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Fight Environmental Crime

Illegal e-waste shipments from the EU to China

Quantitative and monetary analysis of illegal shipments and its environmental, social and economic impacts

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AUTHOR(S)

Kristof Geeraerts, Institute for European Environmental Policy (IEEP)

Konar Mutafoglu, IEEP

Andrea Illes, IEEP

With thanks to: Patrick ten Brink and Andrew Farmer

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ABSTRACT

This report provides a quantitative and monetary analysis of the environmental, human health and economic impacts of illegal e-waste shipments from the EU to China. The European Union's Waste Shipment Regulation bans the export of hazardous waste, including waste electrical and electronic equipment (WEEE), from the EU to non-OECD countries in the developing world. Since 2000, an import ban of e-waste has been officially implemented in China. Nonetheless, vast amounts of e-wastes from the EU are illegally entering China. This case study presents some of the key estimates of the scale of this e-waste trade and calculates the total volumes of e-waste that have been imported in China from the EU in 2005 and 2012. These illegal EU e-waste shipments into China affect the environment, human health and economies at multiple levels and carry significant risks on the ground. This report provides an overview on the quantitative environmental impacts of informal e-waste recycling in China, including impacts on air, dust, soil, sediments, and plants and presents the quantitative impacts of elevated lead levels in human body and IQ score of children in China. Furthermore, the negative impacts on water supply are due to contamination from e-waste recycling are monetised. Finally, the report provides an estimate on the EU e-waste recycling industry's economic loss and the job losses in the EU e-waste recycling industry as a result of these illegal e-waste shipments.

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LIST OF ABBREVIATIONS

BMD	benchmark dose
BMDL	benchmark dose level
bw	body weight
CAER	Coalition for American Electronics Recycling
Cd	Cadmium
EEE	electrical and electronic equipment
EFSA	European Food Safety Authority
EPA	Environmental Protection Agency
FAO	Food and Agriculture Organisation
FEVC	forced expiratory vital capacity
FoE	Friends of the Earth
FTE	full-time equivalent
FVC	forced vital capacity
kt	kilo tonnes = 1000 tonnes
µg	microgram=10^{-6} grammes
ng	nanogram=10^{-9} grammes
NGO	non-governmental organisation
OECD	Organisation for Economic Co-operation and Development
PAHs	polycyclic aromatic hydrocarbons
Pb	lead
PBDEs	polybrominated diphenyl ethers
PCBs	polychlorinated biphenyls
PCDD/Fs	polychlorinated dibenzo dioxins/furans
pg	picogram= 10^{-12} grammes
PM	particulate matter
POPs	persistent organic pollutants
PPP	purchase power parity
SD	standard deviation
StEP	Solving the E-Waste Problem

TDI	total daily dietary intake
TEQ	toxic equivalent
TSP	total suspended particles
UEEE	used electrical and electronic equipment
UNODC	United Nations Office on Drugs and Crime
WEEE	waste electrical and electronic equipment
WHO	World Health Organisation
WP	work package
WSR	Waste Shipment Regulation
Zn	zinc

Executive summary

In recent years, the cross-border transport of waste electrical and electronic equipment (WEEE) has significantly increased, which also led to the rise of illegal shipments of e-waste from developed countries to the developing world. At the international level, it is the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal which seeks to provide enhanced control over the transboundary movements of hazardous wastes, including e-waste. The EU, together with its Member States, is a party to the Basel Convention since 1994 and the convention is translated into EU law via the EU Waste Shipment Regulation, which bans the export of hazardous waste, including e-waste, from the EU to non-OECD countries in the developing world. Despite China's official e-waste import ban, which was introduced in 2000, China represents the largest downstream destination for e-waste exported from Europe and North America. According the United Nations Office on Drugs and Crime, approximately 80 per cent of the total global amount of e-waste goes to Asia, out of which 90 per cent ends up in China (UNODC, 2013). Most of the illegally imported e-waste enters China's informal refurbishment and recycling sector, which lacks environmental, health and safety standards.

The illegal EU e-waste shipments into China affect the environment, human health and economies at multiple levels and carry significant risks on the ground. This study aims to provide an insight into the negative economic impacts in the EU and the negative environmental and human health impacts in China and aims to quantify and monetise these impacts. Despite the growing body of literature available on illegal e-waste shipments empirical data suffers from high uncertainties and data for instance on the volumes of illegally exported e-waste from the EU to China cannot be considered fully reliable. Furthermore, calculations of monetary figures on the environmental, health and economic impacts of these e-waste trades have to often use assumptions and extrapolations. The e-waste volume figures and monetary impacts presented in this case study therefore should be seen as rough estimates and should be treated with caution.

Volumes of e-waste shipped from the EU to China

Quantifying the illegal export of e-waste from the EU (to China) is especially challenging as there is very little clear information upon which estimates can be based. For this exercise, estimates from 2005 and 2012 have been used on the following aspects:

- The amount of e-waste generated in the EU.
- The illegal share of the exported amount of e-waste from the EU.
- The EU share of illegally imported e-waste into China.

Using the above information it was estimated that **for 2005 and 2012 respectively around 0.74 and 1.16 million tonnes of e-waste have been imported in China from the EU**. In order to incorporate the underlying uncertainties related to these estimates in this case study we also propose a 'minimum China import scenario' and a 'maximum China import scenario'.

Environmental impacts

The illegal export of e-waste from the EU to China has resulted in the release of large amounts of contaminants in the local environment. The potential annual emissions of some environmental contaminants associated with e-waste imported illegally in China from the EU were estimated. It was for instance estimated that respectively **10 and 16 tonnes of PCBs from EU e-waste were potentially released in the Chinese environment in 2005 and 2012**.

The environmental impacts of the activities in the informal refurbishment and recycling sector lead to economic losses and additional costs. For example, due to local contamination of soils and water resources, drinking water needs to be brought in from other regions. It is estimated that in Guiyu, with an population

of about 150,000 in the year 2013, establishing a piped water supply resulted in annual additional cost of around €1.6 million.

Human health impacts

As to health impacts, this study demonstrates that illegal exports from the EU are significantly increasing incidences of chronic disease in China, threatening not just workers but also current residents of e-waste recycling areas and adjacent regions and future generations. In order to demonstrate the health impacts, figures on the routes of exposure, on the human body burden and on scientifically established associations and/or causal links between e-waste exposure and several kinds of diseases and other health impacts are presented. Furthermore, a more detailed quantification was carried out for the impacts of lead poisoning resulting from e-waste exposure on children's neurological development, expressed in terms of children's IQ scores. For China as a whole it is conservatively estimated that around **81,300 children (58,000-93,000) born in the period 1995-2013 have been affected in their neurological development** as a result of e-waste exposure. It was subsequently estimated that these children in China **lost about 97,560 IQ points (69,600-111,600)** as a result of informal e-waste recycling and dumping activities. This amounts to **an average reduction of intelligence of 1.2 points per child**.

