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Regional Persistent Organic Pollutants' Environmental Impact Assessment and Control Model

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Abstract: *The sources of formation, environmental distribution and fate of persistent organic pollutants (POPs) are increasingly seen as topics to be addressed and solved at the global scale. Therefore, there are already two international agreements concerning persistent organic pollutants: the Protocol of 1998 to the 1979 Convention on the Long-Range Transboundary Air Pollution on Persistent Organic Pollutants (Aarhus Protocol); and the Stockholm Convention on Persistent Organic Pollutants. For the assessment of environmental pollution of POPs, for the risk assessment, for the evaluation of new pollutants as potential candidates to be included in the POPs list of the Stokholmo or/and Aarhus Protocol, a set of different models are developed or under development. Multimedia models help describe and understand environmental processes leading to global contamination through POPs and actual risk to the environment and human health. However, there is a lack of the tools based on a systematic and integrated approach to POPs management difficulties in the region.*

Keywords: *Persistent organic pollutants (POPs), Risk assessment, POPs management, POPs models.*

Introduction

Many chemicals benefit our daily lives and our health greatly. However, a lot of them are also extremely dangerous as some man-made chemicals do not disappear once they are released. For some time there has been a significant concern over the possible effects of persistent organic pollutants (POPs) on human and ecosystem health due to their following properties [5]:

- they are extremely persistent, i.e. under normal conditions they remain non-degraded in the environment for a long time;
- they possess bioaccumulative properties, as these pollutants are better soluble in fat than in water resulting in their accumulation in fatty tissues of humans and other living organisms;
- they can "travel" through the air, water, in migrating species (fish, birds); high concentrations of these substances are detected in the Arctic ecosystems, where these substances have never been produced or used;
- they remain toxic for a very long time, alongside with other properties inherent to the substances of this group, and their long-term toxicity poses an extremely great concern.

The investigation of environmental contamination by POPs consists of three main parts: determination of emission sources, sampling/measuring and modelling. Multimedia fate models are useful tools for investigating the environmental fate of POPs on a global scale

because they make it possible to combine processes in different environmental media and to analyse the interplay of these processes within a consistent mathematical framework. In addition to box models, atmospheric transport models with much higher spatial and temporal resolution are being used to investigate the environmental fate of POPs [6]. Multimedia models describing the global transport and fate of POPs basically serve two purposes [3]:

- comprehension of environmental processes leading to global contamination through POPs and development of indicators that would allow a clear definition of what constitutes a POP;
- assessment of the actual risk to environmental and human health requiring the determination of environmental concentrations based on reliable emission estimates in relation to toxicity thresholds.

The Stockholm Convention focuses on eliminating or reducing releases of 12 POPs. Article Seven of the Stockholm Convention states that each Party shall develop and endeavour to implement a National Implementation Plan (NIP) for the implementation of its obligations under this Convention. The United Nations Environment Programme together with the World Bank has developed a guidance document to assist countries in the process of developing a NIP [4]. This guidance is only one of possible variants to develop NIP meeting the requirements of Stockholm Convention. The developed guidance has been compiled taking into account the following essential issues considered of great importance to the successful development of a NIP [4]:

- NIP should be tailored to meet the needs of the country developing it;
- development of NIP should be built on existing work and assessments where they are available and should not "reinvent the wheel";
- NIP should not be developed in isolation but should take due account of the aims of sustainable development in the sense of socially, economically and environmentally appropriate policies and actions to maximize the overall benefits it produces.

POPs transport and behavior in the environment can be assessed by a set of developed POPs fate and transport multimedia models. These tools, however, are not fully sufficient to decide overall POPs priority problems in a country, to identify the best measures to minimize POPs emission to the environment or to manage the most dangerous POPs contaminated sites, waste, as it is required. In this regard, to make decisions a management model can be indispensable to assessing current situation on POPs within the country (systematic POPs management problems evaluation), to prioritizing identified problems according to the set criteria and to identifying integrated management measures for solving the prioritized problems. In principle, for prioritizing the identified problems and management measures, economic, social and environmental parameters should be integrated within the model.

