ŚRODKOWO-POMORSKIE TOWARZYSTWO NAUKOWE
OCHRONY ŚRODOWISKA
Rocznik Ochrona Środowiska
Tom 13. Rok 2011 ISSN 1506-218X 51-64

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How Heavy Metals Affect Sustainable Development

Lucjan Pawłowski
Lublin University of Technology, Poland

Introduction

The concept of sustainable development was introduced in Burtland's famous report *Our Common Future*, which generally says that sustainable development is that which meets the needs of the present without threatening the abilities of future generations to meet their needs.

Talking about sustainable development on the ground of moral values, one can speak of inter- and intra-generational justice. Inter-generational justice refers to the demands of future generations that resources and the quality of the environment be left in a state that allows them to live [5]. Intra-generational justice (i.e. justice within a generation) refers to the present generation and demands equal access to available resources. Both of these principles must be borne in mind when discussing sustainable development.

Practical implementation of these principles is complicated because of many dimensions: philosophical, social, ecological, economical and technical [18]. In this discussion I focus on defining the duties arising from the implementation of sustainable development. That means the transition to defined duties on the basis of ethics, where we can talk about the need to ensure inter- and intra-generational justice [11, 21].

Initially heavy metals are used as new materials for the production of goods. Since they are non-renewable resources and their amount are limited on our planet, sooner or later they may be exhausted, and so future generations may not be able to meet their needs for heavy metals. This is one side of the problem. The other is that by the use of heavy metals by our civilization, they do not disappear from the planet, but are dispersed throughout Earth's surface, polluting it, and thus threatening a safe environment for future generations.

The present world is developing unsustainably. There has been enormous technological progress; however, our technical abilities to change the world are so powerful that they may even lead to its destruction (Pawłowski 2008, Pawłowski 2009a). The almost geometric progress of our technical abilities to change the world has left the development of social sciences far behind, and does not allow answering the question of what values such changes serve. The fact that resources are becoming less available makes it all the more serious (Laszlo 2008, Pawłowski 2009b).

A lot has been said and written in recent years about climate change, and much less about the fact that the main fossil fuels and non-renewable resources may be exhausted. The consequences to the world of energy and non-renewable resource shortages could be much more severe than the greenhouse effect (Lendzen 2010).

Current estimates are that, at the present levels of consumption, there is enough oil for about 40÷50 years, natural gas for about 60÷70 years and coal for about 140÷150 years. The situation is no better for metals. At the present level of consumption, there is enough copper for about 66 years, zinc for 23, lead (Pb) for 58, mercury (Hg) for 46, and cadmium (Cd) for about 31 years, to mention just a few of the best-known heavy metals (Aron 2005). This does not mean that after that time that heavy metals would cease to be available; their shortage would cause poorer deposits to be exploited and substitutes to be more widely used. Nevertheless, the resources of heavy metals are not infinite, and sooner or later they may be exhausted. The sustainable approach requires the slowing of use of heavy metals by saving, recycling and substitution by more available materials, and as well preventing their dispersion throughout the environment.

Even if we assume a large error in the estimates, one must accept that a major crisis in access to conventional resources will occur within a short time, measured rather in decades than in centuries. This means that one of the cardinal rules of sustainable development, namely inter-generational justice, is at stake. The present generation seems to be living at the expense of future generations (Udo and Pawłowski 2010).

All the above clearly indicates that the development of modern civilization is highly unsustainable (Ikerd 2008), and seems to show that full sustainability is impossible; however, this does not mean that we can do nothing. From a practical standpoint the goal of sustainability should be to minimize, as far as practical, the use of energy and irreplaceable raw materials. We should also seek to develop sources of energy and materials which are replaceable or self-regenerating, and as non-polluting as practically possible (Pawłowski 2007, Russel 2010, Venkatesh 2010).

Problems with Heavy Metals

Mercury and lead are the best-known heavy metals and have been used by mankind since ancient times. They belong to a limited class of elements that can be described as purely toxic, and are still widely used and important to our economy. However, because they are toxic, persistent and bioaccumulative pollutants continuously dispersing through whole surface of the earth, they pose a serious threat to the global environment.