Economic impacts

As to the economic impacts of illegal exports of e-waste, it is estimated that the 2.98 million tonnes of illegally exported e-waste from the EU in 2012 correspond roughly with **€31.2 million to €37.5 million loss in profits to the EU e-waste recycling industry**. If one looks at the e-waste **exports to China only (1.16 million tonnes in 2012), the EU recycling industry is estimated to have lost €12.2 million to €14.6 million in profits in 2012**. Assuming that the average intrinsic value of WEEE is about €300 per tonne, **the economic value lost to the EU as a result of illegal exports to China is roughly estimated at €348 million for 2012 only**. The **economic value lost to the EU** as a result of all illegal exports out of the EU is **estimated at €892 million for 2012**.

As to the impact on jobs, the illegal export of e-waste from the EU in 2012 is estimated to represent a **potential loss** of about **38,000 FTE recycling jobs in the EU**. Assuming a typical multiplier of 2, these direct recycling jobs would result in another **38,000 indirect and induced jobs**, for a total of **76,000 jobs**. The **illegal export to China** in particular is estimated to represent a potential loss of circa **14,900 FTE jobs** and another **14,900 indirect and induced jobs**, for a total of **29,800 jobs.** A loss of 14,900 FTE jobs goes along with an estimated loss of economic value added of around €780 million. Though this figure needs to be treated with caution due to data availability and quality issues, it is indicative of the significance of losses in economic terms.

Major gaps and research needs

The quantitative and economic assessments in this report rely on a number of assumptions, while facing considerable data availability and quality issues. The analysis combines different sources, which themselves carry uncertainties. Consequently, a number of analyses that would be useful could not be conducted, such as an estimate of the economic impacts on human health and the health sector in regions with considerable activities in the informal e-waste sector. Likewise, the economic implications of contaminated water and soils could not be depicted entirely. For example, it would be desirable to assess the local and regional clean-up costs with regard to soil.

1 Introduction

1.1 Key aspects of illegal e-waste shipment from the EU to China

In recent years the cross-border transport of waste electrical and electronic equipment (WEEE) has significantly increased which also led to the rise of illegal shipments of e-waste from developed countries to the developing world. At the international level it is the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal which seeks to provide enhanced control over the transboundary movements of hazardous wastes, including e-waste. The EU, together with its Member States, is a party to the Basel Convention since 1994 and the convention is translated into EU law via the EU Waste Shipment Regulation (WSR)[1]. Compared to the Basel Convention the EU WSR poses stricter control on the export of e-waste as it bans the export of hazardous waste from the EU to non-OECD countries in the developing world intended not only for disposal but also recycling/recovery.[2] Despite these stringent regulations vast amount of e-waste still leave the EU illegally.

Box 1: Definition of waste electrical and electronic equipment in EU legislation

According to the EU Waste Electrical and Electronic (WEEE) Directive e-waste "*means electrical or electronic equipment which is waste within the meaning of Article 3(1) of Directive 2008/91/EC, including all components, sub-assemblies and consumables which are part of the product at the time of discarding"*.

The Waste Framework Directive (2008/91/EC) defines waste as "*any substance or object which the holder discards or intends or is required to discard".*

Source: Directive 2008/91/EC and Directive 2012/19/EU

Although the import of WEEE into China has been officially banned since 2000[3] China represents the largest downstream destination of EU e-waste export and according to the United Nations Office on Drugs and Crime approximately 80 per cent of the total global amount of e-waste goes to Asia, out of which 90 per cent ends up in China (UNODC, 2013). Most of the illegally imported e-waste enters China's informal refurbishment and recycling sector, which lacks environmental, health and safety standards. The main informal refurbishing and recycling sites are located around key waterways and ports of entry and include towns like Guiyu, Taizhou and Longtang (see Figure 1).

[1] Regulation (EC) No 1013/2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste. OJ L 190, 12.7.2006

[2] The Basel Convention only forbids the export of WEEE for disposal from OECD countries to non-OECD countries.

[3] The ban was introduced by the Notification of the Import of the Seventh Category of Solid Waste No. 19/2000.

Figure 1: Major informal e-waste recycling and dismantling sites in China[4]

Source: Ni and Zeng, 2009, p. 3992

The illegal EU e-waste shipments into China affect the environment, human health and economies at multiple levels and carry significant risks on the ground (see Figure 2). This study aims to provide an insight into the negative economic impacts in the EU and the negative environmental and human health impacts in China and a quantitative and monetary analysis of these impacts.[5] It is to be said that while there is a growing body of literature available on illegal e-waste shipments, empirical data suffers from high uncertainties. There are significant data reliability problems with the estimates on the e-waste volumes exported from the EU into China; the chapter in this study assessing the extent of the illegal activities therefore should be treated with caution. Furthermore, the quantification and monetisation of environmental, human health and economic impacts presented in this study should be seen as rough estimates which often use assumptions and extrapolations.

[4] Beijing is only indicated for the reader's geographic reference.

[5] As part of the EFFACE project other key aspects of illegal e-waste export from the EU to China, including the effectiveness of legislation governing the illegal activities, key stakeholders involved in the exports and the links to organised crime, were analysed in another case study. For more information see: Geeraerts et al. 2015.

Figure 2: Overview of key impacts of illegal e-waste shipment from the EU to China

Source: own representation. Note: key impacts analysed in this study are highlighted in bold.

1.2 Structure of the report

The remainder of the report is structured as follows:

- Chapter 2 provides an overview of the literature available on the volume of e-waste illegally exported from the EU to China and the environmental, health and economic impacts of these illegal shipments.
- Chapter 3 describes the methodological approach that has been applied in this study.
- Chapter 4 presents the quantitative analysis of the volumes of e-waste illegally shipped from the EU to China and the environmental, health and economic impacts of such illegal activities. This chapter also presents a brief case study on the impacts of elevated lead levels in children on their IQ scores.
- Chapter 5 presents the monetary analysis of environmental, health and economic impacts of illegal e-waste export from the EU to China.
- Chapter 6 outlines the main conclusions of the study.
- Annex 1 provides details of the Chinese soil quality standards.
- Annex 2 provides population statistics of Guiyu.

