BENEFITS AND TRADE-OFFS BETWEEN REDUCTIONS OF GREENHOUSE GASES AND UNINTENTIONALLY PRODUCED PERSISTENT ORGANIC POLLUTANTS

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Abstract

The goal of this paper is to identify opportunities and trade-offs in the management of two environmental problems: greenhouse gases (GHG) and persistent organic pollutants (POPs). For POPs management in this paper, the application of state-of-the-art technology and best practices as described in the Stockholm Convention Best Available Techniques - Best Environmental Practices Guidance Document is assumed. The impact of these techniques on greenhouse gas emissions from these processes is assessed in a qualitative way. As far as greenhouse gas mitigation measures are currently applied in the source categories listed in Annex C of the Stockholm Convention, their potential impact on POPs emissions is reviewed as well. Having in mind the limitations of such a screening process the authors suggest three guiding principles for first-order analysis. These principles summarise identified trends such as benefits from improved combustion practices and from efficiency improvements. Nevertheless, the complexity of certain assessments, in particular in the field of waste management, is emphasised as well as the need of case specific analyses that take into account life cycle considerations.

Introduction

Annex C of the Stockholm Convention lists twenty source categories having significant impact on the formation and release of unintentionally produced persistent organic pollutants (uPOPs) to the environment, including PCDD/PCDF, polychlorinated biphenyls (PCBs) and hexachlorobenzene (HCB). uPOPs are formed and released from thermal processes involving organic matter and chlorine as a result of incomplete combustion or chemical reactions[1]. At the same time combustion processes are the main source of greenhouse gas emissions (GHG) in particular of CO_2. The Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) emphasized a need for capturing synergies and avoiding trade-offs when addressing greenhouse gases (GHG) mitigation and air pollution control. The efficiency of a framework depends on the choice and design of the policy instruments and their integration. Air pollutants and GHGs are often emitted by the same sources, and, therefore, a single set of technologies or policy measures (an integrated approach) has co-benefits for emission reduction. However, there are situations when energy efficiency improvements may have limited or negative impact on the release of air pollutants (trade-offs)[2]. There is large uncertainty in the scientific literature and among policy makers about the possible benefits and trade-offs between energy conservation practices and releases of PCDD/PCDF and other air-born PTS. This analysis on behalf of the Scientific and Technical Advisory Panel (STAP) of the Global Environment Facility (GEF) is meant provide some qualitative guidance concerning the benefits and trade-offs uncertainty.

Methodology for identifying benefits and trade-offs of control measures

The approach chosen here is a qualitative one aiming at the identification of potential benefits and trade-offs of greenhouse gas mitigation measures and/or uPOPs control measures applied to the source categories of the Stockholm Convention. In a first step those sources with a high relevance for both GHG and uPOPs emissions have been identified. This screening process resulted in the list of source categories given below. The categories “destruction of animal carcasses”, “textile and leather dyeing and finishing”, “shredder plants for the treatment of end of life vehicles” and “waste oil refineries“ have been excluded from the subsequent analysis. Furthermore, cross-cutting considerations have been included covering aspects which apply to more than one source category such as waste management issues and end-of-pipe flue gas treatment.

Table 1: Source categories of the Stockholm Convention analysed for benefits and trade-offs of control measures

Annex C source categories of the Stockholm Convention	
Part II	(a) waste incinerators
	(b) cement kilns firing hazardous waste
	(c) production of pulp using elemental chlorine or chemicals generating elemental chlorine for bleaching
	(d) (i) secondary copper production
	(d) (ii) sinter plants in the iron and steel industry
	(d) (iii) secondary aluminum production
	(d) (iv) secondary zinc production
Part III	(a) open burning of waste
	(b) thermal processes in the metallurgical industry not mentioned in part II: - Secondary copper, aluminum, zinc and lead production - Sinter plants in the iron and steel industry - Primary aluminum production, magnesium production, primary base metals smelting
	(c) residential combustion sources
	(d) fossil fuel-fired utility and industrial boilers
	(e) firing installations for wood and other biomass fuels
	(f) specific chemical production processes releasing uPOPs
	(g) crematoria
	(h) motor vehicles
	(l) smoldering of copper cables

