International Journal of Hygiene and Environmental Health xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Hygiene and Environmental Health

journal homepage: www.elsevier.com/locate/ijheh

The added value of a surveillance human biomonitoring program: The case of FLEHS in Flanders (Belgium)

Hans Reynders[a,*], Ann Colles[b], Bert Morrens[c], Maja Mampaey[a], Dries Coertjens[c], Gudrun Koppen[b], Greet Schoeters[b], Ilse Loots[c], Hana Chovanova[d], Wim Winderickx[e], Karen Van Campenhout[a]

[a] *Environment & Health, Flemish Government, Environment, Nature and Energy Department, Brussels, Belgium*
[b] *Flemish Institute for Technological Research (VITO), Dpt. Environmental Risk and Health, Mol, Belgium*
[c] *Faculty of Social Sciences, University of Antwerp, Antwerp, Belgium*
[d] *Flemish Ministry of Welfare, Public Health and Family, Flemish Agency for Care and Health, Environmental Health Section, Brussels, Belgium*
[e] *Strategy and Coordination Division, Department of Economy, Science and Innovation, Flemish Government, Brussels, Belgium*

ARTICLE INFO

Article history:
Received 5 August 2016
Received in revised form
16 September 2016
Accepted 16 September 2016

Keywords:
Human biomonitoring
FLEHS
Chlorinated POPs
Phased action plan
Science-policy interface

ABSTRACT

Since 2002, the Flemish Government decided to carry out the Flemish Environment and Health Survey (FLEHS), an extended human biomonitoring (HBM) program, which is integrated in the environmental health policy.

Through the FLEHS studies, a vast amount of data such as biomarkers of exposure and effect, exposure-effect associations, time trends and geographical differences, became available to the Flemish policy makers. In order to facilitate the policy interpretation, a phased action-plan was developed collaboratively by FLEHS researchers and policy makers.

In this article we look back on more than 15 years of investments of the Flemish government in HBM and reflect on how this large scaled and challenging HBM-initiative contributed to shaping the environmental health policy in Flanders. We used the FLEHS I (2002–2006) and II (2007–2011) results on persistent organic pollutants (POPs) and the resulting policy actions as an example to illustrate the added value of HBM for policy making. Policy measures for POPs, including source-related regulation (e.g. further optimization and tightening of existing Flemish legislation on open fires), investment in monitoring networks and communication and awareness campaigns, are presented and the added value for environmental health policy is discussed.

We also reflect on how HBM can support science and innovation in the environmental monitoring context. Finally, we describe what society can gain from HBM in terms of opportunities for (1) feeding the political and societal debate, (2) stimulating community involvement and (3) empowering participants and citizens.

All together, the gained insights and phased action plan showed that next to compliance with high scientific standards, results of the Flemish human biomonitoring campaign could be translated in targeted policy actions even for chemicals that have since long been regulated.

1. Introduction

In 2002 the Flemish Government decided to initiate the Flemish Environment and Health Survey (FLEHS), an extended human biomonitoring (HBM) program to assess and monitor human exposure of the Flemish population to environmental pollution and its impact on public health. Flanders is a densely populated area in the North of Belgium with intense traffic and widespread industrial and agricultural activities, which have a measurable impact on environmental quality and human health. It has been estimated

* Corresponding author.
E-mail addresses: hans.reynders@lne.vlaanderen.be (H. Reynders), ann.colles@vito.be (A. Colles), bert.morrens@uantwerpen.be (B. Morrens), maja.mampaey@lne.vlaanderen.be (M. Mampaey), dries.coertjens@uantwerpen.be (D. Coertjens), gudrun.koppen@vito.be (G. Koppen), greet.schoeters@vito.be (G. Schoeters), ilse.loots@uantwerpen.be (I. Loots), hana.chovanova@wvg.vlaanderen.be (H. Chovanova), wim.winderickx@ewi.vlaanderen.be (W. Winderickx), karen.vancampenhout@lne.vlaanderen.be (K. Van Campenhout).

http://dx.doi.org/10.1016/j.ijheh.2016.09.013
1438-4639/

that 6.3% of the total burden of disease in Belgium, *assessed using Disability-adjusted life years (DALYs),* is associated with a range of well characterized environmental stressors (i.e. particulate matter (PM2.5), secondhand smoke, traffic noise, radon, lead, ozone, dioxins, benzene and formaldehyde) (Hänninen et al., 2014). DALYs were estimated using primarily World Health Organization data on burden of disease, national environmental exposure data and epidemiological or toxicological risk estimates. However, for many other chemicals, the exposure levels and associated health effects are not well assessed or poorly understood.

Within this scope, human biomonitoring (HBM) adds value to environmental monitoring programs by assessing internal human exposure to chemicals with potential health impact. HBM integrates exposure through inhalation, ingestion and dermal uptake from a variety of sources taking into account personal characteristics and individual life styles. The FLEHS HBM program provides information on the distribution of chemicals in the general population allowing to identify high exposure groups. It provides reference values for selected chemicals in a representative population and allows to study time trends, spatial comparisons and exposure of vulnerable population groups such as pregnant women and adolescents (Baeyens et al., 2014; Croes et al., 2014; Den Hond et al., 2013; Koppen et al., 2009; Morrens et al., 2012; Schoeters et al., 2012). Relationships between exposure and biological and health effects are studied to support environmental risk assessment and health impact assessment (Choi et al., 2014; Croes et al., 2015, 2009; Den Hond et al., 2015; Dhooge et al., 2011; Franken et al., 2014; Lagerqvist et al., 2015; van Larebeke et al., 2006; WHO Regional Office for Europe, 2015). To assure the policy relevance of FLEHS, the Flemish government included specific requirements in the project call. FLEHS had to be implemented as a surveillance program to produce reference values of selected exposure biomarkers for the general population of Flanders. These reference values could then be used to compare with so-called 'hot spots', e.g. cities, industrial areas or regions with extensive fruit cultivation, and later on to study time trends in Flanders. The multidisciplinary composition of the research consortium (with all relevant scientific disciplines represented, including social scientists) and the establishment of structures for interaction with policy makers were other requests. Extension to relevant scientific research projects was encouraged for optimal use of the information of the surveillance program and its logistic framework. In addition, a special program had to be launched to use FLEHS data for policy making.

Since 2003 HBM is also specifically mentioned as a legal instrument for evidence-based environmental health policy making in the Flemish Decree on Preventive Health Care. Moreover, since 2004, the translation of HBM results into policy is mentioned in every yearly policy declaration of the Flemish Minister of Environment. Accordingly, a dozen of additional projects were launched building on the FLEHS results (additional research, participatory processes to evaluate FLEHS results and develop targeted policy interventions and specific action plans). These initiatives clearly indicate the political support for HBM in Flanders and the engagement to use HBM results for policy making.