2 Background: summary of available literature

2.1 Illegal exports from the EU and imports in China

A number of publications and websites were found to present estimates of the amount of waste electrical and electronic equipment (WEEE) generated globally (e.g. Breivik et al. 2014 and StEP 2015) and generated in and exported from the EU (e.g. StEP 2015, Zoeteman et al. 2009 and Huisman et al. 2008) and from specific European countries to developing countries (StEP 2015). Literature is available on major sourcing countries of WEEE, such as the Netherlands (e.g. Huisman et al. 2012), Belgium (e.g. Seum and Hermann 2010), Germany (e.g. Sander and Schilling 2010) and the UK (e.g. Interpol 2009). Several publications were found to present rough estimates of the amount of WEEE imported illegally into China (e.g. UNODC 2013; Wang et al. 2013; Early 2013). The volume figures identified in relevant literature are seen as rough estimates which often use assumptions and extrapolations. An obvious reason for inaccuracy lies in the nature of any types of illegal activity but for instance the lack of differentiation between new and used EEE exported from the EU in statistical databases also makes data inaccurate.

2.2 Environmental and health impacts

Quite a number of studies have been published on the environmental and health impacts of e-waste recycling in China. Many studies investigate environmental and/or health impacts in Guiyu (e.g. Labunska et al. 2013; Leung et al. 2006; Leung et al. 2008; Bi et al. 2010; Deng et al. 2006; Zhu et al. 2012; Chan et al. 2013) and Taizhou (e.g. Han et al. 2010; Bai et al. 2011; Tang et al. 2010a, 2010b; Fu et al. 2008; Leun et al. 2010). Other places in China where recycling activities take place have been studied as well, such as Jiangsu (e.g. Xue et al. 2012), Shanghai (e.g. Fang et al. 2013), Longtang (e.g. Luo et al. 2011), Shijiao (Luo et al. 2008), Fengjiang (e.g. Wen et al. 2011) and Qingyuan (e.g. Zheng et al. 2012; Luo et al. 2009).

Many studies focus on **environmental** effects arising from one particular type of pollutant. Heavy metals have received a lot of attention from researchers, to give one example (Wu et al; 2014; Song & Li 2014a; Bi et al. 2010; Deng et al. 2006). Song & Li (2014a) for instance have reviewed studies in relation to environmental effects of heavy metals from e-waste recycling activities in China. Other studies focusing on metals have been carried out by among others Alabi et al. (2012), Zhao et al. (2010, 2011), Zhang and Hang (2009), Fu et al. (2008) and Bai et al. (2011). Several environmental and health studies on PBDEs have been found (e.g. Labunska et al. 2013). Studies focusing on polychlorinated biphenyls (PCBs) only are also quite common (e.g. Wang et al. 2011; Han et al. 2010). Some studies focus on the broader group of persistent organic pollutants (POPs), which include along others polybrominated diphenyl ethers (PBDEs), PCBs and polychlorinated dibenzo dioxins/furans (PCDD/Fs) (Bao et al. 2012).

Some studies on environmental impacts focus on concentrations of pollutants in several environmental media simultaneously (Labunska et al. 2013; Song & Li 2014a). Most studies however focus on one or two media only such as water and/or sediment (Bao et al. 2012; Leung et al. 2006), soil and/or vegetation (Alabi et al. 2012; Wang et al. 2011; Wu et al. 2014; Zhao et al. 2010, 2011; Fu et al. 2008) or air (Bi et al. 2010; Deng et al. 2006; Han et al. 2010; Fang et al. 2013) thereby usually studying several types of pollutants. Quite a number of studies in China deal with heavy metal contamination of (food) plants, mostly focusing on rice (Zhao et al. 2010-2011; Fu et al. 2008), though other plants such as vegetables and wild plants have also been studied (Luo et al. 2011).

As to **health** impacts, studies can be divided into four categories: studies focusing on certain routes of exposure (e.g. dietary intake), studies focusing on the human body burden (e.g. blood lead levels), studies focusing on the health effects (e.g. increased incidence of respiratory diseases); and studies bringing together these different health aspects of (informal) e-waste recycling and dumping (Song & Li 2014b).

As to the routes of exposure, most studies focus on dietary intake (e.g. Chan et al. 2013; Qin et al. 2011; Labunska et al. 2013; Leun et al. 2010) while some studies focus on inhalation from the air (e.g. Xing et al.

2009; Wen et al. 2011) and soil/dust ingestion and dermal exposure (Ma et al. 2008). The most commonly studied pollutants here are PBDEs. Other pollutants included in the studies are PBBs (e.g. Zheng et al. 2012), PCBs (e.g. Xing et al. 2009), PCDD/Fs (e.g. Song et al. 2011), PAHs (e.g. Wang et al. 2012b), heavy metals (Fu et al. 2008) and dioxin-like chemicals (Frazzoli et al. 2010).

As to studies focusing on body burdens of e-waste exposure, many have clearly indicated a causal relationship between emissions from informal e-waste recycling and dumping activities and the level of pollutants in human bodies (Song & Li 2014b). These studies commonly include the following types of human tissues: placenta (e.g. Leung et al. 2010; Zhang et al. 2011; Guo et al. 2010), umbilical cord blood (e.g. Wu et al. 2011), breast milk (e.g. Leung et al. 2010), blood and serum (e.g. Yang et al. 2013; Zhang et al. 2012; Wang et al. 2011; Huo et al. 2007), urine (e.g. Wang et al. 2011b), hair (e.g. Wang et al. 2009c) and other tissues (Zhao et al. 2009).

Many studies have been conducted on the health consequences of exposure to e-waste in China. The majority of select studies reviewed by Grant et al. (2013) showed associations between exposure to e-waste and physical health outcomes, including lung function (Zheng et al. 2013), physical growth (Zheng et al. 2013; Huo et al. 2007), reproductive health (Guo et al. 2010, 2012; Wu et al. 2011, 2012; Xu et al. 2012), thyroid function (e.g. Zhang et al. 2010) and changes in cellular expression and function (Yuan et al. 2008; Liu et al. 2009; Chen et al. 2010; Wang et al. 2011a). Negative associations were also shown for blood lead levels on the one hand and mental health outcomes (Liu et al. 2011; Xu et al. 2012; Li et al. 2008a) and IQ scores in children on the other hand (Wang et al. 2012a).

In addition to articles reporting results from one study, review articles have been identified: on environmental effects of heavy metals from e-waste recycling (Song & Li 2014a), on the human body exposure of e-waste (Song & Li 2014b) and on the health consequences of e-waste exposure (Grant et al. 2013).