For the same list of source categories the Guidelines on Best Available Techniques and Best Environmental Practices (BAT/BEP)[3] have been developed and published to facilitate the implementation of the respective requirements of the Stockholm Convention. On the basis of these guidelines the authors screened the listed sources with regard to two basic questions:

- What are the relevant measures for GHG mitigation in a given category and to what extent do these measures impact uPOPs emissions of that source?
- Is there an impact of the application of BAT/BEP control measures on GHG emissions from that source?

In many cases qualitative trends could be identified. Nevertheless, quantification in terms of changes of the actual emission load was beyond the scope of the study. In some areas indirect GHG emissions need to be taken into account when control measures or alternative processes are discussed. In these cases no general trend could be identified and the need for case specific detailed investigations such as Life Cycle Assessment was emphasised. The conclusions are highlighting those control measures with clear synergies for both GHG and uPOPs emissions. An outline of results for selected sectors and for certain cross-cutting considerations is given below.

Results for selected source categories

Fossil fuel fired utility and industrial boilers are one of the largest sources of GHG emissions worldwide. Even though the amounts of POPs emitted are small compared to other sources and the primary purpose of correct application of BAT/BEP is the reduction of SO_2, NO_x, particulates and heavy metals, correct design and operation of proper flue gas cleaning equipment will also further reduce the emissions of POPs. Best environmental practices (BEP) combined with necessary secondary best available techniques (BAT) flue gas cleaning systems (ESP or baghouses for particulate control, SCR for NO_x-control and FGD for SO_2 control) further reduce the emissions of uPOPs. Additionally, improvements in power generation efficiency reduce the amount of fossil fuel consumed per unit energy generated leading to proportional reductions of GHG and POPs emissions.

Combustion of fossil fuels in households is one of the largest sources of CO_2 in the world (21% of total CO_2 emissions in 2005). In the **residential combustion sector** complete, efficient combustion of clean, chemically untreated fuels for cooking and heating is of primary importance for reducing the formation and release of POPs. BAT and BEP for residential combustion include ensuring separation of household waste from fuel to avoid burning of such waste in cooking and heating appliances. GHG can be reduced in the residential sector by increasing the share of virgin biomass fuel (CO_2-neutral by policy) and by increasing energy efficiency and reductions on the demand side. Coal and biomass burning stoves dominate energy supply for households in rural areas of developing countries. Improved stoves can save from 10 to 50% of fuel consumption for the same cooking service at the same time reducing indoor air pollution. In industrialized countries there is a risk of increasing POPs releases in the case of a switch from efficient liquid or gaseous fossil fuels to solid or biomass fuels. uPOPs are best avoided by appropriate technology, that is, stoves and boilers with automatic fuel supply and standardized or at least dry and homogenized biomass fuels.

uPOPs can also be generated in non-residential (large scale) firing **installations for wood and other biomass fuels**, particularly when using non-virgin biomass. Best available techniques to reduce PCDD/F emissions include the control of fuel quality (including exclusion of treated woods and non-virgin biomass and other waste), optimized combustion technology, optimized air supply, mixing and residence time as well as optimized plant operation. Combustion of virgin biomass is considered CO_2-neutral by many government policies. However, combustion of non-virgin biomass or non-biomass combustible material, results in the emission of additional GHGs, mostly in form of CO_2. Other greenhouse gases may be formed through incomplete combustion (nitrous oxide, methane). In general, fuel efficiency and conservation can reduce GHG emissions when combustion is used to generate electricity particularly via combined heat and power approaches.