Development of the Regional POPs Environmental Impact Assessment and Control Model

Due to a high level of risk of POPs, there is a high level of interest among governments, international organizations, environmental and industrial non-governmental organizations, and academia in both addressing POPs issues in a concerted way and searching for solutions to the problems caused by POPs. With the global Stockholm Convention in place, it can be moved forward to eliminate globally POPs, considered by some to be the most toxic man-made substances [2]. It is very important in each region (or country) to perform analysis of POPs life-cycle evaluating POPs formation, their distribution in the environment and products, identification of various decontamination possibilities and destruction technologies.

Therefore, to support decision making some tools are needed and researches in this regard are performed. Such tools should be based on a life-cycle approach, as all substances and all media have to be covered. Life-cycle of persistent organic pollutants includes all the stages of existence of these dangerous substances, from the origin through the usage to the final disposal. The developed Regional POPs Environmental Impact Assessment and Control Model can assess the POPs issues in a region and identify the most effective integrated management measures in regard to economic, environmental and social parameters. The principle and methodical schemes of the model are presented in Figs. 1 and 2.

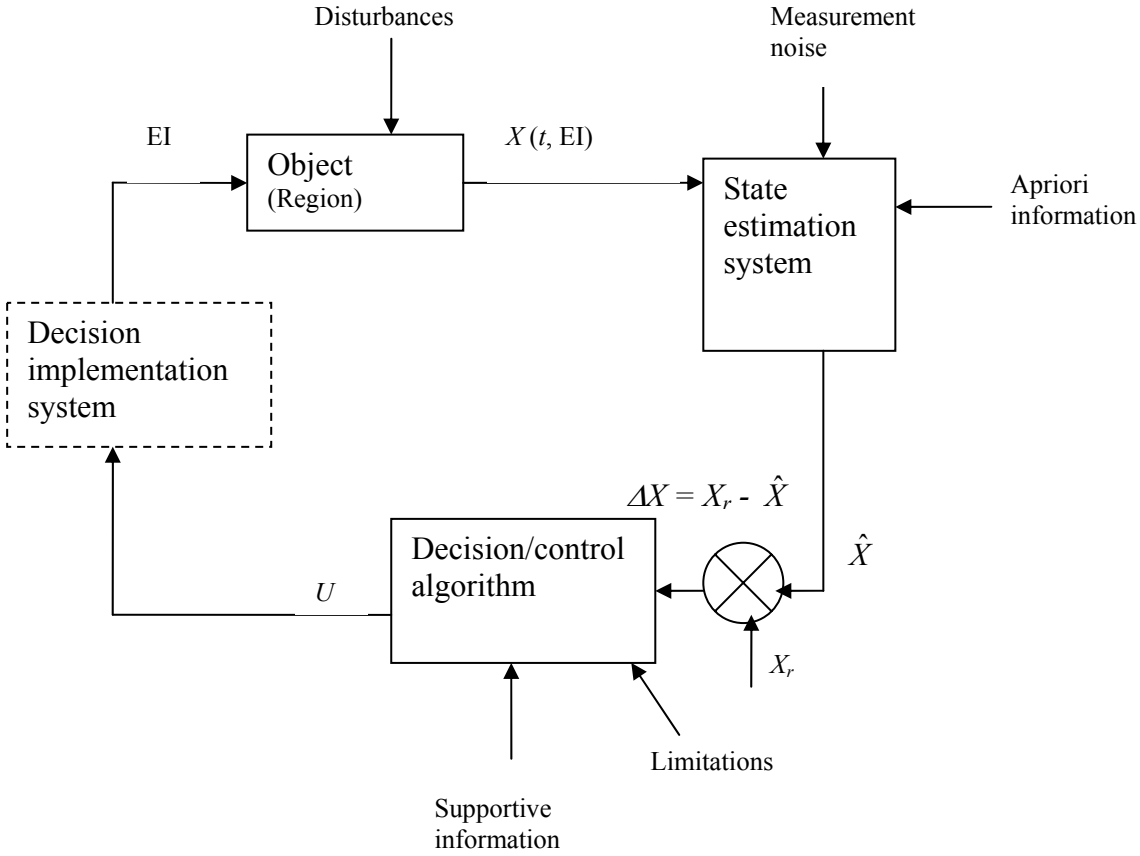

Fig. 1 Principal scheme of the Regional POPs Environmental Impact Assessment and Control Model