2.3 Economic impacts

Only a limited number of reports exist in which economic impacts have been assessed for the waste management/recycling sector in source countries. An Amec study from 2012 for instance has estimated the overall economic impact of illegal waste exports from the UK, including the loss in profits to WEEE treatment facilities in the UK (Amec 2012).

Economic/financial reports on status of the EU or American (electronic) waste markets are mostly very pricey and thus not readily available for the research team. A 2013 study (or at least a power point presentation) by Sullivan & Frost on the EU e-waste recycling market was freely available though (Sullivan & Frost 2013). A document from the WEEE Forum also includes several economic figures on the e-waste recycling sector, including the average intrinsic value of e-waste (WEEE Forum 2013). A UNODC study from 2013 also provides figures on the economic value of e-waste. The website of the European Recycling Platform provides figures on the value of certain precious metals contained in waste and used electronic equipment (ERC 2014).

As to jobs, a 2013 study for the Coalition for American Electronics Recycling (CAER) has calculated the number of jobs that could be created by diverting e-waste from landfill or illegal export (DSM 2013). A 2004 study by the London South Bank University (LEPU 2004) did the same for different types of waste within the context of London. A Friends of the Earth Report assessed the potential for job creation through higher rates of recycling in the UK and EU (FoE 2010). Several other reports assess the (actual or potential) number of jobs dependent on environment and resource efficiency improvements in general (e.g. Rademaekers et al. 2012).

3 Research Methodology

3.1 Environmental impacts

The environmental impacts have among others been **quantified** through calculating the potential amounts of pollutants released in the Chinese environment originating from the illegal imports from the EU (building further on the quantification of the amounts of e-waste being shipped from the EU as a whole and from the EU to China in particular). The annual emission estimates of some contaminants are based on estimated concentrations in components of Swiss e-waste (figures from Morf et al. 2007) and on estimates of the 2005 and 2012 illegal imports in China from the EU. These concentrations are multiplied with the estimated amounts of e-waste that are being shipped illegally from the EU to China.

In addition, concentrations of pollutants (mostly heavy metals) in different environmental media (air, dust, sediment, soil, plants) in traditional e-waste recycling towns such as Guiyu and Taizhou have been presented to sketch a quantitative picture of the pollution resulting from the informal recycling of e-waste. It was however not possible to determine the exact share of pollution stemming from European e-waste at particular sites, although figures are presented which might give a rough indication of the share of EU-borne e-waste processed in China. In this respect it should be noted that these Chinese recycling towns also recycle or have recycled huge amounts of e-waste imported from other developed countries (US in particular) and are probably recycling more and more e-waste generated domestically as living standards and domestic consumption in China have been rising substantially in the last 10 years.

The environmental impacts have been **monetised** by estimating the (actual) direct costs for constructing water supply infrastructure (drinking water pipelines) in Guiyu.

3.2 Health impacts

As to the **quantification** of health impacts on e-waste workers and inhabitants of e-waste recycling towns (and inhabitants of neighbouring areas) figures on the routes of exposure, on the human body burden and on scientifically established associations and/or causal links between e-waste exposure and several kinds of diseases and other health impacts are presented. For purposes of illustration and to keep track it was decided to present select figures, mostly in relation to heavy metal pollution in two traditional informal e-waste recycling towns, i.e. Guiyu and Taizhou. A more detailed quantification has been carried out for the impacts of lead poisoning on children's neurological development. Similar quantifications can be done for other pollutants, for other health impacts and for other groups of people (children vs. adults, e-waste workers vs. inhabitants, inhabitants of e-waste recycling towns vs. inhabitants of adjacent regions) but these are not presented in this publication. Quantification efforts in this respect might bump into several obstacles such as a lack of data and/or limited access to data, especially data on the number of people effectively affected in China by e-waste exposure and the precise contribution of EU-borne e-waste to the overall e-waste exposure and to the overall exposure to pollutants.

As to the impacts of lead poisoning on children's neurological development, the number of children exposed to critical blood lead exposure in Guiyu have been estimated and subsequently extrapolated to China as a whole (i.e. to the number of children living in e-waste recycling areas). For the extrapolation estimates from Breivik et al. (2014) on the number of e-waste recycling workers in Guiyu vs. China as a whole and on the tonnes of e-waste being informally processed in Guiyi vs. China have been used.

For determining the number of children affected by IQ losses the 95th percentile lower confidence limit of the benchmark dose (BMD) of 1 per cent extra risk ($BMDL_{01}$) determined by the European Food Safety Authority (EFSA) Panel on Contaminants in the Food Chain at 12 µg/L (B-Pb) has been used (see Box 2). This level has been set by the EFSA Panel as a as a reference point for the risk characterisation of lead when assessing the risk of intellectual deficits in children measured by the Full Scale IQ score.

Subsequently the total amount of IQ loss has been quantified based on the assumption that for each 10 µg/dl of blood lead, IQ is reduced by 2 points.

As to the **monetisation** of the health impacts, the following could be assessed: opportunity costs in terms of *lost productivity* (i.e. decreased current value of expected lifetime revenues); *direct resource educational costs* related with compensatory education; opportunity costs of *lost income during remedial compensatory education*; *medical treatment costs*; and, *disutility* resulting from human development disabilities. In order to estimate the medical treatment costs in China for instance, one could start working from a range of values that correspond to the lowest and highest values given in existing studies – we have identified 2 studies from the US. These figures need to be adapted to the situation in China if one wants to use these for estimating the medical treatment costs. This also requires an analysis into the medical treatment of certain diseases in China and/or in Chinese e-waste recycling areas in particular: to what extent get lead-poisoned children a medical treatment and what type of treatment do they get.

Box 2: The benchmark dose approach

In general, a dose-response relationship describes the relationship of the likelihood and severity of adverse health effects (the responses) and the amount and condition of exposure to an agent (the dose provided). The benchmark dose (BDM) approach is applicable to all toxicological effects. The BDM by definition is a dose level which is associated with a specified change in response, the Benchmark Response (BMR). The BMDL is the BMD's lower confidence bound and it is usually used as a reference point. For instance, for a BMR of 5 per cent the BMDL, the benchmark dose lower confidence limit, can be interpreted as $BMDL_{05}$ and it means a dose where the response is likely to be smaller than 5 per cent. The term 'likely' is defined by the statistical confidence level, usually 95 per cent.