Cement production represented about 70 – 80% of the energy use in the non-metallic minerals sub-sector, consuming 8.2 exajoules (EJ) of energy per year (7% of the total industrial fuel use)[4]. BAT and BEP to avoid POPs emissions from cement kiln operation include comprehensive primary measures such as fuel quality control, process control and rapid cooling of flue gases. End-of-pipe measures are mainly installed to reduce particulate emissions, SO_2 or NO_x and control of POPs emissions is a welcome side effect of such measures. Main options for the reduction of greenhouse gas emissions include technology improvements, clinker substitutes for cement production and the use of certain types of waste as a fuel Technology improvements with an increase of energy efficiency of the process show the highest GHG emission reduction potential and a clear co-benefit of GHG and POPs emission reduction. Depending on the type of waste, its use as a fuel can create adverse effects. The use of such fuels requires careful input and process control to avoid an increase of POPs and/or heavy metals emissions. The benefit of GHG emission reduction through substitution of fossil fuels needs to be assessed on a site specific basis.

Secondary steel, copper, aluminum, zinc and lead production are significant sources of uPOPs. However, secondary production of metals generally consumes significantly less energy than primary production; thus, metal recycling has a significant positive impact on GHG, compared with metal production from ores. BAT/BEP measures to reduce uPOPs emissions can generate low GHG impacts which are largely outweighed by the benefits of very high positive impacts in terms of uPOPs minimization.

Smoldering of copper cables should be eliminated; such elimination is a significant reduction in POPs generation and also results in reduced GHG if waste material is not combusted.

Primary metal production (from ores) is very energy intensive. Total final energy use in iron and steel industries world-wide was 21.4 EJ in 2004. Half of the energy consumed in the non-ferrous metal production sector is for primary aluminum production. Aluminum production from ore used 5.3 EJ of primary energy in 2004, followed by primary production of copper (1.3 EJ)[4]. Hence the impact of BAT/BEP measures on GHG emissions are considered to be neutral to low, for sinter plants in the iron and steel industry and for non-ferrous metals primary production. In the specific case of alternative processes as proposed in the BAT-BEP guidance document, these are likely to generate significant (positive or negative) impacts in terms of CO_2 emissions. These impacts should be assessed on a plant-by-plant basis.

The pulp, paper and printing industry sector is the fourth largest industrial consumer of energy, consuming globally 5.7% of the total industrial energy use or 6.45 EJ[4]. BAT for elimination of **production of pulp using elemental chlorine** is described as Elemental Chlorine Free or Totally Chlorine Free bleaching. The two are distinguished by the use of chlorine dioxide as bleaching agent in the former along with various other steps which may also use oxygen, hydrogen peroxide and ozone. ClO_2 is derived from sodium chlorate which requires more energy to produce than elemental chlorine or sodium hypochlorite; ozone is generated electrochemically from oxygen. The bleaching process is a small component of energy use in making pulp and paper. BAT application may carry a 1% penalty in GHG in exchange for virtual elimination of POPs in the process, but the difference between prior practice and BAT is very small.

BAT for **specific chemical production processes** involves purification of intended product and isolation of POPs in a waste stream that are to be destroyed by hazardous waste incineration. When integrated into a manufacturing facility, waste process heat can be used for the purification step and the inherent fuel value of the waste sustains its combustion. Slightly increased GHG emissions (as CO_2) result from combustion of 1-2% waste from the processes; process energy use - with or without waste destruction - is a much larger source.

Waste incineration as part of an environmental sound waste management system is an accepted technique for minimizing the impacts on the environment of the whole system – provided that BAT and BEP is effectively implemented. BAT and BEP for the process includes the implementation of operational (primary) measures, effective end-of-pipe techniques and appropriate treatment/disposal options for solid residues (esp. for fly ash). Primary measures both reduce GHG and POPs emissions either by the prevention of POPs formation or by providing the basis for high energy efficiency and reduced process demand of energy. In addition, the application of BAT and BEP helps to optimize the process by increasing the efficiency of end-of-pipe techniques over the life-time of the plant. A very limited number of end-of-pipe techniques exist for the sole reduction of POPs emissions. The majority of these techniques have the co-benefit of minimizing the emissions of a variety of pollutants (including particles, NO_x, SO_2, HCl and (heavy) metals). The operation of end-of-pipe techniques is in general accompanied by energy consumption and an overall increase of GHG emissions. However, from a total perspective the benefits in terms of energy efficiency and emission reduction (including GHG) achieved by BAT and BEP outweighs this drawback of energy consumption by far.