The object of a POPs management model is all the processes, products, media where POPs are present or which are the reason of POPs pollution. Model analyses all these processes, products and media, identifies POPs management problems within the region and selects POPs management and control measures to reduce the POPs impact on environment and human health. Model is based on both a systematic and integrated approach to POPs problems and measures to be implemented for the risk reduction in a region and on the assessment of POPs impact on the environment and human health and its minimization. The POPs impact function can be described by:

$$F(t) = \int_{t_0}^{t_g} EIdt \qquad (1)$$

where:
t_0 - start point of the assessment;

t_g - end point of the assessment;
EI - assessed POPs impact on the environment or/and human health at some time moment.

A developed model aims mainly at minimizing POPs impact on the environment and human health as much as possible, i.e. $F(t) \rightarrow \min$.

This developed regional POPs life-cycle assessment and control model can be applied to the regions of different size and type. Nevertheless, possible application of the model has some limitations, such as the boundaries of the region the model is applied to. The legal basis of a particular region limits the stages of POPs management problems and measures identification. The model can be applied to the 12 POPs which are regulated by the Stockholm Convention.

There is a set of different disturbances which can influence the object of the model. The implementation of the identified measures and its effectiveness depend on these disturbances. Possible disturbances can be split into the following groups:

- technical disturbances (e.g. onetime accidental discharge of dioxins into the environment);
- economical disturbances (e.g. lack of financial resources for the implementation of identified measures);
- human factors (e.g. low quality of the results of POPs laboratory analyses, lack of competence).

The state estimation system evaluates whether the set aims X are reached or not. X (aims, output variables) can be qualitative (e.g. development of a pollution prevention system) or quantitative (e.g. concentrations of POPs in some medium), but it should be expressed in quantifiable units. Depending on the given state estimation system reply, decisions to minimize POPs impact on the environment and human health are taken. These decisions – impacts on the system of object (U) - called as measures have an impact on the system of the object aspiring to reach aims (X). After implementation of the identified measures impacts (EI) are evaluated and the information of current POPs situation in the country is obtained at a new level. Looking from the methodical point of view there are four main steps within the model (Fig. 2):

- assessment of the POPs management situation in a region (including assessment of POPs distribution in the environment, wastes, products and POPs pollution sources);
- identification and prioritization of POPs management problems in a region;
- development of integrated measures for the solution of prioritized problems and POPs risk reduction;
- evaluation of the effectiveness of chosen measures in regard with the identified indicators.

The first step of the developed model is assessment of POPs current situation in a region. The principal aim of the model being the reduction in the POPs risk in a region, its application results in a developed actions plan. Therefore, the basic trends of the situation analysis are to be identified. Depending on produced, used or released POPs to the environment in a region, the primary attention should be given to the important substances, media and products.

With a view to preparing an effective POPs actions plan, the most important problems are to be identified. It can be done at the problems prioritization stage. It is a needful stage, as the POPs group consists of quite different substances widely used for very different applications