So far, three successive FLEHS studies (FLEHS I: 2002–2006, FLEHS II: 2007–2011, FLEHS III: 2012–2015) were commissioned, steered and funded by the Flemish government and were designed and carried out scientifically by the Flemish Centre of Expertise on Environment and Health (CEH) (Fig. 1). A fourth survey is now ongoing (FLEHS IV: 2016–2019). The FLEHS studies cover now 15 years of HBM in Flanders, in three age groups of the general population (newborns and their mothers, adolescents and adults) and in several hot spots using a combination of cross sectional and prospective cohort studies. In total more than 5500 participants were included within the first three FLEHS studies, Flemish reference values were obtained for more than 50 biomarkers of exposure and effect, including classical pollutants such as toxic metals, dioxins, polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs) and dichlorodiphenyltrichloroethane (DDT), as well as new emerging pollutants which appeared in the environment on a larger scale mainly during the last decade such as phthalates, musks, parabens and organo phosphate pesticides (Schoeters, et al., 2011). Biological effect markers and health effects studied in FLEHS were genotoxicity markers (micronucleus assay, comet assay), hormone levels (e.g. testosterone, FSH), puberty stadia in adolescents, inflammation and oxidative stress markers in e.g. breath condensate, self-reported information on fertility and asthma and allergy (Baeyens et al., 2014; Croes et al., 2015, 2014; Dhooge et al., 2011; Franken et al., 2014; Kiciński et al., 2012; Sioen et al., 2013). Remaining biological samples are stored in a biobank, currently containing about 10.000 samples.

Through these FLEHS studies, a vast amount of HBM data became available for the Flemish policy makers. The evaluation of these research results in terms of public health impact, priorities for policy action and possibilities for policy intervention is, however, not always as straightforward as it might seem. This process of interpretation is most often complicated by scientific complexity, uncertainty and discussion. Also a plurality of societal perspectives on environmental health risks, its acceptability and support for policy interventions need to be taken into account. In order to facilitate this process, a phased action-plan was developed collaboratively by FLEHS researchers and policy makers (Keune et al., 2009), and was implemented after each FLEHS study. This phased action-plan combines scientific analysis and societal deliberation in a structured and participatory approach. In several successive phases HBM results are prioritized for policy action, explanatory factors are identified and targeted policy interventions are developed. This approach has successfully resulted in several action plans, with a diversity of policy actions in addition to existing policies and in cooperation with various national and regional actors.

In this article we look back on more than 15 years of investments of the Flemish government in HBM and reflect on how this large scaled and challenging HBM-initiative contributed to shaping the environmental health policy in Flanders. Based on our experience with HBM, we elaborate on the question why policy makers need to keep investing in HBM, even for substances which have already been regulated or banned since many years? We will use the FLEHS I and II results on persistent organic pollutants (POPs) and the resulting policy actions as an example, to illustrate the added value of HBM for policy making and the diversity of eligible policy interventions. Secondly, we reflect on how HBM can support science and innovation in the environmental monitoring context. And thirdly, we describe what society can gain from HBM.

2. Material and methods

In this methods section a brief description of the methodology of the FLEHS campaigns, in particular FLEHS I and FLEHS II, and the methodology of the phased action plan is included, as a basis for the description of the POPs case to illustrate the added value of HBM for policy making. Secondly, we also clarify the methodology used in this article to demonstrate the added value for policy, science and society in Flanders.

2.1. The cycle of the Flemish human biomonitoring programs (FLEHS I and FLEHS II) and the phased action plan

In FLEHS I participants were recruited in eight geographical areas with different environmental characteristics, while in FLEHS II all Flemish provinces were included to establish reference values,

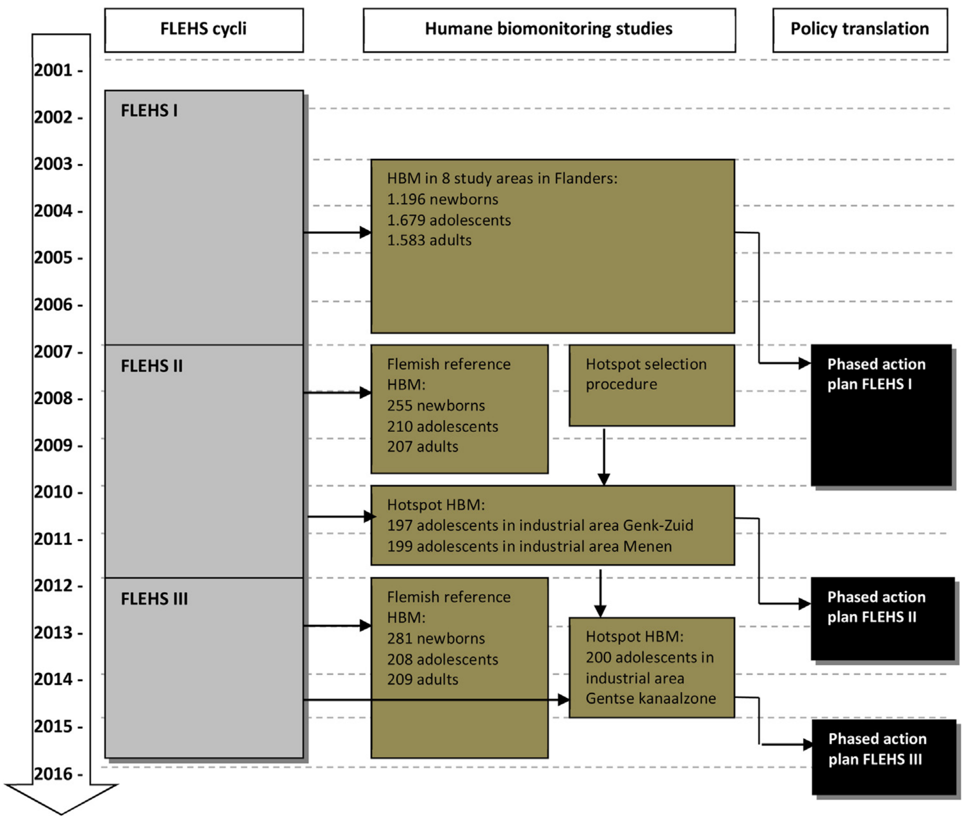

Fig. 1. Timeline of the FLEHS cycli, human biomonitoring studies and policy translation process.

complemented with the study of two industrial contaminated sites (hot spots).

The study populations consisted of mothers and their newborns, adolescents (14–15 years of age) and adults (50–65 years of age in FLEHS I and 20–40 years of age in FLEHS II). All participants completed a self-administered questionnaire to provide information on explanatory factors such as occupation, life style, living conditions, socioeconomic status, diet, tobacco smoke exposure, traffic exposure, diseases and medication. Depending on the study population samples of cord blood, peripheral blood, urine and/or hair were collected to be analyzed for biomarkers of exposure and/or biomarkers of effect. More information on study design, protocol, analysis, database management and statistical analyses is available in following publications: (Croes et al., 2014; Den Hond et al., 2013, 2009; Schoeters et al., 2011; Schroijen et al., 2008).

After each campaign, the evaluation of FLEHS results and the formulation of a policy response was structured and facilitated in a phased action plan, consisting of four successive phases (Fig. 2). In a first phase priorities for policy action were selected, not only based on scientific criteria but also taking into account policy and societal relevance. In a second phase possibilities for policy interventions were considered, by analyzing explanatory factors on the one hand (such as potential sources, exposure routes and vulnerable groups), but also by evaluating existing policies and acceptability and support for additional interventions. In a third phase new policy was implemented, if deemed necessary in support of already existing policy. And finally a fourth phase focused on the evaluation of implemented policy interventions. The concept of the phased action plan is based on the analytical-deliberative approach, which stresses the importance of combining scientific analysis and societal deliberation to obtain evidence-based but also more acceptable decisions for interested

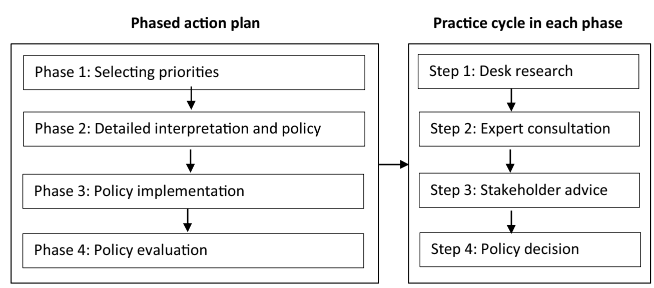

Fig. 2. The different phases and practice steps in the phased action plan.

and affected parties (Stern and Fineberg, 1996). The main elements of this analytic-deliberative approach are incorporated in the phased action plan by broadening the scope of relevant decision criteria (to include societal and policy considerations in addition to merely scientific or medical criteria) and to invite diverse scientific disciplines, policy makers and relevant stakeholders to participate in the process (e.g. in a stakeholder jury, a community advisory board and/or focus groups with citizens and FLEHS participants, depending on the particular context of each FLEHS study).

