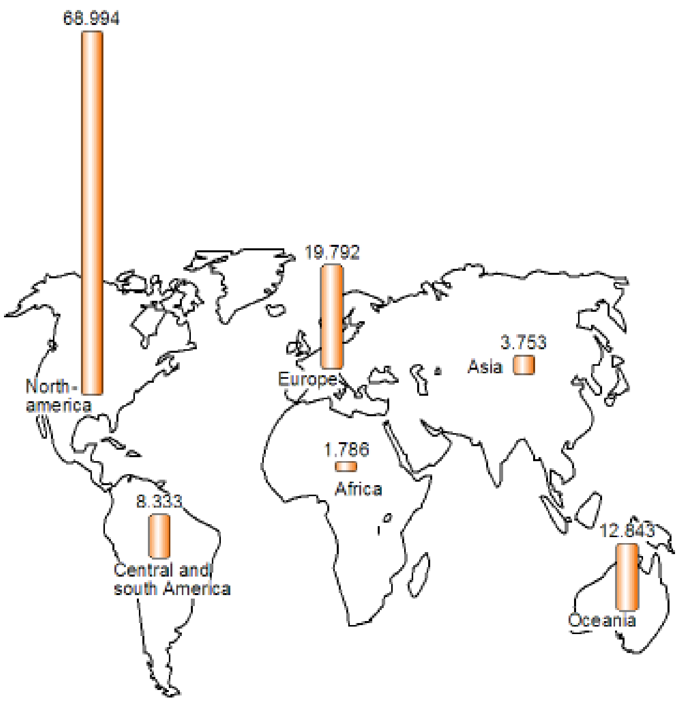
The environmental impact of e-waste

An international comparison with a special focus on India using the Environmental Kuznets Curve as a model



E-waste generation per continent (kg per capita / year)

Data source:
Bundesministerium für Wirtschaftliche Zusammenarbeit und Entwicklung (BMZ) 2000: 22.

by Mareike Buth

2007

COOPERATION REPUBLIC OF INDIA FEDERAL REPUBLIC OF GERMANY
gtz

"It is believed that combustion, particularly combustion of chlorine-containing wastes, is the major source of PCDD/Fs to the global environment."

(Minh et al. n.a.: 2.)

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Glossary

BAN	Basel Action Network
BFR	Brominated flame retardants
CRT	Cathode ray tube
EKC	Environmental Kuznets Curve
EEE	Electrical and electronic equipment
EMPA	Swiss Federal Laboratories for Materials Testing and Research (Eidgenössische Materialprüfungs- und Forschungs-Anstalt)
EU	European Union
GDP	Gross domestic product
GDP p.C.	Gross domestic product per capita
IC	Integrated circuit
I-TEF	International toxicity equivalency factor (established 1988 by a NATO/CCMS working group)
KC	Kuznets Curve
NGO	Nongovernmental Organization
OECD	Organisation for Economic Co-operation and Development
PCB	Polychlorinated biphenyl
PCDD	Polychlorinated dibenzodioxin
PCDF	Polychlorinated dibenzofuran
POP	Persistent Organic Pollutants
PPP	Purchasing power parity
PVC	Polyvinyl chloride
PWB	Printed wiring boards
TDI	Tolerable daily intake
TEF	Toxicity equivalency factor
TEQ	Toxic equivalent
UBA	German Federal Environment Agency (Umweltbundesamt)
UNEP	United Nations Environment Programme
WEEE	Waste from electrical and electronic equipment
WHO	World Health Organization
WHO-TEQ	Toxic equivalent by WHO norm (established in 1997)

1. Introduction

1.1. Research questions

Waste electrical and electronic equipment (WEEE or e-waste) is "the fastest growing waste stream in the world"[1], containing very hazardous materials. That is why the handling of it is a question about health and environmental protection.

Some states are facing an alarming toxic waste problem. But where are these problems located? Who generates the waste and whose health and direct environment is deteriorated by its hazardous components?

The aim of this paper is to show the environmental impact of e-waste in an international comparison. Since there is no possibility to collect data showing the total environmental damage generated by e-waste, a focus on a specific and countable impact is needed. Therefore this study deals exemplarily with concentrations of dioxins (PCDDs) and furans (PCDFs) in different mediums.

Electrical and electronic devices are for the most part luxury goods, often a kind of status symbol. A connection between economic prosperity and the sale of new equipment is obvious. The question which is discussed in this paper is if there is also a connection between prosperity and the environmental impact of e-waste. To find the answer, the theory of the Environmental Kuznets Curve (EKC) is applied.

A special focus is set on the situation in India, because here we can find a fast-growing market for EEE[2] as well as a special recycling situation which makes the problem discussed in this paper even more significant.

1.2. Hypotheses

The use of the Environmental Kuznets Curve shows that there is an expected connection between the environmental impact of e-waste and prosperity, described by the GDP per capita. A connection which shows – graphically represented – an inverted U-curve, the typical Kuznets Curve, is unlikely. However if

[1] Toxics Link 2007: 1.

[2] Sinha-Khetriwala / Kraeuchi / Schwaninger 2005: 493.

you view the theory as ČIEGIS does, as a "hypothesis on the interrelation between economic growth and environmental quality"[3] you can still apply it.
The second assumption is that environmental loss induced by WEEE is not located in the industrialized and wealthy states, where most of the e-waste is generated. Therefore, another indicator for the environmental impact, other than the generation of e-waste, had to be found. The concentration of dioxins and furans should be a proper one.

1.3. Composition of this paper

Firstly, the theory of the Environmental Kuznets Curve should be introduced and adumbrated briefly. The methodology will then be described with a focus on the question "How to do an EKC for e-waste?".
A description of the e-waste problem, the toxicity of e-waste and the connection between e-waste and dioxins and furans will follow in chapter three.
In chapter four PCDDs and PCDFs shall be presented and afterwards used to construct an EKC for the environmental impact of e-waste.
To acquire the problem at large the dioxin and furan sources apart from e-waste will be shown for three exemplary countries.
A conclusion and a forecast as well as some critical notations will close the paper.

2. An Environmental Kuznets Curve for e-waste?

2.1. Environmental Kuznets Curve – an introduction

The Environmental Kuznets Curve is related to the Kuznets Curve, implemented by SIMON KUZNETS 1955. In his paper "Economic Growth and Income Inequality" he described the relationship between inequality in income distribution and income growth. It is a dynamic model showing a state with growing prosperity. First the income would be small for everybody. Then with increasing income the inequality would raise as well, that means that not all people can benefit of the economic growth at the same time. The third step shows a wealthy state with a low inequality in income distribution when the rising pros-

[3] Čiegis 2004: 5.

perity reached most people. KUZNETS compared this process with an inverted U-curve.[4]

The first studies which converted KUZNETS' theory to environmental issues have been written in the early 1990s[5]. Nowadays, one can find a lot of papers and studies which tried to show Kuznets Curves for several environmental indicators, like emissions of CO_2 or SO_2 or the attendance of people to pay for environmental protection[6]. These attributes were related to economic data like the GDP or social data like education statistics.

The environmental data should present a damage which is reversible; otherwise a decrease of the curve would not be possible.[7]

The Environmental Kuznets Curve reflects primarily the history of the industrialized states. For example, CO_2-emissions were very low before industrialization began in the late 19th century. Through industrialization emissions grew rapidly, as did income. Then, at the peak of the EKC, the importance of environmental protection was discovered and the population was wealthy enough to carry out environmental protection measures. As a result greenhouse gas emissions declined because of new technologies and a change towards a service economy; income however did not decline. Nevertheless there are studies which apply the EKC model to developing countries. There are also studies which adopt the EKC model to cross-country data sets, as will be done in this paper also.

Optimists think that the EKC is proof that global economic growth would automatically lead towards global eco-friendly behavior. They see "environmental deterioration […] [as] an unavoidable stage in economic development, a mere temporary phenomenon before we become rich enough to implement seriously the necessary pollution abatement activities"[8]

EKC however also faces much criticism. On the one hand, there are other factors[9] apart from economy growth which influence the development of a culture of conservation and antipollution, like policy focuses, the state system and edu-

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[4] cp. He 2007: 6, 19.

[5] He 2007: 6.

[6] Obviously this EKC would not show an inverted U-curve but a U-curve.

[7] cp. Dasgupta / Mäler 1994: 7.

[8] He 2007: 4.

