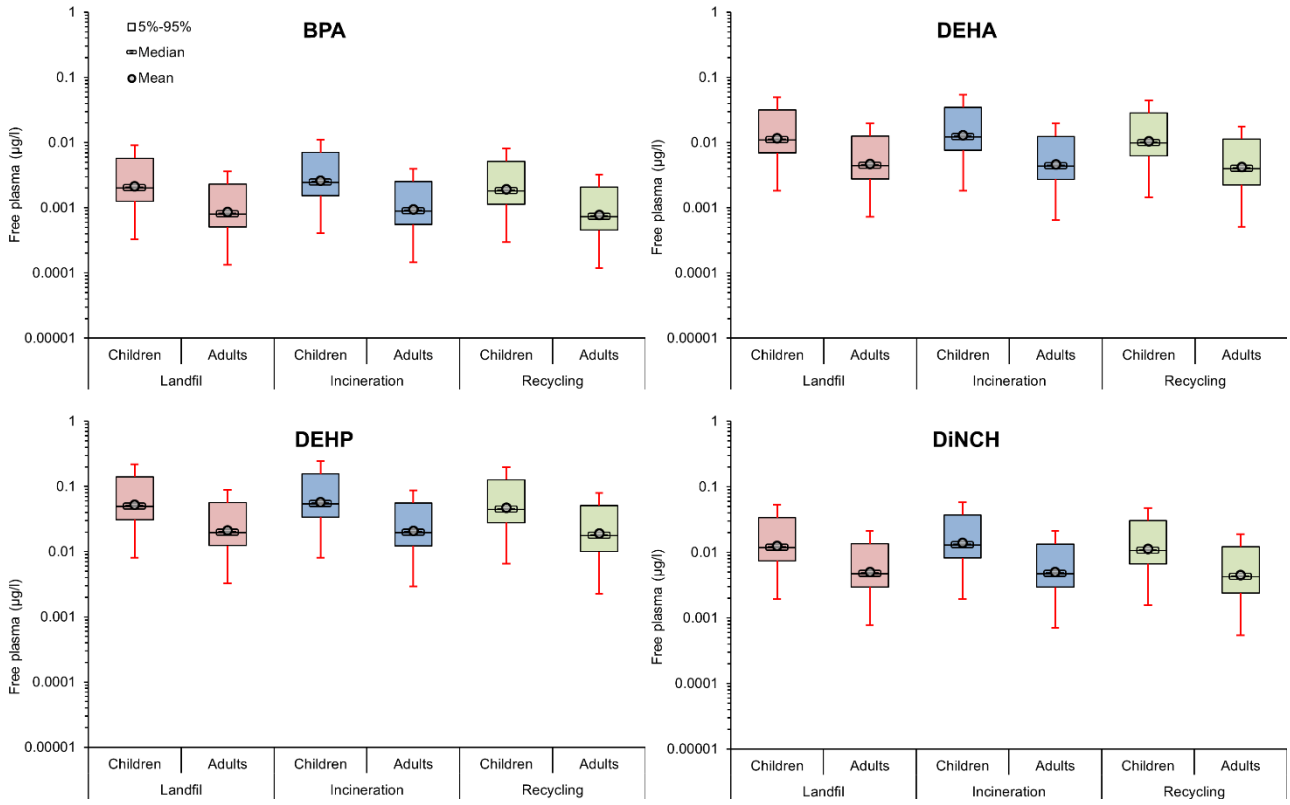

Figure 8. Internal dose (free plasma concentration) of the various plasticisers for both adults and children under the various waste management scenarios

4 Discussion

The estimated risks of the investigated plasticizers seem to be low, since in most cases the estimated intake was 1 to 2 orders of magnitude below the respective tolerable daily intake levels (TDIs). In order to assess potential health risk we define the hazard quotient as follows:

$$HQ = \frac{Uptake\ rate}{Tolerable\ Daily\ Intake}$$

and apply it for all plasticizers in this study. For each compound for which $HQ > 1$ the population exposure is unacceptable and risk management measures need to be taken. For compounds with $0.5 < HQ < 1$ population exposure does not exceed the tolerable daily intake or any other toxicological reference dose. However, given the range of uncertainties for population-wide assessments, the corresponding health risk is considered significant and further study or risk management measures are needed. For compounds with $HQ << 0.5$ the level of exposure is considered low enough to result in negligible health risk given our current knowledge regarding the toxic potency of the compound.