Successively action plans were developed for elevated plasma levels of persistent organic pollutants (POPs) in rural areas, for the increased asthma prevalence in urban areas, for exposure to PAHs of the general population and for local increased chemical exposure in the industrial hot spots Menen and Genk-Zuid. Each action plan was coordinated by a policy advisor on environment and health leading to targeted policy actions communicated by the ministers for environment and health.

2.2. Different aspects of added value of the FLEHS studies for policy, science and society

We hesitate to use 'policy effectiveness' as a key concept for the evaluation of the added value of the FLEHS studies. Effectiveness refers to the demonstrated gain of policy outcomes (and accomplishing policy targets) on behalf of specific policy measures (and the knowledge behind them). According to the methodologies of policy sciences and (environmental) policy evaluation in particular, it remains difficult to 'assess' effectiveness, given the lack of data to demonstrate causal relationship between knowledge, policy making and policy outcome (Crabbeí and Leroy, 2008). Taking the science-policy nexus in mind, we prefer to modestly provide illustrations of three different types of added value: for policy, for science and for society. We extract examples, shared insights, policy outputs and actions out of FLEHS's study reports, papers, external assessments and policy documents but also gave the floor to the expert's experiences within and outside the CEH.

(i) We describe the added value of HBM for environmental health policy with the action plan of POP's in rural areas (FLEHS I) and the action plan for hot spot Menen (FLEHS II), which partly focussed on POPs as well. The actions for POPs are divided into types of policy instruments, the added value is discussed, and bottlenecks in the policy translation process are identified.
(ii) The added value of HBM for science and innovation is described based on the evaluation of the scientific and innovative performance during each FLEHS cycle, done through an independent consultancy bureau. This evaluation was comprised of (1) a self-evaluation by the CEH, (2) an evaluation of the policy relevance by the stakeholders, in this case: the department of Environment, Nature and Energy and the Agency for Care and Health and cabinet members of the ministers of Environment and Health and (3) an external evaluation by three international scientific experts in the field of Environmental Health research. The evaluation considered scientific criteria such as innovative character of the research themes, international character of the research, relevance, valorization of research results and productivity of the CEH. In addition, composition of the consortium, multidisciplinarity and exchange of knowledge were judged as policy relevance criteria.
(iii) The added values for society are described in terms of opportunities for (1) feeding the political and societal debate, (2) stimulating community involvement and (3) empowering participants and citizens.

3. Results and discussion

3.1. Key question 1: additional policy actions for already regulated POPs

Performance in the science-policy nexus is firstly to be deducted from policy progress made by the Phased Action Plan. This can be illustrated by the specific action plan developed for POPs. Firstly, this paragraph looks into the specific insights that were gained for an optimized and more targeted environmental policy making.

The FLEHS I study showed that HBM is able to reveal geographical differences in internal exposure in Flanders (Schroijen et al., 2008). Although the rural areas were originally expected to represent background levels for environmental exposure in Flanders, exposure to dioxin-like compounds, PCBs and the pesticides HCB and DDE (DDT-metabolite) was found to be significantly ($p < 0.05$) higher than average in all age groups from the rural areas. In literature, the organochlorine compounds have been associated with endocrine disrupting activities, interference with fetal growth and immune system (Croes et al., 2014; Den Hond et al., 2015; Govarts et al., 2012; Leijs et al., 2009), and some are carcinogenic, indicating the health concern of increased exposure. In addition, despite a declining time trend in chlorinated POP blood levels (Schoeters, this issue) in Flanders, associations with biological body functions and health effects were still observed in FLEHS I and II (e.g. effects on hormone levels, fetal growth and increasing the odds of asthma) (Croes et al., 2014; Govarts et al., 2012).

In the phased action plan the higher POPs blood levels in the rural areas were selected as one of the priorities of FLEHS I for policy making (Keune et al., 2009). Additional policy actions were needed to further reduce POPs body burdens and to meet the objectives of the Stockholm convention, signed by Belgium in 2006.

In a joint exercise with expert consultations and a stakeholder debate, structured by the procedure 'Phased Action Plan', risk managers formulated policy measures that were based on an extensive evaluation of existing policies and led to either an extension or optimization of current policy. An overview is given in Table 1. These policy instruments represent a broad range, because they are illustrative for – although not fully cover – the range of different strategies behind policy responses (Bressers and Klok, 1988). Both our examples (supporting existing policy and new policy actions) go into command-and-control measures (source-related regulation) and persuasive instruments (persuasion of target groups via providing information, communication initiatives and awareness raising). These suggested actions were accompanied by policy measures of public administrations, such as investing in own monitoring networks.

In Belgium, pesticides DDT and HCB were banned since the 1970s. Production of PCBs is banned since 1986, collection and destruction of PCB applications was completed in 2010. Since the early 1990s environmental dioxin and PCB concentrations decreased in Flanders mainly due to emission reduction programs (Lieshout et al., 2001).

An interesting question rose on which additional actions could be taken for pollutants already banned or regulated? The most obvious type of measure is further reducing unintentional and concealed emissions. Based on the HBM results in the identified hot spots, companies were actively stimulated to apply the best available technologies to reduce dioxin emissions. Based on the still higher DDT blood levels in rural areas, extra control measurements/inspections for the presence of banned pesticides like DDT in farms were initiated (Keune et al., 2008a) to stimulate the reduction in use of pesticides and to collect residues of pesticides (e.g. remaining stock of forbidden pesticides like DDT) via the already existing Household Hazardous Waste collection in every municipality. An analysis of the collected pesticides (residues and empty packagings) set up by OVAM, the Public Waste Agency of Flanders, showed the presence of DDT –containing pesticides in the collected Household Hazardous Waste at the time the awareness campaign ran. DDT-containing pesticides were collected in all studied geographical areas in FLEHS I, but higher amounts were collected in areas with highest DDT-blood levels (e.g. rural areas).

Further desk research on the FLEHS data resulted in indications of important routes of exposure. Indeed, inhabitants of the rural regions of Flanders had a significant higher consumption of locally grown food (70% of the participants in rural areas vs. 39% in other areas) and use of stoves for heating (wood stove 22% of participants in rural area vs. 10% in other areas). Consumption of locally grown food was associated with increased plasma levels of PCBs, HCB and DDE in newborns (e.g. p,p′-DDE +18% for participants consuming locally grown vegetables) and adolescents (Den Hond et al., 2009). Wood burning was associated with increased serum levels of PCBs (+6%) in the adult study population. In FLEHS II and III the association between wood burning and consumption of locally grown food with higher POPs blood levels was confirmed. Resulting

Please cite this article in press as: Reynders, H., et al., The added value of a surveillance human biomonitoring program: The case of FLEHS in Flanders (Belgium). Int. J. Hyg. Environ. Health (2016), http://dx.doi.org/10.1016/j.ijheh.2016.09.013

Table 1
overview of selected policy actions based on the POPs results in the FLEHS studies.