[9] cp. Dasgupta / Mäler 1994: 7.

cation for instance. On the other hand, even if it would be right that the pollution would decrease dramatically after the development of all countries, it would be "a dangerous strategy for the whole planet"[10] to wait for it without trying to lessen the anthropogenic impact to environment.

But these facts shouldn't detain us to discover the effect of prosperity on the status of environment and – in our case – the impact by e-waste.

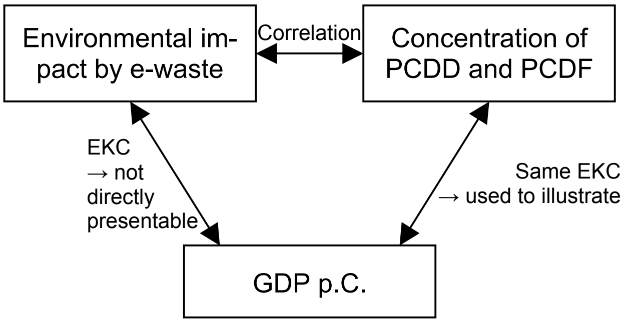
2.2. Methodology

It was mentioned before that, for constructing an Environmental Kuznets Curve for e-waste, a proper indicator is needed. "E-waste" is nothing one can chart in a coordinate plane and data about the generation of e-waste does not show the environmental impact because it does not indicate how much e-waste is recycled or exported or dumped and in which manner this takes place. That is why PCDD/PCDF statistics are chosen for this paper to present the effects of e-waste on human health and the environment.

The idea behind is, that an indicator which shows a correlation to the environmental impact of e-waste (and every toxic which is emitted during the recycling processes does) can be used to chart the relationship between the pollution and the income in a country or region. An EKC showing the relationship between the concentration of PCDD and PCDF and the GDP p.C. shows in a way the EKC of the environmental impact of e-waste as well.

Statistics used in this paper have been collected from several studies. It should be noted that in India, the country selected for this study, no monitoring of dioxin and furan concentrations exists. However, there are studies for which data has been collected and this data will be used for this paper.

Figure 1: Scheme of the paper's structure



The comparison of data from different studies does not prove to be a problem, as an international standardized system for dioxins and furans exists for specifying the toxicity of PCDD/PCDF con-

[10] He 2007: 26.

centrations, a composition of toxicity equivalency factors (TEFs) and the toxic equivalent (TEQ), which will be introduced later in this paper.
The data collected shows dioxin and furan concentrations in different mediums like butter or human milk from different countries and different years.
For constructing the Environmental Kuznets Curve these data will be related to the GDP per capita (comparably by purchasing power parity (PPP)). To chart them a coordinate plane will be made showing the GDP p.C. (PPP) on the x-axis and the PCDD/PCDF data on the y-axis, using MSExcel. The program will be asked to set a polynomial trendline in the coordinate plane and its equation.
Afterwards the results will be discussed.

3. <u>E-waste and pollution</u>

3.1. E-waste facts

3.1.1. What is e-waste?

E-waste "is the term used to describe old, end-of-life electronic appliances such as computers, laptops, TVs, DVD players, mobile phones, mp3 players etc. which have been disposed of by their original users"[11]. This means that every device which is at the end of its useful life is waste, even if it is dumped in the cellar.
Much electrical and electronic equipment is still working when it becomes waste. It is often rejected on the basis that it is not the latest fashion or not compatible with new software or one can buy better quality equipment for a lower price.

3.1.2. E-waste generation and transboundary movement

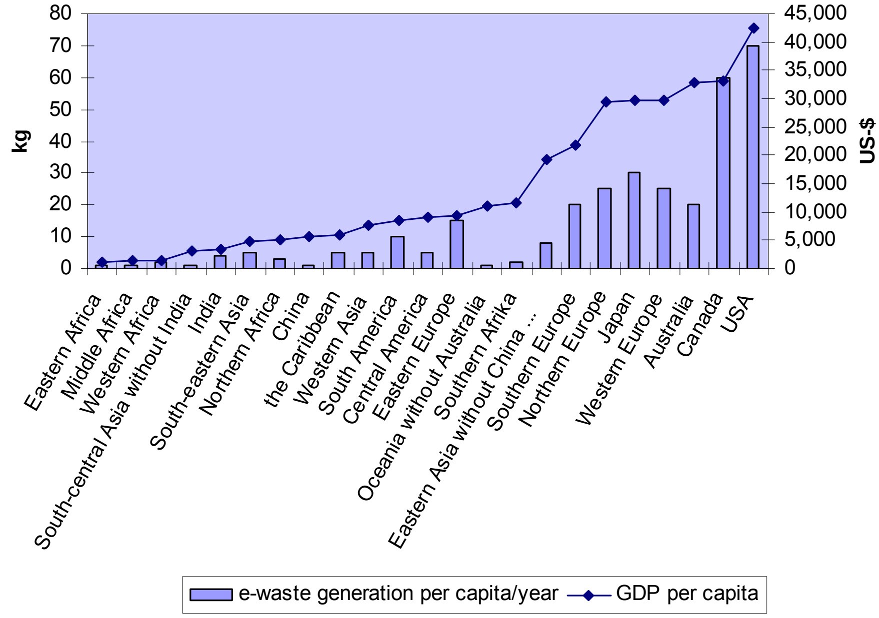
According to the United Nations Environment Programme (UNEP), up to 50 million metric tons of e-waste is globally generated each year[12]. A clear trend shows that regions with a high GDP and a high living-standard are producing much more e-waste than less developed regions (see Figures 2 and 3).

[11] Indo-German-Swiss e-Waste Initiative 2007

[12] United Nations Environment Programme (UNEP) 2006

The quantity still continues to grow. Manufacturers continuously develop new

Figure 2: E-waste generation and GDP
Data sources: BMZ 2000: 22.
van der Heyden 2007.



and better devices and the equipment has more and more functions. So EEE has de facto a shorter life than it could theoretically have. “The average lifespan of a computer has shrunk from four or five years to two years”[13], for mobile phones the lifespan is even lower.

But what happens with all this waste? The larger volume of it is not recycled where it is generated. In fact it is exported to developing countries, because a proper recycling in developed countries is very expensive and in Africa and Asia the export firms can even sell the trash. This is a perfect example for an externalization of costs.

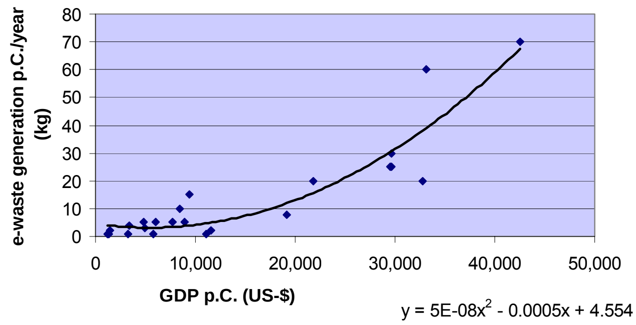


Figure 3: E-waste generation and GDP: Trendline
(data are the same as in Fig. 1; each point is for one region)
Data sources: BMZ 2000: 22.
van der Heyden 2007.

The export of e-waste to devel-

[13] Puckett et al. 2002: 5.

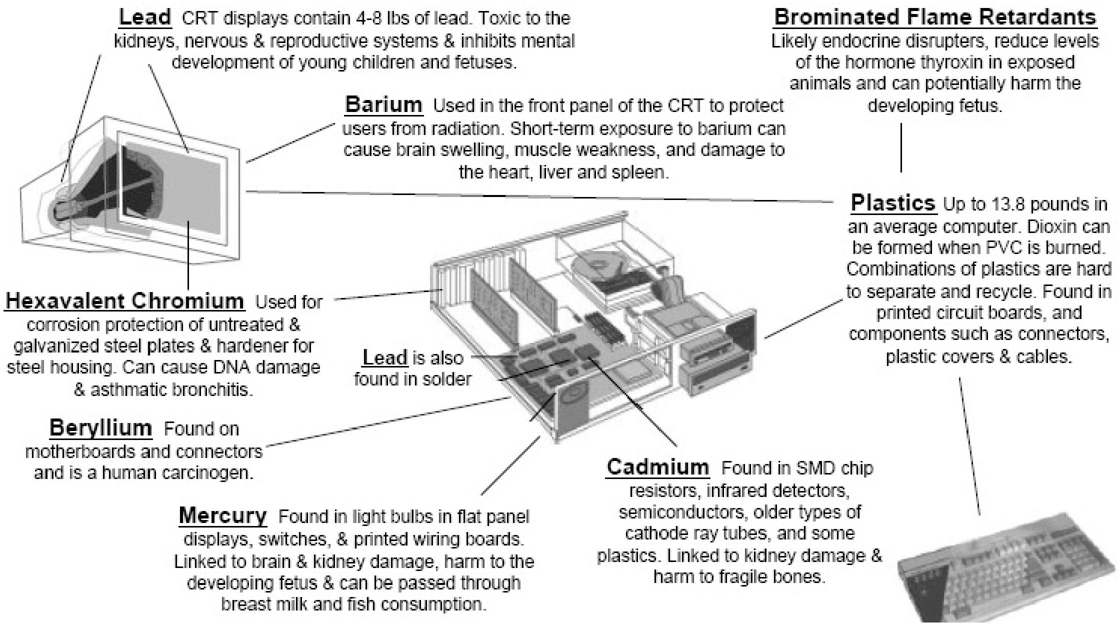


Figure 4: Hazardous materials in a PC (modified)
Source: Silicon Valley Toxics Coalition / Computer TakeBack Campaign n.a.: 1.

oping countries is illegal, but it is estimated that 500 containers alone reach Lagos, Nigeria, every month[14]. The e-waste is often declared as “used goods”.