Source: EFSA 2009, p. 7-12

3.3 Financial/economic impacts

The economic impacts for Europe resulting from the illegal export of e-waste are twofold: the economic loss to the EU e-waste recycling sector (loss in profits and loss of economic value) and the loss of jobs in this sector. Our methodology for **estimating potential loss of jobs** in the EU e-waste recycling sector is based on best available published data for the EU27, the UK and the US and applying lessons learnt from more detailed studies on jobs per 1,000 tonnes of material recycled, and multipliers for indirect and induced jobs (DSM 2013; LEPU 2004; CASCADIA 2009). We have made some simplifying assumptions in arriving at conservative estimates of potential job loss in the recycling sector.

Employment loss from illegal e-waste exports outside of the EU may be calculated by following an approach whereby the lost total turnover for the EU e-waste recycling sector is divided by the sector's labour intensity (i.e. the level of turnover per full-time equivalent (FTE) job). As no data were retrieved on the sector's labour intensity, another approach has been followed, i.e. an approach using the lowest estimates for coefficients for FTE jobs for diverting 1,000 tonnes of e-waste from landfill, incineration or illegal export. It should be noted that some of these jobs could be overseas if recycling rates are achieved by exporting recycled material. Subsequently, indirect and induced (loss of) employment has been estimated by applying a typical multiplier of 2 taken by 2013 study commissioned by the Coalition for American Electronics Recycling. Alternatively, multipliers could be applied from a 2010 study by Friends of the Earth UK (FoE 2010). In this study indirect and induced (loss of) employment has been estimated by applying separate multipliers for indirect and induced jobs: a multiplier of 1.50 to calculate the indirect jobs resulting from direct employment in the recycling sector and a multiplier of 1.75 to calculate the induced jobs. The authors the Friends of the Earth (FoE) study consider these multipliers as conservative, as these are lower than those generally applied in other economic sectors (FoE 2010).

The direct job loss for the EU e-waste recycling industry may be **monetised** by multiplying the number of jobs lost with the average economic value added per employee in the sector.

The **loss in profits** for the EU e-waste recycling sector arising from illegal e-waste exports may be monetised by extrapolating an estimate of the loss in profits to the UK industry (taken from an existing study) to the EU as a whole. The **economic value lost** to the EU may be monetised by building further on an estimate of the average intrinsic value of WEEE per tonne (and multiplying this average value with the estimated volumes of WEEE exported out of the EU). In addition or alternatively, the economic value lost may be monetised (fully or partially) using a bottom-up approach: the monetary value of precious metals within WEEE exported from the EU may be estimated by building further on existing estimates of the value of precious metals contained in one kilogram of WEEE.

4 Quantitative analysis of impacts

4.1 Volumes of e-waste shipped from the EU to China

Quantifying the illegal export of e-waste from the EU (to China) is especially challenging as there is very little clear information upon which estimates can be based. Nevertheless an attempt has been made to come up with estimates for 2005 and 2012.

As a first step the estimate by Zoeteman et al. (2009) of the amounts of e-waste imported from the EU to China in 2005 was taken. As a second step the e-waste imported from the EU to China in 2012 was assessed thereby applying Zoeteman's methodology to 2012 figures.

Generation of WEEE in the EU

According to Zoeteman et al. (2009) 0.62 million tonnes of e-waste were imported from the EU to China in 2005. This estimate was calculated as follows. Firstly, the generation of WEEE in the EU in 2005 was calculated by multiplying the number of EU inhabitants by the average WEEE generated:

457,000,000 inhabitants x 0.015 tonnes (15 kg/inhabitant/year) = ***7,005,000 tonnes in 2005***

Zoeteman et al. (2009) estimated that:

- 50 per cent of this volume of e-waste was large household appliances (category 1 - fridges and washing machines): 7.5 kg/inhabitant/year;
- 10 per cent small household appliances (category 2 - vacuum cleaners, toasters) : 1.5 kg/inhabitant/year;
- 20 per cent office and communication waste (category 3 - computers, cell phones): 3.0 kg/inhabitant/year; and
- 20 per cent entertainment electronics (category 4 - categoryradios, TVs, stereos): 3.0 kg/inhabitant/year.

According to the StEP project **9,918,000 tonnes** of e-waste have been generated in the EU **in 2012** (StEP 2015c).

Export from the EU

Zoeteman et al. (2009) assumed that **10-20 per cent** of the total amount of **WEEE** generated in the EU is *illegally* exported (between 700,500 and 1,401,000 tonnes); furthermore **30 per cent** of **used computers, TVs and mobiles** are *legally* exported to developing countries for reuse (approximately 840,600 tonnes). It is important to note that part of this UEEE either becomes WEEE during the transport (e.g. if there is no appropriate protection of the product during the transport) or a short period of time after arriving in the destination country (BIO IS 2013) and therefore are treated as illegally exported WEEE in the below calculation. In this context it is also interesting to note the typical lifespan of different EEE items (see Table 1).

Table 1: Typical lifespan of various EEE items

Type of EEE	Typical lifespan (years)
Computer	3
Mobile telephone	2

Radio	10
Television	5
Video recorder and DVD player	5
Dish washer	10
Electric cooker	10
Freezer	1
Kettle	3
Microwave	7
Toaster	5
Washing machine	8

Source: Robinson 2009

By adding up these figures Zoeteman et al. (2009) concluded that **1.9 million tonnes** of WEEE and used EEE left the EU in **2005** (see also Table 2 and Table 3).

0.15 x 7,005,000 (free riders part) + 0.3 x (0.2 + 0.2) x 7,005,000 (tonnes categories 3 + 4 WEEE) = ***1.9 million tonnes in 2005***

According to a study for the European Commission (BIO IS 2013) around **15 per cent of used electrical and electronic equipment (UEEE)** is exported, mainly for re-use. As no detailed data are available for 2012 on the amounts within the four WEEE categories applied by Zoeteman et al. (2009), we apply this percentage of 15 to the UEEE figure as a whole instead of applying the 30 per cent to only two out of the four categories.

0.15 x 9,918,000 (free riders part) + 0.15 x 9,918,000 (used EEE legally exported for reuse) = ***2,975,400 tonnes*** *or ca.* ***2.98 million tonnes in 2012***

Illegal imports of WEEE in China

Zoeteman et al. (2009) assumed that 20 per cent of EU export ends up in West-Africa and 20 per cent in Eastern Europe and North Africa. The remainder 60 per cent was assumed to go to Asia of which 65 per cent was assumed to go to China and 35 per cent to India, thereby neglecting export to smaller other Asian Countries. The import in China of e-waste from the EU was calculated as follows:

0.6 x 0.65 x 1,900,000 tonnes = 741,000 tonnes ***≈ 0.74 million tonnes (in 2005)***

A similar calculation was done for 2012 thereby assuming that only the total amount of e-waste exported from the EU has changed and that the relative distribution of these exports over the various destination countries has not changed: in other words it was assumed that in 2012 ca. 40 per cent of EU exports still end up in China.