	Source-related regulation	Monitoring programs	Communications/awareness raising
Supporting existing policy	• Further optimisation and tightening of existing Flemish legislation on open fires (2015–2016) • Active stimulation by the environmental inspectorate of companies to apply the best available technologies principle (continuous)	• Optimizing and expanding the monitoring network of dioxins and PCBs in ambient air (new thresholds in 2010, every year the monitoring network is evaluated and adapted if necessary)	
New policy actions	• Extra control measurements/inspections of the environmental inspectorate for the presence of banned pesticides in farms (2008) • Collection of remaining stock of banned pesticides for waste disposal (2007–2008)	• Monitoring chlorinated compounds in mother milk in rural areas (2009–2011) • Monitoring chlorinated compounds in locally produced eggs in the hot spot Menen (2013)	• Campaign of awareness raising on the use of (banned) pesticides (first campaign in 2007, last campaign in 2016) • Blueprint of 'good practice' for cultivation of crops and eggs in (public) gardens (2015) • New campaigns of awareness raising on outdoor and indoor stoking/wood burning (since 2012) • Construction of a common locally embedded communication platform between citizens, companies and local authorities (2013–2014)

policy actions reducing POPs exposure through wood/waste burning and consumption of locally grown food (Table 1) are expected to contribute in reducing body burdens with consequent health benefits.

Concerning actions regarding locally grown food, a specific campaign of awareness raising for use of DDT and other forbidden persistent pesticides was set up by the Flemish government. Chlorinated compounds were analyzed in locally produced eggs of the industrial hot spot Menen with the aim to adapt the general advice on egg consumption to the locally increased levels. The adjusted advice for eggs was communicated to the general public in this hot spot area. In a next step, a general blueprint of 'good practice' for cultivation of crops and eggs in (public) gardens was developed and communicated by the Flemish minister for Environment in March 2015. This campaign puts emphasis on the positive aspects of gardening such as economic benefits, less waste, less transport costs, more physical exercise, better social cohesion, awareness raising for children concerning healthy food and feeding habits and less food wastage, but alerts the citizens for possible risks of soil pollution. The main information channel was a website (http://www.gezonduiteigengrond.be) with information on healthy gardening and healthy eggs.

In response to the results related to wood/waste burning, Flemish legislation on open fires was further optimized and tightened as a measure to decrease emissions (such as dioxins, PCBs) from combustion processes into the air. A prohibition to make open fires was included in Flemish Environmental law (8 specific exclusions such as extinguishing work, campfires and open fires for phytosanitary reasons). This measure is expected to reduce also exposure to other pollutants such as PAHs. New campaigns on awareness raising on outdoor and indoor wood burning were initiated (www.stookslim.be). More than half (N = 180) of the 308 Flemish municipalities ordered at least one of both information leaflets.

The higher POP blood levels in rural areas drew attention to the fact that exposure to POPs is wide-spread and not only restricted to industrial or source-related areas. Based on these results the Flemish Environment Agency invested in additional environmental monitoring stations. The monitoring network of dioxins and PCBs in ambient air was optimized and recurrently expanded to include also residential and agricultural areas in addition to source oriented (industrial) locations. Extra follow-up of the presence of chlorinated compounds in mother milk in rural areas was organised (Croes et al., 2012) and was used in the policy evaluation process to formulate targeted advice to lower personal exposure to chlorinated compounds.

Taken all together, the action plans identified gaps of existing policies leading to their reinforcement and optimization. The renewed attention for existing policy measures stimulated their effectivity, capacity and acceptability. Thanks to the participative nature of the process, the gap between policy, citizens and industry decreased, leading to more cohesion and mutual understanding of arguments and policy measures.

When carrying out and evaluating the phased action plans and the policy translation process we also identified difficulties and bottlenecks.

The procedure of the phased action plan designed for the POPs proved to be very fruitful for policy translation of HBM results. However, there is no blueprint that fits all purposes for policy translation. Moreover, not every environment and health issue urges for a participatory and time-consuming approach. For acute or less complex problems a short-cut is necessary and immediate action following the HBM results is warranted. So a flexible approach is recommended in which the procedure is always tailored to the specific context.

A bottleneck identified in the phased action plan is finding suitable experts that are willing to participate. The pool of experts for the FLEHS studies is limited since documents are only available in Dutch. Participation fatigue might occur when the same experts are consulted too often. In a European-wide HBM-campaign the critical mass will increase as more experts can be consulted and documents will be available in English.

Another difficulty encountered in the FLEHS studies is the fact that policy translation of the FLEHS studies was mainly directed towards the competences of the Flemish Government. Results of the FLEHS studies, that were of relevance for national or international legislation, have also been transferred to the national and European level, but it is not clear how these results have contributed to targeted policy advices or actions. Also, other examples of good practice in policy translation are not shared easily and are often not published in English or in peer-reviewed literature. It is therefore difficult to compare with the process of policy translation of HBM results in other (European) countries. The upcoming European HBM project is however a good opportunity to make significant progress in coordinating HBM data collection from member states and streamlining policy translation in an integrated framework.

Demonstrating the effectiveness of this policy translation process remains another important bottleneck. Where the evaluation of action plans in terms of specific outputs (implementation of policy measurements) is to some extent straightforward, evaluating the outcomes and especially the impacts of the action plans (the mid and long term effects in terms of decreases in pollutant levels and associated health effects) is much more difficult.

Despite a general declining time trend in blood POP concentrations over the different FLEHS campaigns, the percentage decrease attributed to the specific action plans is not possible to assess since the further decrease in POPs concentrations also benefited from existing policy. Moreover POPs bioaccumulate in the body. A decrease in dietary or environmental exposure is therefore not immediately reflected in a decrease in internal concentrations. This complexity and bottlenecks in evaluating the effectiveness of an action plan from a scientific point of view makes it difficult to convince politicians to invest in HBM. At the same time however it also illustrates the long term nature of surveillance HBM programs.In addition, this highlights the need for criteria or indicators to measure the performance and impacts of HBM programs both on a regional and European level, capturing for example progress in research activities and impact on policy. These criteria or indicators could help in providing rationales for a long-term HBM campaign on a regional and European level.

Finally, it is also important to stress that not all environment and health problems find their solutions in HBM. First of all, the applicability of HBM depends on the availability of reliable biomarkers. Continued investments and efforts to improve analytical methods, to improve our understanding of metabolic pathways and to develop biomarkers for emerging pollutants are essential to keep up with technological innovation. Secondly, HBM is a measure for integrated exposure from different routes of exposure. Assigning internal biomarker concentrations to specific sources can be difficult and complex. For source identification directed emission and immission measurements are still the gold standard. The FLEHS studies however showed that for the identification of contributing routes of exposure and determinants of exposure, HBM provided valuable information for science and policy.