The statistics are alarming: According to the Basel Action Network (BAN), 50 to 80 percent of the WEEE collected for recycling in the western USA is exported to less developed countries[15] and according to UNEP, more than 90 percent of the globally generated e-waste “ends up in Bangladesh, China, India, Myanmar and Pakistan”[16].

In these countries serious health and environmental damages are the results of illegal dumping of e-waste and the rudimentary recycling systems practiced in these countries emit toxics into the environment, flora and fauna and impact the health and wellbeing of humans.

3.1.3. E-waste toxics and the recycling system in India

E-waste contains more than 1,000 different substances and chemicals[17] of which many are toxic. Some of them are illustrated in Figure 4 (a more detailed list can be found in Annex 1).

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[14] Basel Action Network (BAN) 2005:

[15] Puckett et al. 2002: 1.

[16] United Nations Environment Programme (UNEP) 2007: 225.

[17] cp. Puckett et al. 2002: 5. and Toxics Link n.a.: 4.

During the recycling in countries like India and China, many of these toxic substances are released. “Recycling” means that valuable materials which are part of e-waste like gold, silver and copper are extracted, collected and re-sold. Recycling is done mainly by the informal sector, in rudimentary backyard recycling set-ups without protective equipment or machinery and with no attention to occupational health and safety measures. The processes include acid baths during the metal recovery and open burning of plastics and other materials, which results in toxic smoke leading to the pollution of air, groundwater and soil.
The Swiss Federal Laboratories for Materials Testing and Research (EMPA) estimate that in Delhi at least 10,000 unskilled workers are employed in recycling and recovery operations[18]. Most of them are migrants[19] who see no other possibility to earn their livelihoods.

3.2. E-waste and dioxins and furans

An average computer contains 13.8 pounds plastic; 26 percent of the plastic is polyvinyl chloride (PVC) [20]. It is used for its fire retardant properties and can be found in computer housings, keyboards, cables and cover panels.

Material	Weight
Plastics	6.32 Billion Pounds
Lead	1.58 Billion Pounds
Cadmium	3 Million Pounds
Chromium	1.9 Million Pounds
Mercury	632,000 Pounds

Table 1: How much waste is in 500 million computers?
Source: Puckett et al. 2002: 6.

During the recycling processes in the informal sector plastic is generally burned in open fires to reach the more valuable materials behind or just to burn the unwanted waste. Devices which are burnt are for instance printed circuit boards[21] and copper wires[22] to extract the metal in them.
The process during the incineration of PVC is not yet totally understood but dioxins and furans are definitely generated when it is burned in certain temperature ranges (200°C to 800°C)[23]. “Thermal processes in which chlorine-containing substances are burnt together with carbon and a suitable catalyst

[18] Sinha-Khetriwala / Kraeuchi / Schwaninger 2005: 500.
[19] Toxics Link 2007: 4.
[20] Puckett et al. 2002: 9. and Toxics Link n.a.: 5.
[21] Puckett et al. 2002: 23.
[22] Toxics Link 2004b: 24.
[23] Steiner 2004: 15.

(preferably copper) at temperatures above 300°C in the presence of excess air or oxygen"[24] are sources of PCDDs and PCDFs.

Two theories are mentioned in the literature:

- The precursor theory says that the formation is out of gaseous chlorinated aromatic precursors and can happen in the solid phase when the precursors are adsorbed on the surface of fly-ash (200°C to 400°C) as well as in the gas-phase (500°C to 800°C).[25]
- The de novo synthesis "is a combination of oxidative decomposition of carbon and chlorination of uncompleted combustion products at the same time"[26]. The carbon source is fly-ash. The dioxin formation in this process "takes place in the zone when combustion gases cool down from about 450°C to 250°C"[27].

The needed substances are part of e-waste. PVC contains 57 percent chlorine and 43 percent hydrocarbon by weight[28]. Copper is very common in e-waste anyway, especially in the burned wires. And ash is a natural product of nearly every incineration process.

STEINER, in her study about e-waste burning in Delhi, shows that a temperature up to 600°C is reached while burning 2kg of cables[29].

But PVC is not the only source of dioxins and furans in e-waste recycling processes (see table in Annex 3). Other plastics which are treated with brominated flame retardants (BFR) for instance will also generate dioxins and furans when burned[30].

4. Dioxins and furans

4.1. Definition

"'Polychlorinated dibenzo-p-dioxins' and 'polychlorinated dibenzofurans' are tricyclic, aromatic compounds formed by two benzene rings connected by two

[24] Fiedler et al. 2000: 21.

[25] cp. Steiner 2004: 14. and Fiedler et al. 2000: 21.

[26] Steiner 2004: 14.

[27] Fiedler et al. 2000: 21.

[28] Srishti / Toxics Link 2000: 39.

[29] Steiner (2004): 29.

[30] cp. Five Winds International 2001: 38.

oxygen atoms in polychlorinated dibenzo-p-dioxins and by one oxygen atom and one carbon-carbon bond in polychlorinated dibenzofurans and the hydrogen atoms of which may be replaced by up to eight chlorine atoms."[31]

This is the definition given in the Stockholm Convention.

Both groups of these ethers consist of several congeners, means of different related chemicals with the same basic structure. There are 75 possible PCDD congeners and 135 possible PCDF congeners[32]. 17 of them are toxic[33].

Dioxins and furans belong to the persistent organic pollutants (POPs), which are regulated internationally in the Stockholm Convention on Persistent Organic Pollutants.

4.2. Persistent Organic Pollutants (POPs)

POPs are a group of twelve chemicals which are toxic and persistent (see Table 2). They accumulate in organisms in terrestrial and aquatic ecosystems and can therefore be found in water and air and transported over very long distances.[34]

Their ability to bioaccumulate results of their high lipid solubility. Their water solubility is in contrast very low[35].

Altogether these attributes mean that they remain in the environment for long times and that they are widespread over the world.

Pesticides
Aldrin
Dieldrin
Endrin
Chlordane
DDT
Heptachlor
Mirex
Toxaphene
Hexachlorobenzene (HCB)
Industrial Chemical Products
Polychlorinated biphenyls (PCBs)
Hexachlorobenzene (HCB)
Unwanted By-products
Polychlorinated dibenzo-p-dioxins (PCDDs)
Polychlorinated dibenzofurans (PCDFs)
Polychlorinated biphenyls (PCBs)
Hexachlorobenzene (HCB)

Table 2: The twelve POPs listed in the Stockholm Convention
Source: International POPs Elimination Project (IPEP) / Toxics Link 2006: 10.

Health defects have been connected to POPs. Dioxins and furans belong to the most toxic of them.

[31] Stockholm Convention on Persistent Organic Pollutants. Annex C. Part IV. Paragraph 1 (b).

[32] Fiedler et al. 2000: 19.

[33] Toxics Link 2004b: 10.

[34] cp. Stockholm Convention on Persistent Organic Pollutants.

[35] cp. Fiedler et al. 2000: 13.