Whereas in the past, important goals of **waste management** were the reduction of the mass of waste and its hazardous potential, now in addition to BAT and BEP also the reduction of GHG emissions becomes more important. To achieve this, every waste management activity should be optimized concerning energy consumption and emissions of CO_2 and CH_4. In addition, interrelations between different waste treatment and disposal options should be investigated on a regional, national or international level.

Treatment and disposal of waste result in emissions of GHGs. Direct CO_2 emissions are caused either by (co-) incineration, gasification or pyrolysis of (parts of) the waste. Other incineration-related GHGs are methane and N_2O. Methane and CO_2 may be emitted by decomposition of waste during storage of waste. Disposal in landfills leads to emissions of CO_2 and methane. Indirect emissions may be caused by the energy consumption of the individual treatment and disposal activities. The relevant POPs formation mechanism is by thermal processes only. Other treatment and disposal operations may lead to the release of POPs which are introduced into the system by chemicals or as impurities.

The Stockholm Convention BAT/BEP Guidelines[3] give reference to the Basel Convention on the Control of Transboundary Movement of Hazardous Wastes and Their Disposal and especially outlines some important principles to be considered in the development of waste and hazardous waste strategies, such as the reduction principle and the integrated life cycle principle. Waste disposal techniques other than BAT and BEP include open burning of waste and dumping of waste on sites or landfills, which are not suitable for this process or which lack the simplest engineering provisions (such as control of waste input, good lining, coverage of surface or capture and incineration of landfill gas). Open burning of landfill sites causes additional adverse impacts on the environment. These processes are not in line with the provisions of BAT and BEP and cause high emissions of GHG (CO_2, methane), POPs and (heavy) metals into the air and water.

Implementation of BAT aims at the minimization of impacts on the environment as a whole which means that a shift of pollution between the various environmental media – air, water, soil, including waste management considerations – should be prevented and **cross-media aspects** (e.g. energy consumption, residue generation, POPs formation) considered on a general level. Reducing emissions such as particulates, NO_x, SO_2, HCl, HF, (heavy) metals and POPs by **end-of-pipe techniques** leads to an increase of the energy consumption of every combustion installation. Energy is in general used in the form of power, heat or steam. In some plants CO_2 is directly emitted as a result of the operation of burners, which may be required for the reheating of flue gas before treatment and release (e.g. SCR) or by operation of afterburners. (Offsite) thermal treatment of bottom ash, slag and fly ash will also result in emissions of CO_2. Treatment of waste water from incineration adds to the energy consumption of an incineration plant thus increasing its (direct or indirect) GHG emissions.
Most process integrated and end-of-pipe techniques offer the possibility for the co-removal of many pollutants, e.g. by separation of particles using electrostatic precipitators (ESP) or bag filters, (heavy) metals and particle bound POPs are removed, too. As a rule, the energy demand of flue gas cleaning systems is in the range of 1 - 5% of the energy output of a combustion plant. This number can be higher in the case of waste incineration plants and some specific industrial production plants. The electricity demand of stand-alone techniques for POPs removal is in the range of an electrostatic precipitator or a bag filter. Thus, it can be concluded that the environmental benefit of these end-of-pipe techniques is in general unquestionable high. However, detailed analyses with respect to GHG emissions have to be done on a case by case basis considering various options for flue gas cleaning.