3.2. Key question 2: the added value for science and innovation built on the HBM platform in Flanders

Since 2001, the collaboration between all four Flemish universities and the Flemish research institutes Provincial Institute for Hygiene (PIH) and the Flemish Institute for Technological Research (VITO), established within the CEH resulted in an interdisciplinary team. The center includes epidemiologists, toxicologists, food scientists, social scientists, chemists and medical doctors. The combination of surveillance, science and communication within one research center was recognized as an important strength of the CEH. Over all these years, familiarity with the different vocabularies and methodologies increased. The CEH can operate in an integrated way: interdisciplinarity moved beyond multidisciplinary cooperation.

The results of the FLEHS studies were published in high ranked peer-reviewed scientific journals and were presented at international scientific conferences. The FLEHS studies resulted so far in more than 120 peer-reviewed scientific publications and 16 PhDs. Additionally to the HBM program, more than 20 policy orientated scientific research projects grafted on the HBM surveillance program were initiated

Innovative research resulting from the HBM program includes:

(i) Research on the development of biomarkers such as application of non-invasive inflammation markers in exhaled breath condensate or nasal mucus (Bloemen et al., 2010; De Prins et al., 2014a,b) biomarkers of exposure to wood burning, optimization of biomarkers for example pesticides and arsenic, the use of transcriptomics data for regulatory purposes (Remy et al., 2014) and the use of gene expression and epigenetic markers for assessment of molecular pathways affected by environmental stressors (Ketelslegers et al., 2008; van Leeuwen et al., 2008; Vrijens et al., in press).

(ii) Research on vulnerable populations: the FLEHS studies allowed exploring personal risk profiles in the context of social inequality in environmental exposure (Morrens et al., 2012). The FLEHS birth cohorts could be linked to other European birth cohorts providing insight in early life exposure effects (Bloemen et al., 2010; Delvaux et al., 2014; Govarts et al., 2014, 2012; Sioen et al., 2013). FLEHS was embedded in several international scientific cooperations such as OBELIX, INTARESE, ENRIECO, CHICOS, COST-action on Industrially Contaminated Sites and Health Network (ICSHNet) (Govarts et al., 2014, 2012; Iszatt et al., 2015). The effects of endocrine disruptors on hormonal systems such as sex hormones and the degree of sexual maturation (Croes et al., 2009; Den Hond et al., 2015, 2011; Dhooge et al., 2011, 2006; van Larebeke et al., 2006), thyroid hormone levels (Maervoet et al., 2007) and neurobehavioral function (Kiciński et al., 2012) were studied.

(iii) Research on associations between several types of environmental and health data: In the context of the FLEHS studies, HBM data were linked with air particulate matter collected in the HBM regions. On these air samples analysis of oxidative stress and DNA damage were assessed via *in-vitro* tests (De Prins et al., 2013, 2014a), indoor air measurements on e.g. PAHs (Pieters et al., 2013) and the use of HBM data in cost benefit analysis of lead, methylmercury and p,p-DDE exposure studies (Remy et al., submitted). The knowledge and expertise was also used in the EU pilot projects for human biomonitoring such as ESBIO, COPHES and DEMOCOPHES and for the preparation of the European Human Biomonitoring Initiative (HBM4EU).

Overall, the HBM program used state-of-the-art knowledge on integrated exposure to environmental chemicals and the related health effects in a general population. It feeded policy makers with accurate information about the actual body burden of the general population and vulnerable groups like new-borns and socially deprived groups. The HBM program also offered opportunities for new innovative research projects broadening and improving the knowledge of environmental health. Due to the interdisciplinary and open minded collaboration between scientists, policy makers, and moreover stakeholders and local actors, the process of mutual learning contributes to a better understanding of needs and possibilities in policy, science and society (Keune et al., 2009, 2008a), leading to policy-oriented science projects of which results were directly transposed in environmental health policy.

3.3. Key question 3: added value to society and politics

Environmental health risks are not just technical or scientific issues, they are also inherently interwoven with our way of life, our perceptions, norms and values (Renn and Rohrmann, 2000; Slovic et al., 2004). Thus, assessing and managing these risks with HBM data implies not only scientific but also societal challenges. Anticipating these challenges within the research process can yield societal benefits. This point goes into illustrations of added value to society and politics, going beyond the science-policy nexus in terms of policy output as already described in the first question.

Firstly, the HBM program and the publicity of the results created agenda-setting opportunities for politicians and pressure groups and fed the societal debate about environmental health problems. Debate and the forming of opinions structure not only issues on the political agenda, (needs that enter the policy process (Crabbeí and Leroy, 2008), but in the end also helped to generate and weigh solutions. For instance, the results of the HBM program and the phased action plans supplied answers to 168 questions from the Flemish parliament, addressed to the ministers of environment and/or health since 1995 (until May 2016). In the late 1990s parliamental questions were related to environmental pollution and health effects in the neighbourhood of waste incinerators, heavy metal pollution hot spots or pesticide use in fruit cultivation areas. In these questions the need for a surveillance program to assess environmental health related problems and to stimulate appropriate policy actions was highlighted. This resulted in a pilot project in 1999 (Koppen et al., 2002; Staessen et al., 2001) and finally in the first FLEHS programs. This means that political and social attention and pressure contributed to the start of the FLEHS campaign. From 2001 on, questions dealt with HBM and the meaning of results for policy translation. HBM was widely discussed in environmental health politics during the last decade. HBM not only constituted a platform for political inquiry; addressed authorities were able to fall back and respond on the base of installed HBM programs.

Secondly, the HBM program actively responded to specific (local) concerns and public perceptions. The HBM studies in industrial hot spots were always conducted in close collaboration with local stakeholders and residents. In each hot spot, a community advisory committee was established during the entire research period, consisting of a flexible group of about 30 persons representing societal gatekeepers as well as local authorities and industry. Members could give voluntary advice during meetings and majority voting was organised for crucial issues in the research design. This extensive community involvement was required to address the high concerns and trust deficit among local parties, often rooted in environmental justice claims of unequal distribution of burdens and benefits. By investing in a community-based participatory research approach, local stakeholders were involved in all aspects of the research process, which created openness towards issue framing and research design, and increased the local relevance and added value of the HBM study. An example might be the increasing involvement of industrial actors in the study and their additional engagement for local environmental care in line with the local policy action plan. Besides through local collaboration, concerns and preferences of citizens are also included in the HBM program through risk perception questionnaires that were supplemented in all HBM- surveys. These questions provided insight in the way participants perceive environmental health risks (air pollution being mentioned as one of the major concerns), showed that participants had more trust in scientific compared to political information providers and wanted to be informed and involved in the environmental health politics (Keune et al., 2008b).

Thirdly, by measuring chemicals and health effects directly into the human body, the HBM program made pollution personal and got citizens involved in scientific research. This provided opportunities for awareness raising, empowerment and support for policy action. Moreover, the integrated approach with markers of exposure to monitor body burden, also better matched the more holistic framing of local residents of the global quality of their direct living environment instead of a compartmentalized assessment of air, water, soil quality and food contamination and respective norms and policy competencies. The Flemish HBM program has a long tradition in dialogical risk communication and reporting back study results (Keune et al., 2008c). Participants not only receive their personal results, they also are informed first about the collective results for the region or complete age group, before any external communication or press release. Participant evaluation surveys conducted by the CEH showed that around 25% of respondents took personal initiatives as a result of their participation. It mainly concerns changing (locally grown) food patterns, conducting preventive health monitoring or mobilising social support for (local) policy actions. These findings were in line with the work of Altman et al. (2008) and Brody et al. (2007) that demonstrated how personal HBM data can shape participants' embodied health experiences.