4.3. Characteristics and toxicity

4.3.1. Characteristics

Polychlorinated Dibenzo-p-dioxins and Dibenzo-furans are unwanted, unintentionally produced by-products of thermal processes. They always occur as a mixture of several congeners, which are all lipophilic, semi-volatile and bioaccumulative.[36]

In water, organisms like plankton absorb the toxics and so they reach over respiration and ingestion higher aquatic animals. Over the water-plankton-fish-bird food chain the chemicals are transported from organism to organism to terrestrial life. Human beings are also affected, especially those who have a high dependence on fish in their diet. [37]

Dioxins and furans are organic chemicals and can be deposited on plant surfaces from the air. This is the other way they can enter the human food chain. It is called the grass-cow-milk-pathway. Animals absorb dioxins and furans by eating plants and the dioxins and furans are then transferred into the human body through the consumption of milk, eggs or meat.[38]

PCDDs/PCDFs in soil stay near the surface and due to erosion processes they finally reach bodies of water[39]. Alternatively, they are absorbed by soil organisms and enter the food chain along this path.

However diet is a major factor that influences the concentration of dioxins and furans in the human body. It is documented that vegetarian mothers have lower levels of these toxics in their breast milk than woman who eat a lot of meet[40]. Dietary exposure is expected to sum up about 90 percent of the human dioxin intake[41]; two-thirds thereof via meat and diary products[42].

Health impacts which are related to dioxins and furans are chloracne, diabetes, alterations in liver enzyme levels and disruption of hormones in children and

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[36] cp. Fiedler et al. 2000: 15.

[37] cp. Fiedler et al. 2000: 47 et seq.

[38] cp. Fiedler et al. 2000: 49 et seq.

[39] Toxics Link 2004b: 10.

[40] cp. Solomon / Weiss 2002: 340.

[41] Solomon / Weiss 2002: 343. and Umweltbundesamt (UBA) 2005: 7.

[42] Umweltbundesamt (UBA) 2005: 7.

adults. In the adult age there can be changes in the immune system, glucose metabolism and reproductive problems. Infants who take in PCDDs/PCDFs with the breast milk can suffer from alterations in thyroid hormone levels and thyroid function and neurobehavioral and neurological deficits. There can be disorder in the development of reproductive, nervous and immune systems of fetuses. PCDDs are known to be carcinogen.[43]

"There is no safe level of dioxins; even concentrations of parts-per-trillion can wreak havoc in human and animal tissue"[44]. However the WHO set the level of 1-4 pg/kg_{weight} as a tolerable daily intake (TDI)[45].

4.3.2. Toxic equivalent

The most toxic congener is 2,3,7,8-TCDD. To simplify the monitoring of dioxins and furans all the other toxic congeners are compared to this one. Therefore in 1988 the NATO/CCMS Working Group on Dioxins and Related Compounds developed the international toxic equivalent factor (I-TEF) to convert the analytical data to a single toxic equivalent (TEQ). This was overworked by a WHO/IPCS working group in 1997 to the newer WHO-TEF, based on a better state of knowledge.[46]

The TEQ allows comparing the dioxin concentrations from different studies and from different regions. There are lists with the TEFs for every congener in different creatures like shown in Annex 4. The TEQ is calculated with the following equation:

$TEQ = ([PCDD_i \times TEF_i]\, n) + ([PCDF_i \times TEF_i]\, n) + ([PCB_i \times TEF_i]\, n)$[47]

4.4. Why can dioxins and furans provide as an indicator for the environmental impact of e-waste?

The connection between e-waste recycling and PCDDs/PCDFs is clear. In places where e-waste is not recycled in an environmentally sound manner,

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[43] cp. Fiedler et al. 2000: 23. and Solomon / Weiss 2002: 343. and World Wide Fund For Nature (WWF) n.a.: 1.

[44] World Wide Fund For Nature (WWF) n.a.: 1.

[45] Steiner 2004: 13.

[46] cp. Fiedler et al. 2000: 22.

[47] Fiedler et al. 2000: 22.

more dioxins and furans are emitted. And the more WEEE is recycled the more toxics are released.

On the other hand it is known that dioxins and furans can be transported in organisms to places where they were not produced and stay there for a long time. That means it is theoretically possible, that the dioxins and furans found in India and China and so on, are not produced in these countries. But in fact this is very unlikely. Many studies showed that there is a generation of PCDDs and PCDFs in developing countries during recycling processes (to find some see the references list).

	1988	1993	Decrease
Rural	28.2	17.7	37%
Urban	29.5	19.2	35%
Industrial	35.9	24	33%

Table 3: Dioxins in breast milk in the European Union
Data shown are average concentrations (pg I-TEQ/g fat).
Source: Solomon / Weiss 2002: 344.

In western industrialized countries the PCDD/PCDF concentration decreased dramatically during the last decades (see Table 3 and Figure 5 as examples). Hence it is unlikely that the production of dioxins and furans and their release to the environment is still significant in these states. The comparably high concentrations there are more a heritage of previous times. Some countries like Germany and the United Kingdom began to take action to reduce PCDD/PCDF emissions as early as the late 1980s[48]. And the peak emissions were even earlier in the 1960s and early 1970s in Western Europe and North America[49]. Direct toxic imports from these regions are low.

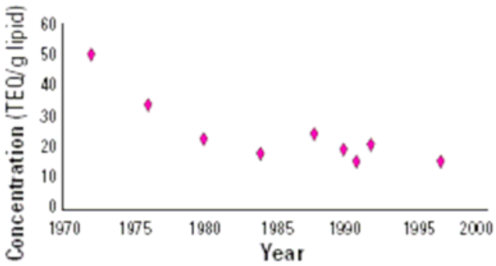


Figure 5: Dioxins in breast milk in Sweden
Source: Solomon / Weiss 2002: 344.

And at least one has to keep the nutrition practices in mind. Especially in the Indian case this is important. Many Indians are vegetarians and the food imports are comparatively low (see Table 4). Dioxins and furans need organisms to be transported over longer distances, which means that the PCDD/PCDF concentrations in humans, who do not eat meat and eat mainly locally produced food, result largely from local emissions.

Industrial processes as a source of PCDDs/PCDFs in connection with the Indian nutrition practices lead the Indian government to believe that the di-

[48] De Vries / Kwakkel / Kijlstra 2006: 209.

[49] Costner 2000: 18.

oxin/furan problem is a non-Indian problem. Overlooking the own local PCDD/PCDF emissions these toxics were regarded as an industrialized country problem which does not affect India.[50]

This ignorance of the problem is one cause for the missing data and monitoring in India.

However to sum up dioxins and furans are a proper indicator to show the environmental impact of e-waste in India in comparison to other states. After all, you can be very sure that the toxics are produced there and the burning of e-waste contributes to this considerably. Toxics Link – an Indian Nongovernmental Organization (NGO) – names uncontrolled waste burning as one of the major sources of dioxins and furans in developing countries in Asia[51].

Food Groups	Production (+)	Exports (-)	Imports (+)	Stock changes & other uses (-)	Consumption (=)
Cereals	187,171	7,940	50	15,149	164,133
Veg.oils	6,269	257	5,093	845	10,259
Sugar & Sw.	28,501	1,573	69	1,473	25,525
Roots & Tubers	31,603	55	17	6,604	24,961
Meat	5,719	309	-	1	5,409
Milk	87,733	310	38	17,869	69,592

Table 4: Food Balance in India 2001-2003 (in 1,000 tones)
Source: Food and Agriculture Organization of the United Nations (FAO) 2006: 2.

5. The Environmental Kuznets Curve for e-waste

In the following chapter Environmental Kuznets Curves are constructed for dioxin and furan concentrations in human milk and butter. A special focus will be set on India and the Indian values in comparison to international data.

5.1. Dioxins and furans in human milk

Toxics Link writes in its POPs report: "Surprisingly, dioxins were found in human breast milk (despite the general belief that dioxins are more an industrialized country problem) in Chennai at levels higher than in other Asian countries"[52].

But actually this is not so surprising when you see the link between dioxins/furans and e-waste as a possible source for the toxics because Chennai is

[50] cp. Srishti n.a.: 5. and Toxics Link 2004b: 5.

[51] cp. Toxics Link 2002: 1. and Toxics Link 2004b: 10.

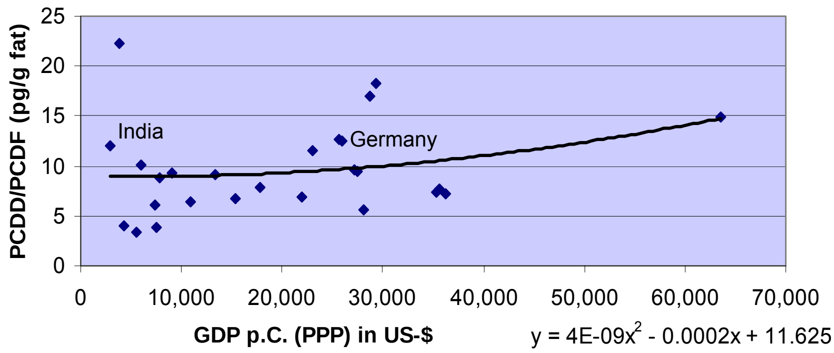
[52] Toxics Link 2004b: 5.

one of the major recycling centers in India including processes like the open burning of copper wires[53].