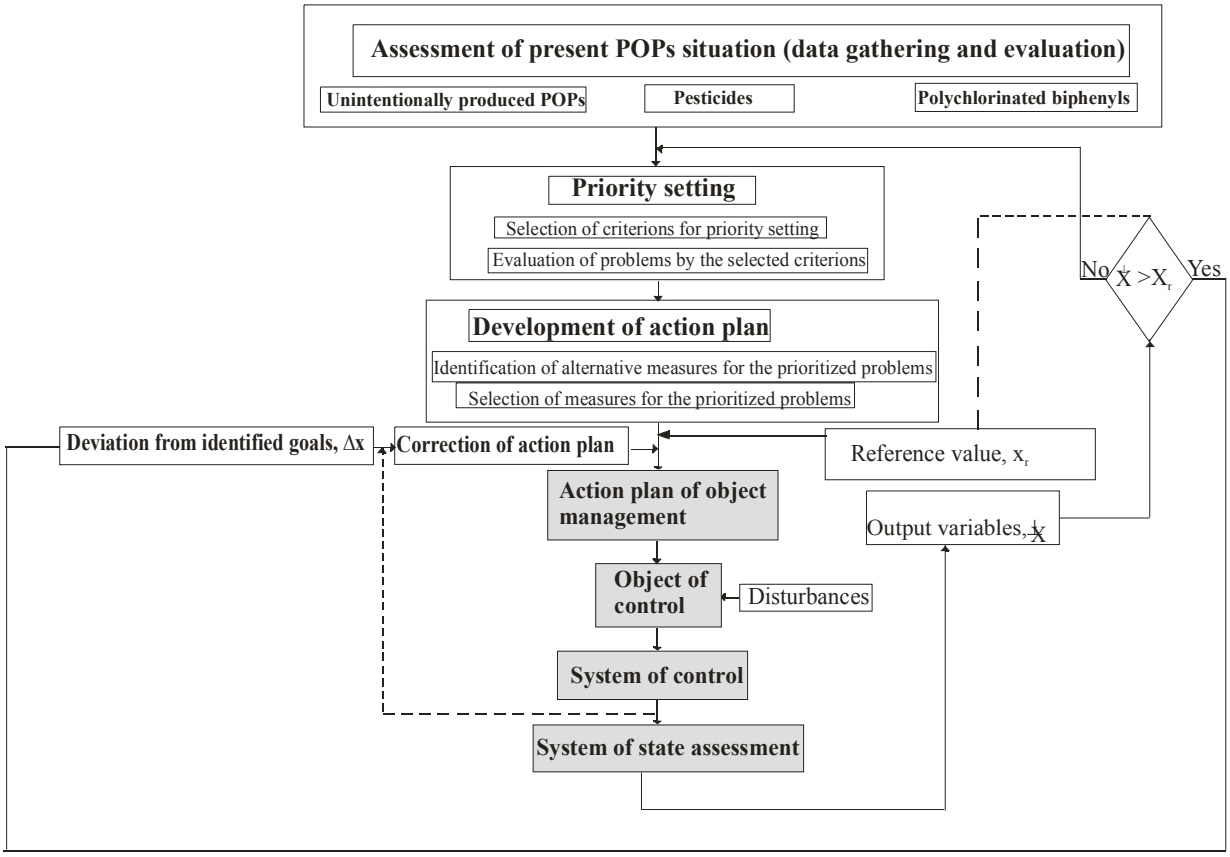

Fig. 2. Algorithm of the Regional POPs Environmental Impact Assessment and Control Model [1]

and related to different environmental issues (e.g. waste management, hazardous chemicals management, air pollution). Due to these reasons, the solution of all identified problems in a region would require appropriate technical and human capacity, financial resources and effective legal basis, all of which are practically difficult to be implemented. Identified problems should be solved progressively. Considering the importance of the problem to the region, its solution is to be ranged in time and matched to the technical and financial potentiality of the region.

Arranging the procedure of prioritization of the problems, the factors which will be assessed are to be identified. Each problem is to be evaluated against the chosen factors and according to the obtained points the problems will be ranged.

$$T = (Aa+Bb+Cc+Dd+Ff)/100 \quad (2)$$

where:

T	- total score;
A, B, C, D, F	- weight of each factor for a certain problem ($A + B + C + D + F = 100\%$);
a, b, c, d, f	- value of each factor for a certain problem (from 1 to 10);
A, a	- coefficients evaluating legal requirements;
B, b	- coefficients evaluating an impact on humans;
C, c	- coefficients evaluating an impact on the environment;
D, d	- coefficients evaluating an economic problem impact on the region;
F, f	- coefficients evaluating a social problem impact on the region.