4. Conclusion

The boundary work between different scientific disciplines and between scientists, policymakers and stakeholders proved to be very fruitful but should not be underestimated in complexity. It is a process of learning by doing, of exploring and crossing the borders of science and policy. There is no blueprint that fits all purposes for policy translation. In addition the process is intensive and time consuming.

Nevertheless, the gained insights and phased action plan showed that next to compliance with high scientific standards, results of the Flemish human biomonitoring campaign could be translated in targeted policy actions even for chemicals that have since long been regulated.

Acknowledgment

The FLEHS studies were commissioned, financed and steered by the Flemish Government (Department of Economics, Science and Innovation; Department of Environment, Nature and Energy and Flemish Agency for Care and Health).

Bibliography

Altman, R.G., Morello-Frosch, R., Brody, J.G., Rudel, R., Brown, P., Averick, M., 2008. Pollution comes home and gets personal: women's experience of household chemical exposure. J. Health Soc. Behav. 49, 417–435.

Baeyens, W., Vrijens, J., Gao, Y., Croes, K., Schoeters, G., Den Hond, E., Sioen, I., Bruckers, L., Nawrot, T., Nelen, V., Van Den Mieroop, E., Morrens, B., Loots, I., Van Larebeke, N., Leermakers, M., 2014. Trace metals in blood and urine of newborn/mother pairs, adolescents and adults of the Flemish population (2007–2011). Int. J. Hyg. Environ. Health 217, 878–890, http://dx.doi.org/10.1016/j.ijheh.2014.06.007.

Bloemen, K., Koppen, G., Govarts, E., Colles, A., Van Den Heuvel, R., Nelen, V., Witters, E., Desager, K., Schoeters, G., 2010. Application of non-invasive biomarkers in a birth cohort follow-up in relation to respiratory health outcome. Biomarkers 15, 583–593, http://dx.doi.org/10.3109/1354750X.504307.

Bressers, H., Klok, P., 1988. Fundamentals for a theory of policy instruments. Int. J. Soc. Econ. 15, 22–41, http://dx.doi.org/10.1108/eb014101.

Brody, J.G., Morello-Frosch, R., Brown, P., Rudel, R.A., Altman, R.G., Frye, M., Osimo, C.A., Pérez, C., Seryak, L.M., 2007. Improving disclosure and consent: "is it safe?": new ethics for reporting personal exposures to environmental chemicals. Am. J. Public Health 97, 1547–1554, http://dx.doi.org/10.2105/AJPH.2006.094813.

Choi, J., Mørck, T.A., Polcher, A., Knudsen, L.E., Joas, A., 2014. Review of the State of the Art of Human Biomonitoring for Chemical Substances and Its Application to Human Exposure Assessment for Food Safety. EFSA Support. Publ, 2015 EN-724324.

Crabbeí, P., Leroye, P., 2008. The Handbook of Environmental Policy Evaluation. Earthscan.

Croes, K., Baeyens, W., Bruckers, L., Den Hond, E., Koppen, G., Nelen, V., Van de Mieroop, E., Keune, H., Dhooge, W., Schoeters, G., Van Larebeke, N., 2009. Hormone levels and sexual development in Flemish adolescents residing in areas differing in pollution pressure. Int. J. Hyg. Environ. Health 212, 612–625, http://dx.doi.org/10.1016/j.ijheh.2009.05.002.

Croes, K., Colles, A., Koppen, G., Govarts, E., Bruckers, L., Van de Mieroop, E., Nelen, V., Covaci, A., Dirtu, A.C., Thomsen, C., Haug, L.S., Becher, G., Mampaey, M., Schoeters, G., Van Larebeke, N., Baeyens, W., 2012. Persistent organic pollutants (POPs) in human milk: a biomonitoring study in rural areas of Flanders (Belgium). Chemosphere 89, 988–994, http://dx.doi.org/10.1016/j.chemosphere.2012.06.058.

Croes, K., Den Hond, E., Bruckers, L., Loots, I., Morrens, B., Nelen, V., Colles, A., Schoeters, G., Sioen, I., Covaci, A., Vandermarken, T., Van Larebeke, N., Baeyens, W., 2014. Monitoring chlorinated persistent organic pollutants in adolescents in Flanders (Belgium): concentrations, trends and dose-effect relationships (FLEHS II). Environ. Int. 71, 20–28, http://dx.doi.org/10.1016/j.envint.2014.05.022.

Croes, K., Den Hond, E., Bruckers, L., Govarts, E., Schoeters, G., Covaci, A., Loots, I., Morrens, B., Nelen, V., Sioen, I., Van Larebeke, N., Baeyens, W., 2015. Endocrine actions of pesticides measured in the Flemish environment and health studies (FLEHS I and II). Environ. Sci. Pollut. Res. Int. 22, 14589–14599, http://dx.doi.org/10.1007/s11356-014-3437-z.

De Prins, S., Koppen, G., Jacobs, G., Dons, E., Van de Mieroop, E., Nelen, V., Fierens, F., Int Panis, L., De Boever, P., Cox, B., Nawrot, T.S., Schoeters, G., 2013. Influence of ambient air pollution on global DNA methylation in healthy adults: a seasonal follow-up. Environ. Int. 59, 418–424, http://dx.doi.org/10.1016/j.envint.2013.07.007.

De Prins, S., Dons, E., Van Poppel, M., Int Panis, L., Van de Mieroop, E., Nelen, V., Cox, B., Nawrot, T.S., Teughels, C., Schoeters, G., Koppen, G., 2014a. Airway oxidative stress and inflammation markers in exhaled breath from children are linked with exposure to black carbon. Environ. Int. 73, 440–446, http://dx.doi.org/10.1016/j.envint.2014.06.017.

De Prins, S., Marcucci, F., Sensi, L., Van de Mieroop, E., Nelen, V., Nawrot, T.S., Schoeters, G., Koppen, G., 2014b. Exhaled nitric oxide and nasal tryptase are associated with wheeze, rhinitis and nasal allergy in primary school children. Biomarkers 19, 481–487, http://dx.doi.org/10.3109/1354750X.937362.

Delvaux, I., Van Cauwenberghe, J., Den Hond, E., Schoeters, G., Govarts, E., Nelen, V., Baeyens, W., Van Larebeke, N., Sioen, I., 2014. Prenatal exposure to environmental contaminants and body composition at age 7–9 years. Environ. Res. 132, 24–32, http://dx.doi.org/10.1016/j.envres.2014.03.019.

Den Hond, E., Chovanova, H., Dumez, B., Keune, H., Schoeters, G., Teughels, C., Van Campenhout, K., 2009. Human biomonitoring in Flanders: some aspects related to study design, future, communication and ethics. Bull. Epidemiol. Hebd.

Den Hond, E., Dhooge, W., Bruckers, L., Schoeters, G., Nelen, V., van de Mieroop, E., Koppen, G., Bilau, M., Schroijen, C., Keune, H., Baeyens, W., van Larebeke, N., 2011. Internal exposure to pollutants and sexual maturation in Flemish adolescents. J. Expo. Sci. Environ. Epidemiol. 21, 224–233, http://dx.doi.org/10.1038/jes.2010.2.

Den Hond, E., Paulussen, M., Geens, T., Bruckers, L., Baeyens, W., David, F., Dumont, E., Loots, I., Morrens, B., de Bellevaux, B.N., Nelen, V., Schoeters, G., Van Larebeke, N., Covaci, A., 2013. Biomarkers of human exposure to personal care products: results from the Flemish Environment and Health Study (FLEHS 2007–2011). Sci. Total Environ. 463–464, 102–110, http://dx.doi.org/10.1016/j.scitotenv.2013.05.087.