0.6 x 0.65 x 2,975,400 tonnes = 1,160,406 tonnes ***≈ 1.16 million tonnes (in 2012)***

Table 2: Total export of e-waste from the EU and import to China from EU, estimations for 2005 for overall WEEE and per WEEE category

WEEE category	Total export from EU in 2005 (in million tonnes)	China import from EU in 2005 (in million tonnes)
Total	**1.9**	**0.74**
Category 1: large household appliances	0.97	0.39
Category 2: small household appliances	0.19	0.07
Category 3: office and communication equipment	0.37	0.14
Category 4: entertainment electronics	0.37	0.14

Source: adapted from Zoeteman et al. (2009). Note: large household appliances include fridges and washing machines; small household appliances include vacuum cleaners and toasters; office and communication equipment include computers and cell phones; entertainment electronics include radios, TVs and stereos. As indicated above Zoteman et al. (2009) estimated that of the total amount of generated WEEE in the EU in 2005 50 per cent are large household appliances, 10 per cent are small household appliances, 20 per cent are office and communication equipment and 20 per cent were entertainment electronics. For the export and import figures presented in this table it was assumed that the share of the categories is the same as for the generated WEEE.

Table 3: Estimates of e-waste generated in the EU, e-waste exported from the EU and e-waste imported in China in 2005 and 2012 (in million tonnes)

Year	E-waste generated in the EU	E-waste exported from the EU	E-waste imported in China	E-waste imported in China from EU
2005	7,005,000	1,900,000	2,030,000[a]	**741,000**
2012	9,918,000	2,975,400	8,000,000[b]	**1,160,406**

Source: own representation. Note: [a] estimate found in Wang et al. (2013); [b] estimate from UNODC (2013)

In order to incorporate the uncertainty about this percentage of EU exports ending up in China[6], we might want to work with a 'minimum China import scenario' and a 'maximum China import scenario', alongside this 'default scenario'. This approach might at the same time incorporate the uncertainty surrounding the percentage of EU generated e-waste that is 'guesstimated' to be illegally exported outside of the EU, by working with a 'minimum EU export scenario' and a 'maximum EU export scenario'. If we combine these two sets of minimum and maximum scenarios, we might come up with a 'minimum export/import scenario' and a 'maximum export/import scenario'.

For the below presented minimum and maximum scenarios the following estimates were used:

- According to Zoetman et al. (2009) 10-20 per cent of the total amount of WEEE generated in the EU is illegally exported.
- According to a study for the European Commission (BIO IS 2013) around 15 per cent of used electrical and electronic equipment (UEEE) is exported, mainly for re-use.

[6] Given control measures being implemented in China, future flows of e-waste management may be diverted to less affluent countries or jurisdictions where costs related to environmental regulation are minimised (Lepawsky & Billah 2011; Lepawsky & McNabb 2010). This is however extremely difficult to monitor and quantify.

- Finally, Zoetman et al. (2009) estimated that 60 per cent of EU export WEEE ends up in Asia of which 65 per cent was assumed to go to China, i.e. approximately 40 per cent of EU WEEE export is shipped to China.

Based on the above estimates, it is suggested to use following percentages for the '**minimum export/import scenario**':

- 10 per cent of EU WEEE is exported illegally out of the EU,
- 10 per cent of the EU WEEE is exported legally as UEEE, and
- 35 per cent of these EU exports are imported in China.

Table 4: The minimum export/import scenario in 2005 and 2012 (in tonnes)

	2005	2012
E-waste illegally exported from the EU	7,005,000 x 0.1 = 700,500	9,918,000 x 0.1 = 991,800
E-waste legally exported from the EU as UEEE	7,005,000 x 0.1 = 700,500	9,918,000 x 0.1 = 991,800
Total amount of e-waste exported from the EU	700,500 + 700,500 = **1,401,000**	991,800 + 991,800 = **1,983,600**
E-waste exported from the EU imported into China	1,401,000 x 0.35 = **490,350**	1,983,600 x 0.35 = **694,260**

Source: own calculation. Note: According to Zoetman et al. (2009) 7,005,000 tonnes of WEEE were generated in the EU in 2005, while StEP project estimated that 9,918,000 tonnes of e-waste have been generated in the EU in 2012 (StEP 2015c).

The '**maximum export/import scenario**' would be as follows:

- 20 per cent of EU WEEE is exported illegally out of the EU,
- 20 per cent of the EU WEEE is exported legally as UEEE, and
- 45 per cent of these EU exports are imported in China.

Table 5: The maximum export/import scenario in 2005 and 2012 (in tonnes)

	2005	2012
E-waste illegally exported from the EU	7,005,000 x 0.2 = 1,401,000	9,918,000 x 0.2 = 1,983,600
E-waste legally exported from the EU as UEEE	7,005,000 x 0.2 = 1,401,000	9,918,000 x 0.2 = 1,983,600
Total amount of e-waste exported from the EU	1,401,000 + 1,401,000 = **2,802,000**	1,983,600 + 1,983,600 = **3,967,200**
E-waste exported from the EU imported into China	2,802,000 x 0.45 = **1,260,900**	3,967,200 x 0.45 = **1,785,240**

Source: own calculation. Note: According to Zoetman et al. (2009) 7,005,000 tonnes of WEEE were generated in the EU in 2005, while StEP project estimated that 9,918,000 tonnes of e-waste have been generated in the EU in 2012 (StEP 2015c).

4.2 Environmental impacts

As illegally imported e-waste by its nature is mostly processed in the informal Chinese recycling sector, the environmental impacts of e-waste shipments from the EU mostly relate to informal recycling activities in China (as opposed to formal recycling activities).

The intensive informal and thus uncontrolled recycling of e-waste in China has resulted in the release of large amounts of contaminants in the local environment, such as **heavy metals**, polybrominated diphenil ethers (**PBDEs**), polychlorinated dibenzo dioxins/furans (**PCDD/Fs**), polychlorinated biphenyls (**PBCs**), chlorofluorocarbons (**CFCs**) and polycyclic aromatic hydrocarbons (**PAHs**).
Table 6 lists the potential environmental contaminants associated with e-waste imported illegally in China from the EU. The annual emission estimates of some contaminants are based on concentrations in components of Swiss e-waste (Morf et al. 2007) and on the estimates of the 2005 and 2012 illegal imports in China from the EU (see previous chapter). Although recycling may remove some contaminants, large amounts still end up concentrated in e-waste recycling and dumping sites. To give one example: according to our rough estimates/calculations respectively **10 and 16 tonnes of PCBs** were (potentially) **released in the Chinese environment** in **2005 and 2012** as a result of the informal recycling and dumping of e-waste imported from the EU (see
Table 6). Other figures from the table are for instance the potential release of **1,258 and 1,972 tonnes of antimony** and of ca. **30,000 and 35,000 tonnes of copper** in 2005 and 2012 respectively.