Conclusions
Since by definition all GHG emissions are to the earth's atmosphere, this analysis mainly centered on air emissions of uPOPs; however, there are many Stockholm Annex C processes with significant potential for direct uPOPs emissions to water (pulp and paper) and land (ash and residue from various processes). Additionally, utilization of Stockholm BAT-BEP Guidance, particularly for large combustion sources, has an impact—generally salutary--on other pollutants; for example, particulates, heavy metals including mercury, SO_x, NO_x and CO. There are clear benefits to reducing air emissions of these pollutants in particular with regard to human health effects; on the other hand, this study did not specifically evaluate the impacts of each of these in addition to consideration of uPOPs and GHG.

For certain categories, a simple change in type of fuel - for example, from coal to natural gas - can have a positive effect on GHG and potentially uPOPs emissions with little impact on the underlying process. However, in other cases of fuel or technology switch, for example, changing motor transportation from gasoline or diesel fuel to electricity from the grid, the analysis is not so clear. This is especially true when differences in efficiencies and types of combustion, as well as necessary changes in engines, fuel delivery systems and emissions from all sources in the process chain are taken into account. Here, more comprehensive life cycle considerations are necessary which are beyond the scope of this study.

In some cases, elimination of a process such as open burning of waste can seemingly eliminate generation of GHG such as CO_2 as well as uPOPs. However the need to deal with the waste by some means remains. Landfilling generates methane, a more potent GHG than CO_2. If this methane is fully captured and combusted, there is less emitted CO_2 than if all the waste were burned, but there is some potential for creating uPOPs during that combustion (in addition there is still a certain rate of methane slip). Or, a modern, BAT incinerator could be constructed and uPOPs emissions would be greatly curtailed; however, this expensive solution must be operated carefully and will still result in GHG emissions. These questions need to be considered within an overall waste management program, which needs to take into account local conditions, economic viability and social aspects.

Thus, a relatively simple question regarding synergies and tradeoffs can quickly evolve into the need for very complex analyses on a case by case basis. Fortunately, there are some simplifying approaches that can and should be utilized for a first cut estimate.

Even the substitution of other non-elemental-chlorine bleaching techniques for chlorine bleaching of pulp or segregation and destruction of uPOPs from chemical production, while possessing major potential for reduction of uPOPs, engender little differential impact on global GHG when those specific operations alone are considered, not the larger energy consumption of the total pulp and paper or total chemical sector.

In general, this results in the consideration of Annex C sources that involve significant combustion for heat or energy generation or destruction of waste. Here the authors suggest three guiding principles for first-order analysis:

1. Good combustion practices will tend to reduce generation of uPOPs, even if they are not totally mitigated.

2. Maximizing thermal efficiency will reduce GHG emissions as well as, potentially, uPOPs by reducing the overall activity leading to both. This includes improved fuel efficiency through combined heat and power strategies or higher temperature/efficiency processes e.g., in the electrical energy generating sector. Maximizing carbon efficiency is analogous, such as a simple substitution of natural gas for coal. Efficiency improvements on the demand side also tend to be beneficial as they reduce the emission generating activity as such (e.g. insulation of buildings).

3. Utilization of specific BAT and BEP for combustion or thermal processing will reduce both generation and emission of uPOPs across a wide range of combustion sources from biomass to iron sintering to cement manufacture. In some cases there will also be synergistic benefits with respect to reduction in other pollutants or increased thermal efficiency. The utilization of specific BAT BEP end-of-pipe technology necessary for mitigating other air pollutants, such as particulates, heavy metals including mercury, SOx and NOx, will generally be beneficial for reducing uPOPs emissions even though the power requirements of these end-of-pipe-techniques inevitably cause some small amounts of additional GHG emissions.

However, there are probably no simplifying assumptions beyond these that will help the analysis of complex fuel switching proposals or complex waste hierarchy and treatment alternatives. These problems could benefit from further work that takes into account life cycle considerations. Such analysis may add further clarity for specific and possibly generic situations.

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