Den Hond, E., Tournaye, H., De Sutter, P., Ombelet, W., Baeyens, W., Covaci, A., Cox, B., Nawrot, T.S., Van Larebeke, N., D'Hooghe, T., 2015. Human exposure to endocrine disrupting chemicals and fertility: a case-control study in male subfertility patients. Environ. Int. 84, 154–160, http://dx.doi.org/10.1016/j.envint.2015.07.017.

Dhooge, W., van Larebeke, N., Koppen, G., Nelen, V., Schoeters, G., Vlietinck, R., Kaufman, J.-M., Comhaire, F., Flemish Environment and Health Study Group, 2006. Serum dioxin-like activity is associated with reproductive parameters in young men from the general Flemish population. Environ. Health Perspect. 114, 1670–1676.

Dhooge, W., den Hond, E., Koppen, G., Bruckers, L., Nelen, V., van de Mieroop, E., Bilau, M., Croes, K., Baeyens, W., Schoeters, G., van Larebeke, N., 2011. Internal exposure to pollutants and sex hormone levels in Flemish male adolescents in a cross-sectional study: associations and dose-response relationships. J. Expo. Sci. Environ. Epidemiol. 21, 106–113, http://dx.doi.org/10.1038/jes.2009.63.

Franken, C., Govarts, E., Lambrechts, N., Koppen, G., Den Hond, E., Colles, A., Bruckers, L., Loots, I., Morrens, B., Nelen, V., Sioen, I., Croes, K., Baeyens, W., Van Larebeke, N., Schoeters, G., 2014. Environmental pollutants and DNA damage in adolescents of the 2nd Flemish Environment and Health Study (FLEHSII). Mutagenesis, 504–505.

Govarts, E., Nieuwenhuijsen, M., Schoeters, G., Ballester, F., Bloemen, K., de Boer, M., Chevrier, C., Eggesbø, M., Guxens, M., Krämer, U., Legler, J., Martínez, D., Palkovicova, L., Patelarou, E., Ranft, U., Rautio, A., Petersen, M.S., Slama, R., Stigum, H., Toft, G., Trnovec, T., Vandentorren, S., Weihe, P., Kuperus, N.W., Wilhelm, M., Wittsiepe, J., Bonde, J.P., OBELIX, ENRIECO, 2012. Birth weight and prenatal exposure to polychlorinated biphenyls (PCBs) and dichlorodiphenyldichloroethylene (DDE): a meta-analysis within 12 European Birth Cohorts. Environ. Health Perspect. 120, 162–170, http://dx.doi.org/10.1289/ehp.1103767.

Govarts, E., Casas, M., Schoeters, G., Eggesbø, G., Valvi, M., Nieuwenhuijsen, D., Bonde, M., ENRIECO, OBELIX, CHICOS Consortia, 2014. Prenatal PCB-153 exposure and decreased birth weight: the role of gestational weight gain. Environ. Health Perspect. 122, A89, http://dx.doi.org/10.1289/ehp.1307796.

Hänninen, O., Knol, A.B., Jantunen, M., Lim, T.-A., Conrad, A., Rappolder, M., Carrer, P., Fanetti, A.-C., Kim, R., Buekers, J., Torfs, R., Iavarone, I., Classen, T., Hornberg, C., Mekel, O.C.L., EBoDEWorkingGroup, 2014. Environmental burden of disease in Europe: assessing nine risk factors in six countries. Environ. Health Perspect. 122, 439–446, http://dx.doi.org/10.1289/ehp.1206154.

Iszatt, N., Stigum, H., Verner, M.-A., White, R.A., Govarts, E., Murinova, L.P., Schoeters, G., Trnovec, T., Legler, J., Pelé, F., Botton, J., Chevrier, C., Wittsiepe, J., Ranft, U., Vandentorren, S., Kasper-Sonnenberg, M., Klümper, C., Weisglas-Kuperus, N., Polder, A., Eggesbø, M., OBELIX, 2015. Prenatal and postnatal exposure to persistent organic pollutants and infant growth: a pooled analysis of seven european birth cohorts. Environ. Health Perspect. 123, 730–736, http://dx.doi.org/10.1289/ehp.1308005.

Ketelslegers, H.B., Gottschalk, R.W.H., Koppen, G., Schoeters, G., Baeyens, W.F., van Larebeke, N.A., van Delft, J.H.M., Kleinjans, J.C.S., 2008. Multiplex genotyping as a biomarker for susceptibility to carcinogenic exposure in the FLEHS biomonitoring study. Cancer Epidemiol. Biomark. Prev. 17, 1902–1912, http://dx.doi.org/10.1158/1055-9965, EPI-08-0045.

Keune, H., Koppen, G., Van Campenhout, K., 2008a. From environment and health data to policy-making: the case of DDE in Belgium. Int. J. Environ. Health 2, 209, http://dx.doi.org/10.1504/IJENVH.2008.020661.

Keune, H., Loots, I., Bruckers, L., Bilau, M., Koppen, G., Larebeke, N., Schoeters, G., Nelen, V., Baeyens, W., 2008b. Monitoring environment, health and perception. An experimental survey on health and environment in Flanders, Belgium. Int. J. Glob. Environ. Issues 8 (1-2), 90–111.

Keune, H., Morrens, B., Loots, I., 2008c. Risk communication and human biomonitoring: which practical lessons from the Belgian experience are of use for the EU perspective? Environ. Health 7 (Suppl. 1), S11, http://dx.doi.org/10.1186/1476-069X-7-S1-S11.

Keune, H., Morrens, B., Springael, J., Koppen, G., Colles, A., Loots, I., Van Campenhout, K., Chovanova, H., Bilau, M., Bruckers, L., Nelen, V., Baeyens, W., Van Larebeke, N., 2009. Policy interpretation of human biomonitoring research results in Belgium: priorities and complexity, politics and science. Environ. Policy Gov. 19, 115–129, http://dx.doi.org/10.1002/eet.500.

Kiciński, M., Viaene, M.K., Den Hond, E., Schoeters, G., Covaci, A., Dirtu, A.C., Nelen, V., Bruckers, L., Croes, K., Sioen, I., Baeyens, W., Van Larebeke, N., Nawrot, T.S., 2012. Neurobehavioral function and low-level exposure to brominated flame retardants in adolescents: a cross-sectional study. Environ. Health 11, 86, http://dx.doi.org/10.1186/1476-069X-11-86.

Koppen, G., Covaci, A., Van Cleuvenbergen, R., Schepens, P., Winneke, G., Nelen, V., van Larebeke, N., Vlietinck, R., Schoeters, G., 2002. Persistent organochlorine pollutants in human serum of 50–65 years old women in the Flanders Environmental and Health Study (FLEHS). Part 1: Concentrations and regional differences. Chemosphere 48, 811–825.

Koppen, G., Den Hond, E., Nelen, V., Van De Mieroop, E., Bruckers, L., Bilau, M., Keune, H., Van Larebeke, N., Covaci, A., Van De Weghe, H., Schroijen, C., Desager, K., Stalpaert, M., Baeyens, W., Schoeters, G., 2009. Organochlorine and heavy metals in newborns: results from the Flemish Environment and Health Survey (FLEHS 2002–2006). Environ. Int. 35, 1015–1022, http://dx.doi.org/10.1016/j.envint.2009.05.002.