So, how high are the PCDD/PCDF concentrations in India in comparison to other states? The first EKC to answer this shows the dioxin/furan concentrations in human breast milk. Breast milk is a good indicator for the dioxin and furan burden because it contains a lot of fat and it can be used as an indicator for the whole population[54].

In Figure 6[55] one can see that a U-curved EKC for dioxins and furans in human milk is not distinctive.

Figure 6: PCDD/PCDF concentrations in human milk (WHO-TEQ)
Data sources: van Leeuwen / Malisch n.a.: 3.
Hirai et al. 2003: 4.
The World Bank 2007.



However a trend which shows higher concentrations in countries with a high GDP and in those with a low GDP is visible. In between the PCDD/PCDF concentrations are comparatively low. Dioxin and furan concentrations above 10pg/g_{fat} can be found only in countries with a GDP p.C. (PPP) lower than US-$ 10,000 or over US-$ 23,000.

And one must keep in mind that this data is just average data or in the case of India from control sites which have no connection to waste dumps or recycling. The concentration data for women who live near dumpsites with open burning in India are much higher. Samples taken there show values up to 38pg_{TEQ}/g_{fat}[56] or 27pg_{TEQ}/g_{fat}[57].

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[53] cp. Greenpeace 2007. and Toxics Link 2004a: 12.

[54] cp. van Leeuwen / Malisch n.a.: 1.

[55] Data tables which show the PCDD/PCDF concentration values for the single countries can be found in the annex.

[56] Hirai et al. 2003: 4.

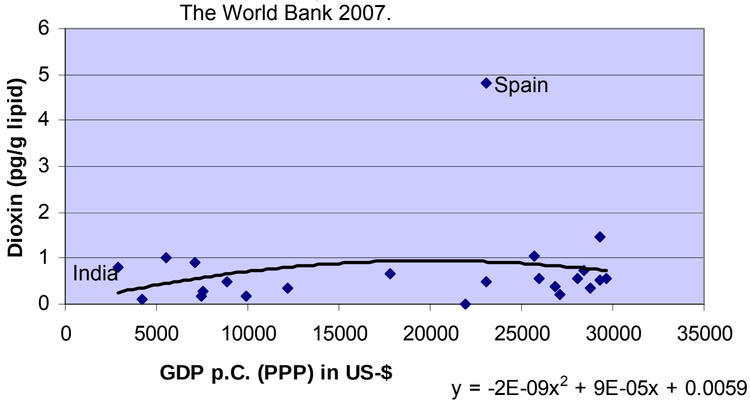
[57] Srishti n.a.: 5.

5.2. Dioxins in butter

The available data for butter show much more obviously a U-curve trend. Between 1998 and 1999 some Greenpeace scientists collected butter samples in several countries and tested them for their PCDD concentrations. Their data is charted in Figure 7.

One can see an Environmental Kuznets Curve in the classical style of an inverted U-curve. But at a first glance one can see, too, that the value for Spain is much higher than for the other countries. Even the authors of this study cannot explain this inconvenient pollution and "given that only one sample was analyzed, of course, it is also not possible to determine whether this pattern of contamination is representative of Spanish butters in general"[58].

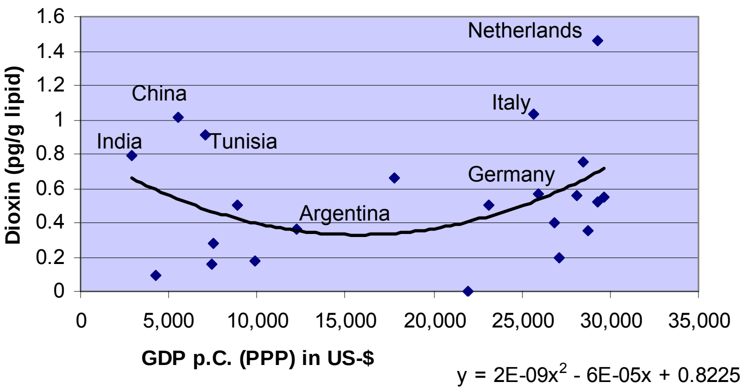
Figure 7: PCDD concentrations in butter (WHO-TEQ); chart contains the value of Spain
Data Sources: Santillo / Stringer / Johnston 2000: 17.
The World Bank 2007.



That's why for our purpose the Spanish maverick is omitted and the data for the other countries charted again.

But this change creates a totally new picture. Without the Spanish value the expected U-curve can be seen (see Figure 8).

Figure 8: PCDD concentrations in butter (WHO-TEQ); without the Spanish value
Data sources: Santillo / Stringer / Johnston 2000: 17.
The World Bank 2007.



[58] Santillo / Stringer / Johnston 2000: 5.

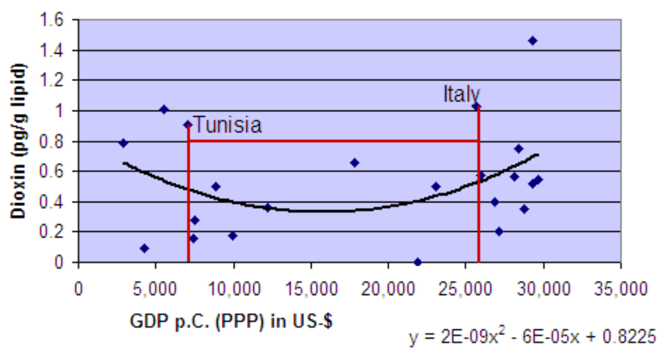


Figure 9: PCDD concentrations in butter (WHO-TEQ); GDP middle range
Data sources: Santillo / Stringer / Johnston 2000: 17.
The World Bank 2007.

Obviously countries can be found which are very poor or very rich and which do not have a high dioxin burden. But one hardly finds countries which have a GDP in a middle range and a significantly high PCDD pollution. Between the points of Tunisia (7094; 0.91) and Italy (25,649; 1.03), none of the eight points reaches the 0.8 pg/g mark and there is even only one country with a PCDD value above 0.6 pg/g (Czech Republic).

The highest PCDD values with a GDP p.C. (PPP) lower than US-$ 8000 can be found in China, Tunisia and India. China and India are the big e-waste dump grounds in Asia.

6. Dioxin and furan sources in a cross-country comparison

Following, three countries and their dioxin and furan sources should be compared exemplary. To explain the Environmental Kuznets Curve shown above one country of every income group will be presented. Germany will stand for those countries which have a high income and relatively high PCDD/PCDF concentrations. In Germany dioxins and furans are monitored for decades and the sources are known. Countries which have relatively low PCDD/PCDF concentrations and an income in a middle range are represented by Argentina. There the dioxin and furan releases have been identified and categorized on the basis of a standardized UNEP toolkit. The example for low-income states with high PCDD/PCDF concentrations is the focus country India.

Even in countries where dioxins and furans are monitored for a long time the emission data is based more on estimations. The toxics are released (among other sources) by uncontrolled burning. For example in Germany toxics are released during the burning of domestic fuel which makes an exact quantification impossible. However, for Germany and Argentina the data is sufficient to use.

6.1. PCDD/PCDF sources in Germany

In Germany measures against the release of dioxins and furans were implemented already in the 1980s. For instance filter systems were installed to reduce the toxic release of (thermic) power plants and in the metal production as well as in waste incinerators. Additionally some substances are banned like polychlorinated biphenyl and petrol additives containing chlorine or bromine. That is why the peak emissions in Germany were already in the 1970s.[59]

These measures were so successful that the PCDD/PCDF concentrations in human milk decreased by about 60 percent since the end of the 1980s [60].

Another result was that the relative importance of the different sources has changed. Previously, waste incineration was one of the major sources. Today emissions are close to zero (see Table 5). In Germany, there are 66 waste incinerators. The total dioxin emissions released by them are today approximately a thousandth part compared with 1990[61].