In reality the amounts of contaminants released into the environment in China as a result of informal (and formal) e-waste recycling and dumping is multiple times higher as the figures above only relate to the imports from the EU. Whereas we estimated that in 2012 1.16 million were imported illegally from the EU experts estimate that in total 8 million tonnes of e-waste are imported in China each year (UNODC 2013). E-waste-related environmental problems however also result from China's rising domestic generation of e-waste. For 2012 it was estimated that 7,253,010 tonnes of e-waste were generated in China (StEP 2015b; see also Figure 3 in paragraph 4.4.2).

Field and laboratory research in China has shown that e-waste is significantly **degrading air, soil, and water quality**, as well as a **range of biota** (Walters & Santillo 2008). In Guiyu and other informal e-waste recycling centres concentrations of multiple pollutants including **heavy metals, PAHs, PBDEs, PCDD/Fs and PCBs** have been found to exceed various international standards and local norms, in some cases by several scale factors (Deng et al. 2007; Deng et al. 2006; Luo et al. 2007; Li et al. 2007; Leung et al. 2006; Wong et al. 2007). There also exists a more nuanced environmental impact from WEEE trade relating to global concerns about resource scarcity and sustainability. Whilst WEEE trade aims at recycling the valuable materials, it is an evidently **wasteful** and **energy intensive industry** and as such operates counter to global and EU ambitions for resource efficiency. There is also an **indirect impact on climate change** given the carbon insensitivity of the primary production of the substances of EEE. Illegal e-waste shipments also have adverse consequences for the ozone layer as obsolete refrigerators, freezers and air conditioning units contain ozone depleting substances such as CFCs which may escape from inadequately recycled or dumped items (Robinson 2009).

Informal recycling activities have caused in particular high concentrations of heavy metals (such as lead, cadmium, mercury, copper, zinc, etc.) in the surrounding air, dust, soils, sediments and plants. In the next paragraphs we focus - for the sake of maintaining the overview – on the environmental impacts related to heavy metals and lead and zinc in particular. We hereby refer mostly to studies investigating adverse environmental impacts in Guiyi and Taizhou, as the most representative locations for informal e-waste recycling. Studies on negative environmental impacts of e-waste recycling in other places in China (such as Jiangsu, Shanghai, Longtang, Shijiao and Fengjiang) have been identified but are not discussed within the

framework of this study. It should be noted that Taizhou has gradually phased out the informal recycling of e-waste as local manufacturing has shifted away from the production of electronics in recent years. As a result of this shift in local manufacturing and stricter regulation of polluting activities related to e-waste recycling (e.g. leaching of circuit boards), very little informal e-waste recycling has been identified in Taizhou in recent years (Wang et al. 2013). However, if informal recycling activities decrease or disappear in one place, these informal activities are usually shifted to other places (in or outside China). But also in Guiyu the public authorities are increasingly trying to regulate the informal recycling sector and to manage the environmental impacts from e-waste recycling and dumping, among others by remediating contaminated soil.

Table 6 provides a non-exhaustive list of potential environmental pollutants in China from informal e-waste recycling or dumping with the contaminants' typical e-waste concentration and emissions from e-waste imported from the EU in 2005 and 2012. Other important contaminants and their relationship with e-waste are presented in Table 7.

Table 6: Potential environmental pollutants in China from informal e-waste recycling or dumping

Contaminant	Relationship with e-waste	Typical e-waste concentration (mg/kg)	Emission in China from e-waste imported from EU in 2005 and 2012 (tonnes)[a]
Polychlorinated biphenyls (PCB)	Condensers, transformers	14	10.36 / 16.24
Antimony	Flame retardants, plastics	1,700	1258 / 1972
Cadmium (Cd)	Batteries, toners, plastics	180	133 / 209
Copper (Cu)	Wiring	41,000	30,340 /35,194
Lead (Pb)	Solder, CRTs, batteries	2,900	2,146 / 2,489
Mercury (Hg)	Fluorescent lamps, batteries, switches	0.68	0.50 / 0.79
Nickel (Ni)	Batteries	10,300	7,622 /11,948
Tin (Sn)	Solder, LCD screens	2,400	1,776 / 2,748
Zinc (Zn)		5,100	3,774 / 5,916

Source: adapted from Robinson 2009 and Morf et al. 2007. Note: [a] Assuming 0.74 million tonnes of illegal imports in China from the EU in 2005 and 1.16 million tonnes in 2012 (see 4.1).

Table 7: Important contaminants and their link to e-waste

Contaminant	Relationship with e-waste
Polybrominated diphenyl ethers (PBDEs) polybrominated biphenyls (PBBs) tetrabromobisphenol-A (TBBPA)	Flame retardants
Chlorofluorocarbon (CFC)	Cooling units, insulation foam
Polycyclic aromatic hydrocarbons (PAHs)	Product of combustion

Polyhalogenated aromatic hydrocarbons (PHAHs)	Product of low-temperature combustion
Polychlronated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs)	Product of low-temperature combustion of PVCs and other plastics
Americium (Am)	Smoke detectors
Beryllium (Be) Silicon-	Silicon-controlled rectifiers
Arsenic (As)	Doping material for Si
Barium (Ba)	Getters in cathode ray tubes (CRTs)
Chromium (Cr)	Data tapes and floppy disks
Gallium (Ga)	Semiconductors
Indium (In)	LCD displays
Lithium (Li)	Batteries
Selenium (Se)	Rectifiers
Silver (Ag)	Wiring, switches
Rare earth elements	CRT screens

Source: adapted from Robinson 2009 and Morf et al. 2007.

4.2.1 Air

Several studies have indicated high levels of heavy metals in the indoor and outdoor atmosphere of Guiyu (Bi et al. 2010; Deng et al. 2006). For instance the level of lead in total suspended particles (TSP)[7] from a typical workshop for recycling of printed circuit boards in Guiyu (4.42 µg/m^3) exceeds 28.5 times the upper limit of average air lead levels for non-urban European sites (these levels are usually below 0.15 µg/m^3). It also exceeds several times urban air lead levels in most European cities which are typically between 0.15 and 0.5 µg/m^3 (Theakston 2001) (see

Table 8). This – together with other results from the study – demonstrates that the recycling of printed circuit boards is an important contributor to heavy metal contamination of the local environment (Bi et al; 2010).