Since heavy metals are elements, they cannot be broken down, and therefore so persist in the environment. Unlike many organic pollutants, which eventually degrade to carbon dioxide (CO_2) and water, heavy metals tend to accumulate in the environment, especially in lake, estuarine or marine sediments. Metals can be transported from one environmental compartment to another. Many heavy metals are toxic to organisms at low concentrations; however, some such as copper and zinc are also essential elements. Concentrations of essential elements in organisms are normally homeostatically-controlled, with uptake from the environment regulated according to nutritional demand. Effects on the organisms are manifest when this regulation mechanism breaks down as a result of either insufficient (deficiency) or excess (toxicity) metal. However, mercury and lead have adverse effects even at exposure to low concentrations.

Mercury

The oldest information on the use of mercury is from China. The ancient Chinese believed that mercury had a positive effect on health and could prolong life. One of China's emperors, Qin Shi Huang Di, drank mercury because he believed that it gave him eternal life. The ancient Egyptians and the Romans used mercury in cosmetics, and alchemists thought mercury was the first matter from which all metals were formed.

Nowadays, mercury is one of the most widely used heavy metals in industry. More significant, however, is its anthropogenic emissions in the environment. According to Pacyna et al. (2006) and Streets et al. (2009), total mercury emissions from anthropogenic sources were 2 320 Mg – calculated from estimated of emission factors.

The greatest mercury emissions are from coal and oil combustion (810 Mg/y) and gold mining (400 Mg/y). Mercury emissions from natural sources are much higher (5207 Mg/y) than from anthropogenic sources (2320 Mg/y). The higher emission from natural sources is caused by the circulation of mercury in the environment. Due to oxidation-reduction and microbial processes, mercury is volatilized mostly to the atmosphere and redeposited back on the surface of the Earth, then emitted again to the atmosphere due to the above mentioned processes. The flux of mercury from natural sources is therefore much higher than that from anthropogenic origins. The circulation of mercury in the environment is responsible for the growing contamination of the whole surface of our planet. The levels of atmospheric mercury are increasing in the remote troposphere, far from known sources (Doctor 2000).

There are two main types of reaction in the mercury cycle that convert mercury into its various forms: oxidation-reduction and methylation-demethylation. In oxidation-reduction reactions, mercury is either oxidized to a higher valence state (e.g. from the relatively inert Hg^0 to the more reactive Hg^{2+}) or through the loss of electrons reduced, the reverse of being oxidized, to a lower valence state.

Another problem with pollution by mercury is an indoor environment, since this is where an average person spends most of their life. When spilled in a small, poorly-ventilated room, mercury can pose significant health threats. Very small amounts of metallic mercury, released into an enclosed space, can raise air concentrations to levels harmful to health. In addition, metallic mercury and its vapors are extremely difficult to remove from clothes, furniture, carpets and other porous items.

As mentioned above, implementation of sustainable development requires a reduction in energy consumption because natural reserves are limited and their combustion increases the concentration of CO_2 in the atmosphere, which seems to lead to climate change (Pawłowski 2009 b). One proposed method of reducing energy consumption is to use fluorescent bulbs. However, the solution to one global problem creates another – fluorescent bulbs contain a small amount of mercury vapor and a larger amount of mercury in a powder or dust form, both of which can become airborne if the bulb breaks. If the breakage is not cleaned up properly, the mercury may continue to circulate. Disposing of these bulbs in the trash can cause also serious harm to health and the environment.

The U.S. Environmental Protection Agency sets a reference concentration of 0.3 μg Hg/m^3 for inhalation exposure to mercury. The reference concentration is a screening tool to help risk assessors determine where to focus their investigation into hazardous exposures – adverse health effects do not necessarily result from exposure at that concentration. For example, if 0.3 μg Hg/m^3 was measured in an air inside a building, the EPA would further investigate the exposure.

Similarly, the US Agency for Toxic Substances and Disease Registry (ATSDR) has set a minimal risk level (MRL) for inhalation exposure for mercury at 0.2 μg Hg/m^3. The MRL is an estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse health effect over a specified period of time. ATSDR also recommends an action level of 1.0 μg Hg/m^3 for remediation if exceeded in indoor air.

Control of mercury concentration in indoor environments seems to be very important due to mass use of fluorescent lamps in EU countries. One must consider that fluorescent bulbs contain 0.5÷1000 mg Hg per bulb. This is only the source where use of mercury will increase in years to come.