Sources	Emissions per year in g I-TEQ		
	1990	1994	2000*
Ferrous and Non-Ferrous Metal Production	**740**	**220**	**40**
Powder Metal Facilities	575	168	< 20
Other Iron + Steel production	35	10	< 5
Waste Incineration	**400**	**32**	**< 0,5**
Domestic Waste	399	30	0,4
Special Refuse		2	0,04
Medical Waste		0,1	0,0002
Sludge		< 0,1	0,03
Power Generation and Heating	**5**	**3**	**< 3**
Industrial Incineration	**20**	**15**	**< 10**
Domestic Fuel	**20**	**15**	**< 10**
Transport	**10**	**4**	**<1**
Crematories	**4**	**2**	**< 2**
Total Emissions to Air	**1200**	**330**	**<< 70**

Table 5: PCDD/PCDF sources in Germany and the amount of dioxins and furans emitted to air
*The data for 2000 are estimations by the Federal Environment Agency (UBA)
Source: Umweltbundesamt (UBA) 2005: 3.

The reason for Germany to show still high PCDD/PCDF concentrations in comparison to other states like Argentina for example is that dioxins and furans remain in organisms for a long time when they are accumulated there. In the human adipose tissue the most toxic 2,3,7,8 TCDD has a half-life of seven years.

[59] cp. Umweltbundesamt 2005: 3. and Jopp 1996.

[60] Umweltbundeamt 2005: 8.

[61] Lahl 2005: 44.

The substance with the longest half-life is 2,3,4,7,8-C_{15}DF which needs nearly 20 years to be reduced to the half.[62]

6.2. PCDD/PCDF sources in Argentina

Argentina shows lower dioxin and furan concentrations than Germany and India. Nevertheless they have dioxin and furan releases too. In Table 6 one can see the estimated quantities. As in India, uncontrolled combustion processes are a serious problem. They are by far the major source for PCDD/PCDF release. Assessed 50 percent of the emissions to air mentioned in this category are released by uncontrolled combustion of domestic waste; the releases to residuals named for this source are completely generated by domestic waste burning[63].

The PCDD/PCDF source on the second range is waste incineration itself.

6.3. PCDD/PCDF sources in India

In India the quantities of dioxin and furan releases are not identified. However one can at least identify the sources, because it is known during which processes dioxins and furans are generated. Toxics Link and Srishti name the sources listed in Table 7.

Even though no data about the quantities is collected, uncontrolled open burn-

Sources / Categories	Annual Releases (g I-TEQ/a) 2001					Total per Category
	Air	Water	Soil	Products	Residuals	
Waste Incineration	83.10	0.00	0.00	0.00	43.05	126.12
Ferrous and Non-Ferrous Metal Production	26.51	0.00	0.00	0.00	69.92	96.43
Power Generation and Heating	31.08	0.00	0.00	0.00	42.20	73.18
Production of Mineral Products	6.49	0.00	0.00	0.00	0.05	6.54
Transport	3.08	0.00	0.00	0.00	0.00	3.08
Uncontrolled Combustion Processes	714.81	0.00	241.02	0.00	718.20	1674.03
Production and Use of Chemicals and Consumer Goods	1.10	0.00	0.00	22.78	65.07	88.95
Miscellaneous	8.10	0.00	0.00	0.00	0.00	8.10
Disposal	0.00	2.49	0.00	6.57	25.30	34.36
Total	**874.27**	**2.49**	**241.02**	**29.35**	**963.79**	**2,110.92**

Table 6: PCDD/PCDF sources in Argentina and the amount of dioxins and furans emitted to several mediums
Source: Ministerio de Salud 2004: 63.

[62] cp. Umweltbundesamt (UBA) 2005; 7.

[63] Ministerio de Salud 2004: 50.

ing of waste is frequently mentioned as one of the major sources.

6.4. Comparison

Comparing the data for Germany and Argentina, it is conspicuous that Argentina shows much higher emission values than Germany (see Table 8) but has lower PCDD/PCDF concentrations. This can be explained by the fact that in Argentina not such high quantities of PCDD/PCDF have been accumulated yet while in Germany the decomposition still needs time. However Argentina now has similar PCDD/PCDF emissions as Germany had during the first half of the 1990s. How high must the quantity of dioxin and furan emissions be in India to reach these high concentration values if in Argentina, where uncontrolled waste burning is a problem as well, still has comparably low concentration data but an annual release of more than 2,000 g (I-TEQ)?

Sources
Biomass burning
By-products in manufacture of pesticides and industrial chemicals
Forest fires/other wood combustion
Industrial, thermal and medical incineration processes
Burning of industrial fuels (coal and petroleum products in the power sector)
Chlorine-based paper and pulp sector
Other high temperature sources (e.g., cement and other ceramic industry)
Production of chemicals (e.g., chlorinated phenols and phenoxy herbicides)
Various primary and secondary metal operations (e.g., iron ore sintering, steel production and scrap metal recovery)
Waste incineration (municipal solid waste, medical and hazardous waste)
Open burning of domestic wastes
PVC manufacturing
Sewage sludge
Thermal Power Plants (coal combustion)
Transportation systems

Table 7: Sources of PCDD/PCDF in India
Sources: INTERNATIONAL POPs ELIMINATION Project (IPEP) / Toxics LINK 2006: 14.
Srishti / Toxics Link 2000: 32.

7. Conclusion and future prospects

DASGUPTA and MÄLER wrote that in a global context the Environmental Kuznets Curve means “that citizens in poor countries absorb environmental risks that are not acceptable to their counterparts in rich nations”[64]. For e-waste this statement becomes even more meaningfully since the waste which is the cause of the problem is exported from the developed countries to the developing countries in great quantities.

[64] Dasgupta / Mäler 1994: 6.

And because of the existing recycling system there the e-waste endangers environment and human health in developing countries much more than it would do if it were recycled in developed countries. The actual connection between the environmental impact of e-waste and prosperity means that the waste is generated for the most part in wealthy states but the environmental pollution and the following health problems are shifted to and settled in poorer countries.

Sources	Germany (g I-TEQ/a)	Argentina (g I-TEQ/a)
	2000	2001
Ferrous and Non-Ferrous Metal Production	40	26.51
Waste Incineration	< 0.5	83.10
Power Generation and Heating	< 3	31.08
Industrial Incineration	< 10	
Uncontrolled Combustion Processes	< 10	714.81
Transport	<1	3.08
Crematories	< 2	8.10
Production and Use of Chemicals and Consumer Goods		1.10
Production of Mineral Products		6.49
Total Emissions to Air	**<< 70**	**874.27**

Table 8: Comparison of PCDD/PCDF emissions to air in Germany and Argentina
Sources: Ministerio de Salud 2004: 63.
Umweltbundesamt (UBA) 2005: 3.

In this paper it is shown that these pollution problems are capacious. While industrialized countries are managing their dioxin and furan burden and are able to decrease them, the release of these toxics is enormous in countries like India. The actual Indian PCDD/PCDF values are comparable to the values of some industrialized states in the 1980s (see Figure 10).

What can be learned seeing this data?

First of all the problem must be noticed. Dioxins and furans are not just an industrialized countries' problem. People should become aware of this to be able to manage the pollution.

To manage the problem in a proper way it is important to have information about it. That is why in countries where no monitoring system exits a monitoring system should be implemented. Collecting data about dioxin and furan concentrations is expensive and there are still no certified laboratories for testing dioxins and furans in South Asia[65]. But some laboratories are planned and the first will start functioning soon, constructed in India with the support of GTZ. However data is needed for without monitoring regulations are quite difficult to implement.

[65] cp. Toxics Link 2004b: 5 et seq.

A first step could be to quantify the sources with the UNEP toolkit like Argentina and some Asian countries like the Philippines and Vietnam already did. Measurements are not needed to use it and it could give a first overview.

For sure, e-waste is not the only source of PCDD and PCDF in Asia. Many papers mention the missing knowledge about the sources[66]. More studies and monitoring would lead to interesting results in this respect.

The other missing thing in states like India is a proper recycling system. BOSMANS and DE CAEVEL enumerate the formation of dioxins during WEEE burning as the first of three mentioned main impacts of e-waste recycling in Non-OECD countries[67]. And uncontrolled open waste burning is one of the major sources of dioxin and furan pollution. That means that a substitution of open burning and other recycling processes would cause a decrease of the release of toxics. In fact the release of dioxins and furans decreases even if you burn things at lower temperatures.