Technical, financial, awareness raising, legal and other possible measures are to be chosen to solve the POPs management problems identified during the situation analysis stage. The selection of appropriate measures can be limited by a number of different factors – legal requirements of a region, financial possibilities, technical capacity and the others. All possible options to solve an identified problem are to be evaluated. Implementation of all options should result in the achievement of the identified aims (qualitative/quantitative, short/long term). Compatibility of chosen options with the other measures is also to be reckoned.

Considering singularity of the region, each factor evaluating the option is given the value from 1 to 10. The more the option is friendly to the environment of the region, the more it is acceptable economically and socially, the more points it will receive. The option having collected the highest sum of points from a set of options to do the problem will be chosen for its solution.

$$T_1 = \sum_{i=1}^{n} a_i + \sum_{i=1}^{n} b_i + \sum_{i=1}^{n} c_i \quad (3)$$

where:
T_1 - total score;
a_i, b_i, c_i - value of each factor for a certain problem (from 1 to 10), when i = 1, 2, 3,..., n;
a - environmental factors;
b - social factors;
c - economic factors.

The POPs action plan, like all action plans is to be accompanied by a proper follow-up in order to gauge the effectiveness of the measures. After the implementation of the measures (or at some stage of implementation of the measures), the identified aims (qualitative/quantitative, short/long term) are to be evaluated in order to find out whether they were achieved. For example, if the aim is a certain concentration of the substance in some environmental media, the desirable substance concentration will be compared to the measured one after the implementation of that measure.

$$\Delta X = X_r - \hat{X} \quad (4)$$

where:
X_r - reference value,
$\hat{X}$ - output variables.

When $\Delta X < 0$, then $\hat{X} > X_r$ and the measure(s) is (are) to be corrected – the action plan is to be renewed. In other cases (when the prioritized problems were solved and identified aims were achieved) the remaining problems are prioritized again and the measures for them are chosen – a cyclic approach to the model operation.

Application of the Regional POPs Environmental Impact Assessment and Control Model

The developed model can be used for the decision making in POPs regional action plan development and risk reduction in a region. This model is based on a systematic assessment of POPs management problems and a distribution situation in a region for the choice of optimal measures. A step of effectiveness evaluation of implemented measures would render

possibilities to evaluate an impact of the measures either on the identified POPs management problems or on POPs distribution levels in a country and to make corrections in an action plan.

The Regional POPs Environmental Impact Assessment and Control Model in Lithuania was used for preparing the POPs action plan. During the situation analysis stage the POPs management problems were identified. Principally they were related to the management of old waste stockpiles, to environmental pollution and shortage of laboratory capacities to perform POPs analyses.

During the priority setting stage the identified problems of each group of substances were evaluated separately (coefficients evaluating different impacts according to Eq. (2) were chosen separately for each group of POPs substances). The results of prioritization of POPs management problems in Lithuania are presented in Table 1.

Table 1. POPs prioritized problems in Lithuania

POPs group of substances	Identified problem of the POPs management in Lithuania	Total value	Aims	
			Short-term (till 2011)	Long-term (2011-2015)
POP pesticides	Evaluation and management of the sites polluted by POPs pesticides	**3.25**	Perform analyses of the polluted sites	Manage all identified polluted sites
PCBs	Identification and management of equipment contaminated by PCBs	**7.25**	Collect, store, decontaminate and/or dispose of all PCB containing oil and equipment	
Dioxins	An operating public municipal waste management system (public municipal waste collection system) does not cover the entire Lithuanian territory	**8.625**	To ensure the accessibility to an operating public municipal waste management system to all inhabitants	To implement EU requirements on municipal waste collection and recovery
	Improper management of medical wastes	**8.375**	To develop the management system of medical wastes	To reduce the emission of dioxins from the medical waste incineration to 50 % of the level in 2000

For each prioritized problem some feasible actions were identified. Technical, legal, financial options were evaluated by chosen factors and the best options were suggested to be included into the POPs action plan (Table 2).