Lead

Lead is the second heavy metal with a global impact. Lead was one of the earliest metals discovered by man and was in use by 3000 BC. The ancient Romans used lead for making water pipes and lining baths. They also used lead pots or lead-lined copper for boiling crushed grapes to make wine. According to the Roman winemaker Columella, lead improves the taste of wine. It was discovered later that, in lead pots, a lead acetate with a sweet taste is formed. Lead touched many areas of Roman life. It was used in pipes, dishes, cosmetics, coins and paints. Some historians believe that many among the Roman aristocracy suffered from lead poisoning and that the fall of the Roman Empire was caused by the degeneration of the ruling class caused by lead poisoning. Even in the Middle Ages, lead acetate, called sugar of lead, was used to sweeten wine.

For centuries, lead compounds have provided pigments for paints, and are still widely used. The total consumption of lead continues to grow, from 7.297 mln Mg in 2004 to 8.649 mln Mg in 2009. One positive aspect, from the sustainability standpoint, is that a significant proportion of the lead used has been recycled.

In terms of tonnage consumption of lead since 1960, the battery market increased almost seven-fold while almost all the other sectors experienced real as well as proportional declines. The growth in total demand for lead has therefore been due almost exclusively to the demands of the battery market. Despite the decline in many of the non-battery uses of lead, some interesting prospects exist for new commercial-scale applications in the future. Significant among these is the use of lead for nuclear waste disposal. Because lead absorbs alpha and gamma rays it can be used as containers for nuclear wastes. As the demand for non-fossil-fuel energy sources intensifies, prospects for nuclear power – and hence for nuclear waste disposal – seem likely to grow. Liquid metal magnetohydrodynamics (LMMHD) is another energy-related potential use of lead. In LMMHD (currently only at the pilot stage), molten lead flows in an enclosed loop through an intense magnetic field to generate an electric current. The system can employ low-grade heat sources and would be particularly suitable for installation in remote locations. With a requirement of about 200 tonnes of lead per MW of installed power, could be an important new market for the metal.

A third new use of lead which has already proven its effectiveness is in earthquake to stabilize buildings.

The present emissions of lead to the environment is declining like the emissions from burnt gasoline, where in 1960 nearly 200 000 Mg of lead was used, reaching a peak of 300 000 Mg in the early 1970s and has declined steadily ever since. By 2005, consumption of lead as gasoline additives accounted for < 10 000 Mg. However, it is estimated that over the past five millennia about 300 million Mg of lead were released into the environment. Such consumption caused a global lead contamination of the whole environment due to circulation in soil, water and air. The amount of lead emitted to the environment over time is such that levels in the human body of today's population are 500÷1000 times greater than that of their pre-industrial ancestors (Nriagu 1988).

Low-level environmental exposure to lead is associated with multiple sources (petrol, industrial processes, paint, and solder in canned food, water pipes) and pathways (air, household dust, street dirt, soil, water and food). Evaluation of the relative contributions of sources is therefore complex and likely to differ between areas and population groups.

Inter- And Intra-Generational Justice

Referring to moral obligations drawn from the idea of sustainable development, one can distinguish two important terms: inter- and intra-generational justice.

Inter-Generational Justice

This is justice between the current generation and those that follow. The term was used in the Brundtland raport definition of sustainable development.

Democracies – both the representative and the direct type – face a structural problem, namely the tendency to favor the present over the future. Future individuals are not yet born, and so are unable to be involved in today's decision-making process.

Apart from an exhaustion of the source of heavy metals what may create a problem with manufacturing of some goods, the other problems for the future generation seems to be even more severe. All heavy metals when released to the environment remain there for an unlimited time, recycling among all compartments through the following mechanisms:

- Natural-source releases due to natural mobilization of naturally occurring heavy metals from the Earth's crust, such as by volcanic activity and weathering of rocks,
- Current anthropogenic (associated with human activity) releases from the mobilization of heavy metals impurities in raw materials such as fuels – particularly coal, and to a lesser extent gas and oil – and other extracted, treated and recycled minerals,
- Current anthropogenic releases of heavy metals used intentionally in products and processes, due to releases during manufacturing, leaks, disposal or incineration of spent products or other releases,
- Re-mobilization of historic anthropogenic heavy metals releases previously deposited in soil, sediments, water bodies, landfills and waste/tailings piles.