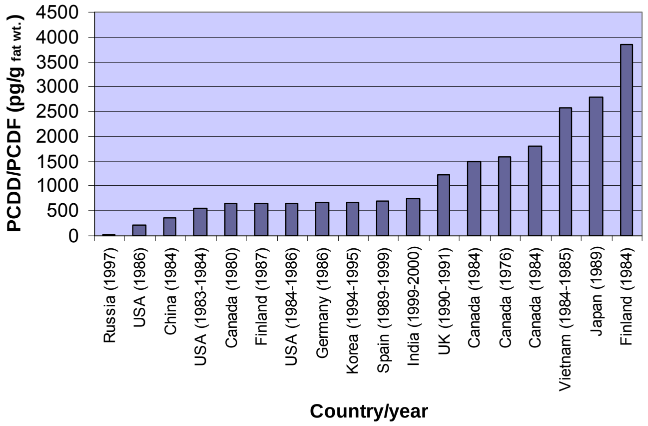


Figure 10: PCDD/PCDF concentrations in human tissues
Data source: Kumar et al. 2001: Supplementary information. 1.

Companies in developed countries should abandon the export of WEEE to countries which are not able to recycle it in an environmentally sound manner without health impacts.

Beyond this, one basic measure is to lower or even to avoid the usage of toxic components and material which generates toxics during recycling processes in EEE. Manufacturers of electronic devices began to substitute PVC with other plastics like ABS plastics[68] but it is still “extremely difficult to identify which types of plastics or flame-retardants are found in each component”[69]. This compli-

[66] For example: Kumar et al. 2001: 1. and Toxics Link 2004b: 27.

[67] cp. Bosmans / De Caevel 2006: 27.

[68] cp. Puckett et al. 2002: 9.

[69] Five Winds International 2001: 22.

cates proper recycling. But a proper recycling is needed in Asia for the whole industry with thousands of workers depend on e-waste recycling.

8. <u>Some critical notes</u>

The author of this paper is aware that some parts can be seen as controversial. Therefore some critical points will be discussed at this point.

8.1. The EKC as a model

The theory of the Environmental Kuznets Curve is disputed; even more if it is transferred from a dynamic model of one state to a static cross-country comparison. That's why it should be alluded again that it is used here just as a theory which links environmental indicators and the income of states.

If dioxins and furans would not stay in organisms for a long time but could be deposited quickly, there would be no U-curve in the case of e-waste since there is only a very limited environmental impact by WEEE (recycling) in wealthy states. The intension was to show that it is possible to demonstrate the relationship between prosperity and environmental loss; keeping in mind that there are factors besides economy which affect the amount of environmental damage.

8.2. PCDDs/PCDFs as an indicator for the impact by e-waste

As perfectly shown in chapter 6, there are other sources of dioxins and furans apart from e-waste. This means that the curves constructed in this paper don't show a 100 percent projection of the e-waste EKC. But it would be impossible to find a toxic or another indicator which is generated only by e-waste. This means that the author decided to accept this inaccuracy rather than not to write a paper of this nature at all.

There is even a second imprecision. The emission of dioxins and furans is not the only environmental impact generated by e-waste. This means that when another indicator is used there may be lower or even higher varieties between the different countries. So, this paper can be seen as an essay to point out an alarming trend in the present economy and recycling systems.

8.3. Data

It was mentioned before that there is no monitoring of dioxins and furans in India. This makes the international comparison of data very difficult. The studies

which have been used to collect data do not show a completely and generally valid picture of the dioxin and furan burden in the whole country.
However, even in countries with a monitoring system you have to work with statistical averages. And the samples used for the Greenpeace study showing PCDD/PCDF concentrations in butter (used mainly in this paper to compare different states) were collected from every country in the same manner. Attention was paid that the butter was made from milk which was locally produced. Since cows eat grass the problem of geographical dispersion of PCDDs/PCDFs via organisms was minimized by this procedure too.

To sum up, this paper should show a realistic picture of the problems of the global e-waste system.

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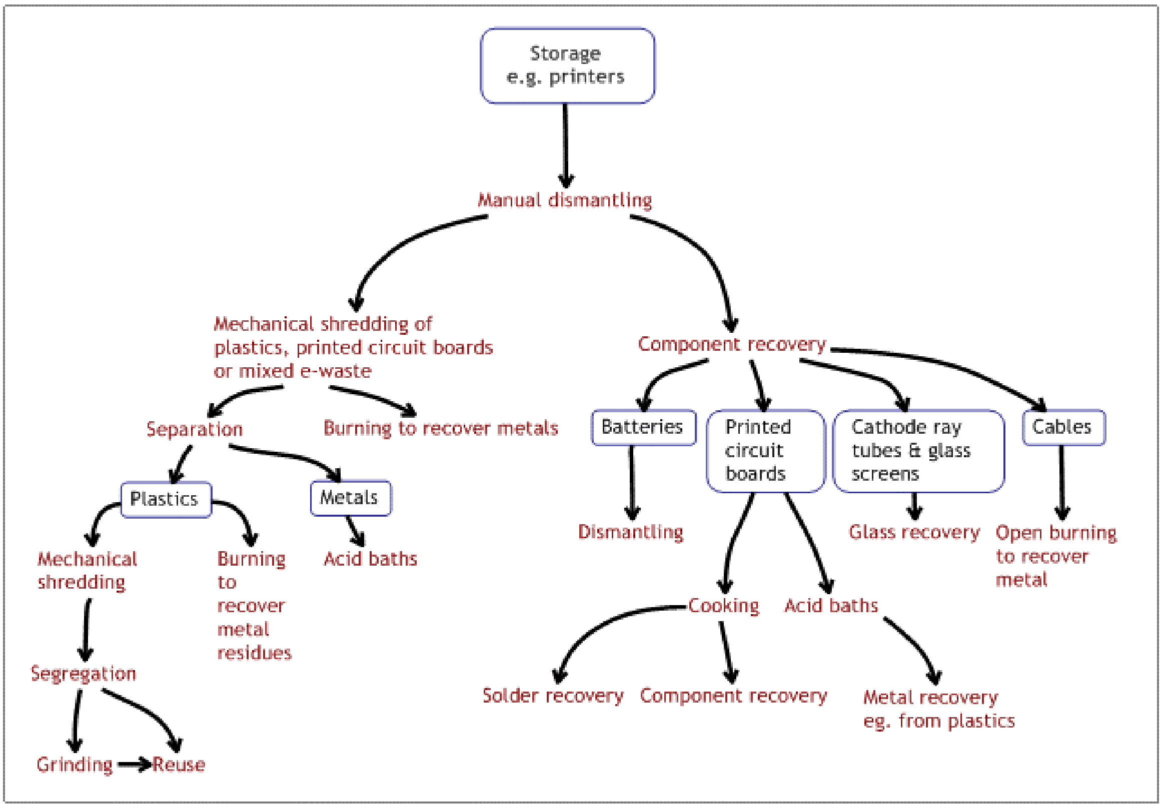
10. Annex

10.1. Annex 1: Hazards of chemicals found in e-waste

Substance	Occurrence in e-waste	Environmental and health relevance
HALOGENATED COMPOUNDS		
PCB (polychlorinated biphenyls)	Condensers, transformers	Cause cancer, effects on the immune system, reproductive system, nervous system, endocrine system and other health effects. Persistent and bio-accumulative.
TBBA (tetrabromo-bisphenol-A) PBB (polybrominated biphenyls) PBDE (polybrominated diphenyl ethers)	Fire retardants for plastics (thermoplastic components, cable insulation). TBBA is presently the most widely used flame retardant in printed wiring boards and covers for components.	Can cause long-term period injuries to health. Acutely poisonous when burned.
Chlorofluorocarbon (CFC)	Cooling unit, insulation foam	Combustion of halogenated substances. May cause toxic emissions.
PVC (polyvinyl chloride)	Cable insulation	High temperature processing of cables. May release chlorine, which is converted to dioxins and furans.
HEAVY METALS AND OTHER METALS		
Arsenic	Small quantities in the form of gallium arsenide within light emitting diodes	Acutely poisonous and on a long-term perspective injurious to health.
Barium	Getters in CRT	May develop explosive gases (hydrogen) if wetted.
Beryllium	Power supply boxes which contain silicon controlled rectifiers, beam line components	Harmful if inhaled.
Cadmium	Printer inks, toners, fluorescent layer (CRT screens) Rechargeable NiCd-batteries, photocopying machines	Acutely poisonous and injurious to health on a long-term perspective
Chromium VI	Data tapes, floppy-disks	Acutely poisonous and injurious to health on a long-term perspective causes allergic reactions
Gallium arsenide	Light-emitting diode (LED)	Injurious to health
Lead	CRT screens, batteries, printed wiring boards	Causes damage to the nervous system, circulatory system, kidneys. Causes learning disabilities.
Lithium	Li-batteries	May develop explosive gases (hydrogen) if wetted.
Mercury	Fluorescent lamps that provide backlighting in LCDs, some alkaline batteries and mercury wetted switches	Acutely poisonous and injurious to health on a long-term perspective
Nickel	Rechargeable Ni Cd-batteries, NiMH-batteries, electron gun	May cause allergic reactions
Rare earth elements	Fluorescent layer (CRT-screen)	Irritates skin and eyes
Selenium	Older photocopying-machines (photo drums)	High levels may cause adverse health effects
Zinc sulphide	Interiors of CRT screens, mixed with rare earth metals	Toxic when inhaled

Source: Toxics Link 2007: 5.