Table 2. Measures to solve the prioritized problems

Identified problem of the POPs management in Lithuania	**Measures**
Evaluation and management of the sites polluted by POPs pesticides	To develop, to approve and to implement the management program of pesticide waste storage sites and the sites polluted with pesticides waste
Identification and management of polluted equipment	To transport abroad for the final disposal of oil and equipment containing PCB
An operating public municipal waste management system does not cover the entire Lithuanian territory	To improve legal regulation of the development of the public municipal waste management system and control of implementation of this development
Improper management of medical wastes	To develop, to approve and to implement the management program of medical wastes

The evaluation of the effective implementation of the measures is to be performed against the identified aims after the implementation of the measures (or their partly implementation). As the POPs risk reduction is a rather slow process, the first effectiveness evaluation stage is planned for the year 2011, for this reason the prediction of the effectiveness of the chosen measures may be inaccurate. However, it can be noticed that all identified measures were included in the National Implementation Plan on POPs of Lithuania which was endorsed by the Government of Lithuania. Implementation of these measures has been started and it can be concluded that some improvements of the POPs management situation in Lithuania can be observed. Proper incineration of medical waste decreases the release of dioxins and furans to the environment by 75 times. 176 t of PCBs contaminated equipment and oils were given for the proper treatment to the hazardous waste treatment companies. Proper incineration of PCBs containing waste results in release of dioxins and furans to the environment which is 3,500 times less than the one from the improper treatment. Preparation of activities for the evaluation and management of the sites polluted by POPs pesticides have also been started.

Conclusions

1. The developed Regional POPs Environmental Impact Assessment and Control Model aiming at the POPs risk reduction in a region can be applied to the regions of different size and situation (economical, geographical, legal). POPs life-cycle management model provides possibilities for systematic evaluation of POPs management problems in a region, for prioritization of identified problems according to the set criteria and for identification of integrated management measures to solve these problems. To prioritize the identified problems and management measures, economical, social and environmental parameters are integrated within the model.
2. The developed Regional POPs Environmental Impact Assessment and Control Model has been applied in Lithuania. Following the application of this model, the POPs management problems in Lithuania have been identified and prioritized against the chosen factors.
3. In the period of the model application in Lithuania, technical, legal, financial measures to solve the prioritized problems have been identified and evaluated against the chosen factors and the most effective ones have been taken. Following the implementation of

these measures, proper incineration of medical waste and PCBs containing waste, as well as development of a municipal waste treatment system have decreased the release of dioxins and furans to the environment. Preparation of activities for the evaluation and management of the sites polluted by POPs pesticides have also been started.

References

1. Česnaitis R. (2007). Regional POPs Life-Cycle Management Model // Environmental Research, Engineering and Management, ISSN 1392-1649, 3(41), 25-32.
2. Fiedler H. (2003). Introduction, The Handbook of Environmental Chemistry Vol. 3, Part O. Persistent Organic Pollutants.
3. Scheringer M., F. Wania (2003). Multimedia Models of Global Transport and Fate of Persistent Organic Pollutants, The Handbook of Environmental Chemistry Vol. 3, Part O. Persistent Organic Pollutants, 237-269.
4. UNEP, The World Bank Group (Revised December 2004). Interim Guidance for Developing a National Implementation Plan for the Stockholm Convention, Revised.
5. Wahlstrom B. A. (2003). Criteria for Additional POPs, The Handbook of Environmental Chemistry Vol. 3, Part O. Persistent Organic Pollutants, 31-45.
6. Wania F., D. Mackay (1999). The Evolution of Mass Balance Models of Persistent Organic Pollutant Fate in the Environment, Environmental Pollution, 100, 223-240.

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