Global emissions remain high and, taking into account accumulation of metals in the environment, further emissions may threaten, above all, the health of children. For example nearly 1.7 million children aged 1÷5 have blood levels of Pb $\geq$ 100 μg/L. Such a level will negatively affect their wellbeing.

Since the oceans are a sink for most heavy metals, there is a danger that growing heavy metal concentrations in the marine environment will disturb plankton growth. These may affect not only the food chain in the marine environment, but also decrease CO_2 assimilation by plankton, one of the very important global sinks of CO_2 – this would accelerate climate change.

A positive trend can also be observed. The anthropogenic emissions of lead in 32 EEA (European Economics Area) countries have declined by 88% during 1990÷2007. This is primarily due to reductions in the road transport sector. The promotion of unleaded petrol within the EU through a combination of fiscal and regulatory measures has been a particular success story. EU member states and other EEA member countries have now phased out the use of leaded petrol, a goal regulated in the EU by the Directive on the Quality of Petrol and Diesel Fuels (98/70/EC). In 2007 the largest emitters of lead were Poland (responsible for 20% of total EEA-32 emissions), Spain (10%), Italy (10%) and

Bulgaria (9%). All countries report lower emissions of lead in 2007 compared with 1990, with the only exceptions being Malta and Bulgaria (EEA Report 2010).

Global change related to climate change and the role of CO_2 emissions has attracted worldwide attention (Golomb 2008, Lindzen 2010). Not many know, however, that heavy metals can disturb the equilibrium of the global environment. In the extreme case of an excessive increase in their concentrations in the oceans, which are the sink for heavy metals, they may inhibit plankton growth. This would disturb the food chain in the oceans and in consequence decrease fish production to a catastrophic level. Plankton also plays an important role in the absorption of CO_2 from the atmosphere – one of the major sinks for CO_2. The disappearance of plankton from oceans would cause a catastrophic growth in the concentration of CO_2 in the atmosphere. Therefore, control of heavy metal emissions is of great global importance.

The improper control of heavy metals can lead to a substantial threat to the inter-generational justice – one of the fundament principles of sustainable development. Therefore, studies of pathways of heavy metals in the environment are equally important as studies on greenhouse gases, as they may affect future life on our globe even more severely than greenhouse gas emissions.

In reference to the term ‘humanity ecological footprint’, which sets the smallest necessary area of the Earth’s surface for the human population to survive (Wackernagee 2006), it has been shown (Global Footprint Network 2006) that our planet’s capacity to sustain our population was exceeded in approximately 1986. Thus, the space available on our planet to sustain a decent life for the human population is already overloaded. There is no room for a growing population.

Intra-Generational Justice

Moreover, a second rule of sustainable development, intra-generational justice, is not respected either. The present course of development in our civilization makes it worse. With the fall of socialism, liberal capitalism, with its chief paradigm ‘grow-or-die’ became the leading socio-economic system (Fotopolous 2007). As a consequence, the consumption of all environmental components increased, including non-renewable resources. This phenomenon was accompanied by a global concentration of economic power, associated by numerous ties with political influence (Baumgaertner 2008).

Appealing to ruthless competition, with no regard to cooperation, has a disintegrating influence on social bonds and creates an atmosphere that favors struggle for dominance, especially economic, associated with political power (Fotopolous 2007). In consequence we have economic and political elite with strong internal bonds, alienated from the rest of society, to an extent that ordinary people have little or no influence on social and economic processes. The criminal war in Iraq provides an example: had the decision to start the war been dependent on a referendum and not made in the privacy of cabinets of the economic and political elite, the war would never have begun.

As Hart (2005) indicates, in 1960 the wealthiest 20% of the population owned 30 times as much wealth as the poorest 20%, whereas this ratio in 1991 reached 60 times, and 78 times in 2004. A UNDP report (UNDP 2005) provides information showing that the annual income of the 500 richest people in the world is equal to that of the 400 million most impoverished; Kofi Annan, Secretary-General of the UN, stated that almost half the population has an income of < $2 a day.