The *HQ* values of the four plasticizers analysed in this study range from almost 1.0 (for DEHP) to 0.03 (for DEHA). Overall, the *HQ* values are summed up in table 1 as follows:

Table 1. Hazard quotient of all plasticizers studied herein

Compound	Hazard Quotient
BPA	0.05
DEHP	1.00
DEHA	0.03
DINCH	0.70

On the basis of our results DEHP is the compound that poses the most significant health risk warranting immediate risk management measures. Indeed, DEHP has been banned from a large number of applications across the EU, even though it can still be found in plastic products and plastic waste creating thus a chemical legacy that will continue to endanger the health of the population residing close to plastic waste management facilities. The potential health risks associated with exposure to DINCH (a key substitute for DEHP with rapidly increasing consumption in the EU) are non-negligible because its uptake from consumer products treatment in on the order of 0.7 μg/kg bw-d, very close to the TDI. This warrants more precise exposure and toxicological studies for DINCH, especially considering the increasing use of this compound as substitute to DEHP. Given the rising uptake trend of DINCH in the EU we need to act in two directions:

(a) Design and perform more precise studies on the toxic potency and the modes and mechanisms of action for DINCH, especially when humans are co-exposed to it and other plasticisers with common modes of action (such as the ones found in our study).
(b) Improve upon the current exposure scenarios possibly with targeted human biomonitoring campaigns as part of the European Human Biomonitoring Initiative (the HBM4EU multi-annual program). On this occasion, socio-economic and waste treatment differences across Europe need to be considered for comprehensive risk assessment and management.

Even though the value of *HQ* for most of these compounds would warrant negligible exposure and thus health risk there area specific exposure scenarios / uses of plastic materials and plasticizers and plastic waste treatment strategies that would result in enhanced exposure levels. A good example is the use of BPA in baby bottles and other goods in contact with infants. Considering the enhanced susceptibility of neonates and infants to the toxic potency of BPA due to their reduced metabolic capacity, particular attention has to be paid to reduce exposure of these population sub-groups to BPA, for instance, by banning its use in products that come into contact with them.

Furthermore, population exposure to plasticisers through landfilling is something that should be further investigated. Beyond that, the cumulative effect of these compounds and the presence of additional plasticizers (beyond the ones investigated herein) within the plastic matrix must be considered as well. Among the various steps of the respective life cycle, waste remaining in the environment is expected to be particles/fragments abraded from end-use products during their service life and during disposal (e.g. particles abraded from car undercoating, coil coating, shoe soles and fragments of plastic bags etc.). Thus, the next steps of the study should include a further biomonitoring analysis of

various plasticizers, and a metabolomics profile analysis of the collected biosamples (currently ongoing). This will allow a more comprehensive analysis of the combined effect of heavy metals and plasticisers on neurodevelopmental disorders. Co-exposure to these compounds is important, since there is evidence suggesting that specific plasticisers (phthalates) affect motor development at environmentally relevant concentrations [34].

5 Conclusion

The estimated risks of the plasticizers investigated above seem to be relatively low, with the exception of DINCH, where the estimated intake is in the same order of magnitude with the respective TDI. Beyond that, the cumulative effect of these compounds has to be taken into account, as well as the presence of additional plasticizers (beyond the ones investigated herein) within the plastic matrix. Among the various steps of the respective life cycle, waste remaining in the environment is expected to be particles/fragments abraded from end-use products during their service life and during disposal (e.g. particles abraded from car undercoating, coil coating, shoe soles and fragments of plastic bags etc.). These particles are primarily released to the urban/ind. soil compartment in landfills. However, the smallest fraction may also be distributed to the air compartment or to the surface water environment ending up in the sediment. Overall, the comprehensive analysis of the waste management options indicated that incineration contributes significantly to increased levels of exposure through inhalation for the population living close to the incinerator facility, while on the other hand recycling results in lower exposure from all environmental exposure pathways.

6 References

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