Lagerqvist, A., Birgisdóttir, B.E., Halldorsson, T.I., Thomsen, C., Darnerud, P.O., Kotova, N. 2015. Human biomonitoring and policy making: Human biomonitoring as a tool in policy making towards consumer safety.

Leijs, M.M., Koppe, J.G., Olie, K., van Aalderen, W.M.C., de Voogt, P., ten Tusscher, G.W., 2009. Effects of dioxins, PCBs, and PBDEs on immunology and hematology in adolescents. Environ. Sci. Technol. 43, 7946–7951, http://dx.doi.org/10.1021/es901480f.

Lieshout, L., Desmedt, M., Roekens, E., Fré, R., De Cleuvenbergen, R., Van Wevers, M., 2001. Deposition of dioxins in Flanders (Belgium) and a proposition for guide values. Atmos. Environ. 35, 83–90, http://dx.doi.org/10.1016/S1352-2310(01)00094-2.

Maervoet, J., Vermeir, G., Covaci, A., Van Larebeke, N., Koppen, G., Schoeters, G., Nelen, V., Baeyens, W., Schepens, P., Viaene, M.K., 2007. Association of thyroid hormone concentrations with levels of organochlorine compounds in cord blood of neonates. Environ. Health Perspect. 115, 1780–1786, http://dx.doi.org/10.1289/ehp.10486.

Morrens, B., Bruckers, L., Den Hond, E., Nelen, V., Schoeters, G., Baeyens, W., Van Larebeke, N., Keune, H., Bilau, M., Loots, I., 2012. Social distribution of internal exposure to environmental pollution in Flemish adolescents. Int. J. Hyg. Environ. Health 215, 474–481, http://dx.doi.org/10.1016/j.ijheh.2011.10.008.

Pieters, N., Koppen, G., Smeets, K., Napierska, D., Plusquin, M., De Prins, S., Van De Weghe, H., Nelen, V., Cox, B., Cuypers, A., Hoet, P., Schoeters, G., Nawrot, T.S., 2013. Decreased mitochondrial DNA content in association with exposure to polycyclic aromatic hydrocarbons in house dust during wintertime: from a population enquiry to cell culture. PLoS One 8, e63208, http://dx.doi.org/10.1371/journal.pone.0063208.

Remy, S., Hambach, R., van Sprundel, M., Teughels, C., Nawrot, T.S., Buekers, J., Cornelis, C., Bruckers, L., Schoeters, G., n.d. Intelligence gain and societal cost savings attributable to environmental lead exposure reduction strategies since the year 2000 in a West-European region. JAMA Neurol.

Remy, S., Govarts, E., Bruckers, L., Paulussen, M., Wens, B., Den Hond, E., Nelen, V., Baeyens, W., van Larebeke, N., Loots, I., Sioen, I., Schoeters, G., 2014. Expression of the sFLT1 gene in cord blood cells is associated to maternal arsenic exposure and decreased birth weight. PLoS One 9, e92677, http://dx.doi.org/10.1371/journal.pone.0092677.

Renn, O., Rohrmann, B. (Eds.), 2000. Cross-Cultural Risk Perception. Springer US, Boston, MA, http://dx.doi.org/10.1007/978-1-4757-4891-8.

Schoeters, G., Colles, A., Den Hond, E., Croes, K., Vrijens, J., Baeyens, W., Nelen, V., Van De Mieroop, E., Covaci, A., Bruckers, L., Van Larebeke, N., Sioen, I., Morrens, B., Loots, I., 2011. The Flemish environment and health study (FLEHS): second survey (2007–2011): establishing reference values for biomarkers of exposure in the flemish population. Biomark. Hum. Biomonit. 1, 135–165, http://dx.doi.org/10.1039/9781849733373-00135.

Schoeters, G., Hond, E., Colles, Den, Loots, A., Morrens, I., Keune, B., Bruckers, H., Nawrot, L., Sioen, T., De Coster, I., Van Larebeke, S., Nelen, N., Van de Mieroop, V., Vrijens, E., Croes, J., Goeyens, K., Baeyens, K., 2012. Concept of the Flemish human biomonitoring programme. Int. J. Hyg. Environ. Health, http://dx.doi.org/10.1016/j.ijheh.2011.11.006.

Schoeters, G., n.d. Three cycles of HBM in Flanders – Time trends observed in the Flemish HBM programme FLEHS. Int. J. Hyg. Environ. Health.

Schroijen, C., Baeyens, W., Schoeters, G., Den Hond, E., Koppen, G., Bruckers, L., Nelen, V., Van De Mieroop, E., Bilau, M., Covaci, A., Keune, H., Loots, I., Kleinjans, J., Dhooge, W., Van Larebeke, N., 2008. Internal exposure to pollutants measured in blood and urine of Flemish adolescents in function of area of residence. Chemosphere 71, 1317–1325, http://dx.doi.org/10.1016/j.chemosphere.2007.11.053.

Sioen, I., Den Hond, E., Nelen, V., Van de Mieroop, E., Croes, K., Van Larebeke, N., Nawrot, T.S., Schoeters, G., 2013. Prenatal exposure to environmental contaminants and behavioural problems at age 7–8 years. Environ. Int. 59, 225–231.

Slovic, P., Finucane, M.L., Peters, E., MacGregor, D.G., 2004. Risk as analysis and risk as feelings: some thoughts about affect, reason, risk, and rationality. Risk Anal. 24, 311–322, http://dx.doi.org/10.1111/j.0272-4332.2004.00433.x.

Staessen, J.A., Nawrot, T., Den Hond, E., Thijs, L., Fagard, R., Hoppenbrouwers, K., Koppen, G., Nelen, V., Schoeters, G., Vanderschueren, D., Van Hecke, E., Verschaeve, L., Vlietinck, R., Roels, H., 2001. Renal function, cytogenetic measurements, and sexual development in adolescents in relation to environmental pollutants: a feasibility study of biomarkers. Lancet 357, 1660–1669, http://dx.doi.org/10.1016/S0140-6736(00)04822-4.

Stern, P.C., Fineberg, H.V. 1996. Understanding Risk: Informing Decisions in a Democratic Society 264, 0–309.

Vrijens, K., Winckelmans, E., Tsamou, M., Baeyens, W., De Boever, P., Jennen, D., De Kok, T., Den Hond, E., Lefebvre, W., Plusquin, M., Reynders, H., Schoeters, G., Van Larebeke, N., Vanpoucke, C., Kleinjans, J., Nawrot, T.S. Sex-specific associations between particulate matter exposure and gene expression in independent discovery and validation cohorts of middle-aged men and women. Environ. Health Perspect. (in press).

WHO Regional Office for Europe. 2015. Human biomonitoring: facts and figures. Copenhagen.

van Larebeke, N.A., Bracke, M.E., Nelen, V., Koppen, G., Schoeters, G., Van Loon, H., Vlietinck, R., 2006. Differences in tumor-associated protein levels among middle-age Flemish women in association with area of residence and exposure to pollutants. Environ. Health Perspect. 114, 887–892.

van Leeuwen, D.M., Gottschalk, R.W.H., Schoeters, G., van Larebeke, N.A., Nelen, V., Baeyens, W.F., Kleinjans, J.C.S., van Delft, J.H.M., 2008. Transcriptome analysis in peripheral blood of humans exposed to environmental carcinogens: a promising new biomarker in environmental health studies. Environ. Health Perspect. 116, 1519–1525, http://dx.doi.org/10.1289/ehp.11401.