Young children are undergoing rapid development, their systems are not fully developed, and consequently they are more vulnerable than adults to the effects of heavy metals, especially lead. Children from poor families are more exposed to heavy metals because they live in older houses where paints containing heavy metals (Pb and Cd) have been used. They also live mostly in the more populated areas where emissions of Pb from gasoline are higher.

A study in the USA (Bulletin WHO 2010) showed that, during 1976÷1991, when lead was removed from gasoline, the prevalent blood lead level of ≥ 100 μg/L for children aged 1÷5 years declined from 85.0 to 5.5% for non-Hispanic white children, and from 97.7 to 20.6% for non-Hispanic black children. The major cause of this decline was the removal of lead from gasoline. Sociodemographic factors associated with higher lead levels in children of non-Hispanic black race were low income and living in older housing. It was concluded that programs for the prevention of lead poisoning should target high-risk persons, such as children living in old houses, belonging to minority groups, and living in families with low incomes.

The worst situation, however, is in developing countries like Africa. Gasoline sold in most African countries contains 0.5÷0.8 g Pb/L. In urban and rural areas and near mining centers, average lead concentrations reach 0.5÷3.0 $\mu g/m^3$ in the atmosphere and > 1000 µg/g in dust and soils. In addition to automotive and industrial sources, cottage industries and the burning of paper products, discarded rubber, battery casings and painted woods for cooking and heating represent additional hazards to individual households (Nriagu 1996).

Although African children are particularly predisposed to environmental lead exposure, because of their lifestyle and socioecological factors, a true picture of childhood lead poisoning in the continent remains undefined. Recent prevalence studies show that > 90% of the children in urban and rural communities of the Cape Province, South Africa have blood lead levels ≥ 100 $\mu g/dm^3$. Studies in other countries likewise suggest that childhood lead poisoning is a widespread urban health problem throughout the continent (Nriagu 1996).

Conclusion

Heavy metals (especially mercury, lead and cadmium) are a global problem that needs to be addressed from a global and sustainable perspective, like climate change. Therefore, I suggest the EU to establish a research project on the effects of heavy metals on the global environment. The research should concentrate on the following:

- A better understanding of what happens to heavy metals from extraction through processing and manufacturing to their ultimate disposal.
- Heavy metals have accumulated over the centuries in all parts of the environment and their fate and pathways within ecosystems need to be better understood.
- The role of methylated heavy metals (monomethyl and dimethyl mercury; dimethyl, trimethyl and tetramethyl lead; and monomethyl cadmium) in the migration of heavy metals in the global environment needs to be better understood.

- The role of heavy metals in the ocean biota needs to be better understood.
- There is a need to develop a detailed global emissions inventory for mercury, lead and cadmium from anthropogenic sources for inclusion in the global tracer transport model.
- There is a need to develop parameterizations for the exchange of mercury, lead and cadmium between the oceans, land surface and biosphere for inclusion in the global tracer transport model.

No doubt the heavy metals are equally important from sustainable development and global perspective as the greenhouse effect, and an increase in the content of heavy metal in the global environment is more dangerous then increase in the content of greenhouse gases.

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Jak metale ciężkie wpływają na rozwój zrównoważony

Streszczenie

Wiele już powiedziano i napisano w ostatnich latach o związku zmian klimatu z zasadą zrównoważonego rozwoju, lecz o wiele mniej o tym, że główne nieodnawialne zasoby mogą ulec wyczerpaniu. Skutki niedoboru tych zasobów mogą być znacznie bardziej dotkliwe niż efekt cieplarniany. Obecne szacunki wskazują, że przy obecnym poziomie konsumpcji, miedzi wystarczy no około 66 lat, cynku na 23, ołowiu na 58, rtęci na 46, kadmu na około 31 lat, by wymienić tylko kilka z najbardziej znanych metali ciężkich.

Jednym ze sposobów zapewnienia dostępności metali ciężkich jest jak najlepsze wykorzystanie ich ograniczonych zasobów. Inne podejście do problemu to, że wykorzystując te toksyczne metale ciężkie, Rozprzestrzeniamy je na całej planecie, zanieczyszczają ją i tworząc zagrożenie niebezpiecznymi warunkami dla przyszłych pokoleń. Zrównoważone podejście pomaga ograniczyć rozprzestrzenianie się tych metali. Oba aspekty zarządzania metalami ciężkimi z globalnego punktu widzenia omówiono w tym artykule.