10.2. Annex 2: Different stages of e-waste recycling processes sampled in India and China



Source: Brigden et al. 2005: 10. (modified)

10.3. Annex 3: PCDD/PCDF releasing processes in the e-waste recycling chain surveyed in Delhi

Process	Description	Hazardous emission
IC extraction from PWB at 60°C	PWBs are heated to melt the solder Pliers are used to remove IC's and other components from the plate	Emission of brominated flame retardants, brominated and chlorinated dioxins and furans (PBDD/Fs, PCDD/Fs)
Copper extraction from PWBs, burning	PWBs with or without components are burned in open fire. Afterwards the copper is segregated from the ash.	Emission of brominated flame retardants, brominated and chlorinated dioxins and furans, heavy metals (e.g. Cu, Pb, Cd), lead-tin fumes, respirable suspended particulates (RSP)
Copper extraction from wires, burning	Wires are burned in open fires. Afterwards the copper wire is segregated from the ash.	Burning of PVC releases PCDD/Fs and PBDD/Fs, PACs
Capacitor burning	Incineration of capacitors to extract aluminium.	PCB and PCDD/F emissions
Gold extraction from PWB, burning	PWBs with or without components are incinerated. The gold is extracted by adding mercury.	Emission of brominated flame retardants, brominated and chlorinated dioxins and furans, heavy metals (e.g. Hg, Cu, Pb, Cd), lead-tin fumes, respirable suspended particulates (RSP)

Source: Steiner 2004: 12.

10.4. Annex 4: TEFs of the 17 toxic PCDD/PCDF congeners

Congener	I-TEF	WHO-TEF		
		Humans/ Mammals	Fish	Birds
2,3,7,8-$C_{l4}DD$ (2,3,4,7 TCDD)	1	1	1	1
1,2,3,7,8-$C_{l5}DD$	0.5	1	1	1
1,2,3,4,7,8-$C_{l6}DD$	0.1	0.1	0.5	0.05
1,2,3,7,8,9-$C_{l6}DD$	0.1	0.1	0.01	0.01
1,2,3,6,7,8-$C_{l6}DD$	0.1	0.1	0.01	0.1
1,2,3,4,6,7,8-$C_{l7}DD$	0.01	0.01	0.001	<0.001
$C_{l8}DD$	0.001	0.0001	-	-
2,3,7,8-$C_{l4}DF$	0.1	0.1	0.05	1
1,2,3,7,8-$C_{l5}DF$	0.05	0.05	0.05	0.1
2,3,4,7,8-$C_{l5}DF$	0.5	0.5	0.5	1
1,2,3,4,7,8-$C_{l6}DF$	0.1	0.1	0.1	0.1
1,2,3,7,8,9-$C_{l6}DF$	0.1	0.1	0.1	0.1
1,2,3,6,7,8-$C_{l6}DF$	0.1	0.1	0.1	0.1
2,3,4,6,7,8-$C_{l6}DF$	0.1	0.1	0.1	0.1
1,2,3,4,6,7,8-$C_{l7}DF$	0.01	0.01	0.01	0.01
1,2,3,4,7,8,9-$C_{l7}DF$	0.01	0.01	0.01	0.01
$C_{l8}DF$	0.001	0.0001	0.0001	0.0001

Source: Fiedler et al. 2000: 23.

10.5. Annex 5: PCDD/PCDF concentrations in human milk (WHO-TEQ)

Country	PCDDs/PCDFs WHO-TEQ pg/g fat	GDP p.C. (PPP) 2004	Reference for PCDD/PCDF
Australia	5.57	28,112	van Leeuwen / Malisch n.a.: 3.
Belgium	16.92	28,638	van Leeuwen / Malisch n.a.: 3.
Brazil	3.92	7,531	van Leeuwen / Malisch n.a.: 3.
Bulgaria	6.14	7,406	van Leeuwen / Malisch n.a.: 3.
Croatia	6.4	10,964	van Leeuwen / Malisch n.a.: 3.
Czech Republic	7.78	17,815	van Leeuwen / Malisch n.a.: 3.
Egypt	22.33	3,870	van Leeuwen / Malisch n.a.: 3.
Fiji	3.34	5,575	van Leeuwen / Malisch n.a.: 3.
Finland	9.44	27,490	van Leeuwen / Malisch n.a.: 3.
Germany	12.53	25,972	van Leeuwen / Malisch n.a.: 3.
Hungary	6.79	15,427	van Leeuwen / Malisch n.a.: 3.
India	12	2,866	Hirai et al. 2003: 4.
Ireland	7.72	35,585	van Leeuwen / Malisch n.a.: 3.
Italy	12.66	25,694	van Leeuwen / Malisch n.a.: 3.
Luxembourg	14.97	63,498	van Leeuwen / Malisch n.a.: 3.
New Zealand	6.86	21,905	van Leeuwen / Malisch n.a.: 3.
Norway	7.3	35,288	van Leeuwen / Malisch n.a.: 3.
Philippines	3.94	4,241	van Leeuwen / Malisch n.a.: 3.
Romania	8.86	7,756	van Leeuwen / Malisch n.a.: 3.
Russia	9.36	9,098	van Leeuwen / Malisch n.a.: 3.
Slovak Republic	9.07	13,392	van Leeuwen / Malisch n.a.: 3.
Spain	11.56	23,043	van Leeuwen / Malisch n.a.: 3.
Sweden	9.58	27,102	van Leeuwen / Malisch n.a.: 3.
The Netherlands	18.27	29,316	van Leeuwen / Malisch n.a.: 3.
Ukraine	10.04	5,934	van Leeuwen / Malisch n.a.: 3.
USA	7.18	36,248	van Leeuwen / Malisch n.a.: 3.

10.6. Annex 6: PCDD concentrations in butter (WHO-TEQ)

Country	GDP p.C. (PPP)	PCDD (pg/g lipid)
Argentina	12,222	0.36
Australia	28,112	0.56
Austria	29,672	0.55
Brazil	7,531	0.28
Canada	28,747	0.35
China	5,490	1.01
Czech Rep.	17,815	0.66
Denmark	29,278	0.52
Germany	25,972	0.57
India	2,866	0.79
Israel	23,077	0.5
Italy	25,694	1.03
Japan	26,850	0.4
Mexico	8,847	0.5
Netherlands	29,316	1.46
New Zealand	21,905	<0.01
Philippines	4,241	0.09
South Africa	9,916	0.18
Spain	23,043	4.8
Sweden	27,102	0.2
Thailand	7,435	0.16
Tunisia	7,094	0.91
UK	28,440	0.75

Sources: Santillo / Stringer / Johnston 2000: 17.
The World Bank 2007.

10.7. Annex 7: PCDD/PCDF concentrations in human tissues from different countries and different years (WHO-TEQ)

Country	Sampling year	PCDD/PCDF (in pg/g$_{fat\ wt.}$)
Canada	1976	202-2,961
Canada	1980	317-985
Canada	1984	1,107-1,899
Canada	1984	1,442-2,187
China	1984	13-700
Finland	1984	<2-7,700
Finland		344-958
France		696.3
France		200
Germany	1986	212-1,113
Greenland		332
India	1999-2000	170-1,300
Japan	1989	2,795
Korea	1994-1995	70-1,280
Korea		32.5
Russia	1997	26
Spain		1,812
Spain	1989-1999	693
Sweden		94-763
UK	1990-1991	1,217
USA	1986	164-286
USA	1984-1986	660
USA		<116-2,719
USA	1983-1984	428-695
Vietnam	1984-1985	422-4,708

Source: Kumar et al 2001: Supplementary Information. Page 1.