Deng et al. (2006) also demonstrated high levels of lead outdoors (both in TSP and $PM_{2.5}$), though obviously lower than inside e-waste recycling workshops (0.444 µg/m^3). However, in these air samples chromium (1.161 µg/m^3) and zinc (1.038 µg/m^3) were the metals the most present in TSP, followed by copper and lead (see also

Table 8).

These high levels of heavy metals in the air generate serious environmental and biological problems (Eckelman & Graedel 2007).

[7] Total suspended particles refer to the mass concentration of particulate matter in community air.

Table 8: Environmental pollution of heavy metals in air

Pollutants	Sampling time	Sampling site	Location	Sample size	Concentrations in µg/m³	Reference values	References
Lead and zinc in particles	09/2007	Circuit boards recycling workshop	Guiyu	4 TSP	Pb: 4.42 Zn: 3.32	Urban air lead levels in EU cities: 0.15 – 0.5 µg/m³	Bi et al. 2010
Lead and zinc in TSP and $PM_{2.5}$	08-09/2004.	Roof of a 3-story building, approximately 10 m above ground level	Guiyu	29 TSP, 30 $PM_{2.5}$	TSP: Pb: 0.444; Zn: 1.038 PM2.5: Pb: 0.392; Zn: 0.924		Deng et al. 2006

Source: adapted from Song & Li 2014a

4.2.2 Dust

The composition of settled dust can be an indicator as well of air pollution such as the heavy metal contamination in the atmosphere. This is because the composition of settled dust is similar to suspended particles in the atmosphere (Song & Li 2014a).

In 2004 Leung et al. (2008) found high average concentrations of heavy metals in e-waste workshop dust (e.g. Pb 110,000 mg/kg and Zn 4,420 mg/kg) and in dust on adjacent roads (e.g. Pb 22,600 and Zn 2,370 mg/kg) (see also Table 9). The lead in road dust was 330 and 106 times higher than for non-e-waste sites located 30 km and 8 km away.

More recently Zhu et al. (2012) investigated heavy metals in dust from family-run workshops in Guiyu. For lead and zinc high levels in workshop dust were found: 892 and 1120 mg/kg respectively.

From the above, it can be concluded that the average lead concentrations in workshop dust were much higher in the past. This might be explained by the fact that more primitive recycling techniques were used in the past in Guiyu, compared with (more formal) e-waste recycling in recent years (Song & Li 2014a).

Table 9: Environmental pollution of heavy metals in dust

Pollutants	Sampling time	Sampling site	Location	Sample size	Concentrations in mg/kg	Reference values	References
Pb and Zn in dust	12/2004	Workshop dust; adjacent roads	Guiyu	-	Workshop dust: Pb: 110,000; Zn: 4,420 Adjacent roads: Pb: 22,600; Zn: 2,370		Leung et al. 2008
Sb and As in dust	2010	Family-run workshops from 13 e-waste recycling villages	Guiyu	34 indoor dust	Sb: 6.1–232 As: 5.4–17.7		Bi et al. 2011
Pb and Zn in dust	2010	Family-run workshops in e-waste recycling impacted area	Guiyu	29 indoor dust	Pb: 892; Zn: 1120		Zhu et al. 2012

Source: adapted from Song & Li 2014a

4.2.3 Soil

Studies on heavy metal contamination of soil in China focus mainly on three typical informal e-waste recycling sites: Guiyu, Taizhou and Longtang (Song & Li 2014a). We have selected the studies on Guiyu and

Taizhou (see Table 10). Within these studies three types of sampling sites can be identified: (1) e-waste recycling and disposal sites (workshops, dump sites, open burning sites); (2) the roadside; and (3) agricultural soil (paddy soil, sewage irrigation areas).

Table 10: Environmental pollution of heavy metals in soil

Pollutants	Sampling time	Sampling site	Location	Sample size	Concentrations in mg/kg	Reference values	References
Pb and Zn in soil	08/2003	Burnt plastic dump site, printer roller dump site, reservoir (control area)	Guiyu	-	Pb: 104; 190; 55 Zn: 258; - ; 78	35; 250 100; 200	Leung et al. 2006
Pb in soil	08/2009 and 10/2010.	E-waste dumpsite soil, Guiyu roadside soil	Guiyu	20-30	Pb: 1431; 540.9	35; 250	Alabi et al. 2012
Pb in soil	11/2005	Paddy soil	Taizhou	6	Pb: 55.81	35; 250	Fu et al. 2008
Pb and Zn in soil	12/2007	Paddy soil	Luqiao in Taizhou	32	Pb: 46.84 Zn: 209.85	35; 250 100; 200	Zhang and Hang 2009
Pb and Zn in soil	03/2008	Sewage irrigation area	Luqiao in Taizhou	54	Pb: 152.96 Zn: 289.99	35; 250 100; 200	Bai et al. 2011
Pb and Zn in soil	08-09/2008	Agricultural soils	Luqiao in Taizhou	20	Pb: 115.1 Zn: 163.4	35; 250 100; 200	Tang et al. 2010a
Pb and Zn in soil	10/2006	Paddy soil	Wenling in Taizhou	96	Pb: 48.3 Zn: 137.0	35; 250 100; 200	Zhao et al. 2010, 2011
Pb, Zn and Hg in soil	08/2008	Large-scale e-waste recycling plants; large-scale gold recovering plants; household e-waste recycling workshops	Wenling in Taizhou	39	Pb: 163.9; 143.6; 956.5 Zn: 300.3; 203.4; 392.4 Hg: 0.4; 1.8; 221.7	35; 250 100; 200 0.15; 0.3	Tang et al. 2010b

Source: adapted from Song & Li 2014a and Wang & Shan 2013; Note: the reference values are the 1995 Chinese Class-1 environmental quality standards for soils (soil background levels) and the Class-2 quality standards for soils with a pH level below 6.5. The Chinese soil quality standards are referred to as the GB15618-1995 standards. See Annex A for full overview of the Chinese soil quality standards. Furthermore, the different concentrations refer to the specific sampling sites listed in the table.

Three studies have examined the heavy metal effects of e-waste recycling processes on soil in Guiyu (two of which are referred to in Table 10). The most seriously polluted soils were found in e-waste dumpsites in Guiyu. The levels of lead and zinc in soil samples at these sites were at least two times higher than those in samples from the control sites (Leung et al. 2006). A more recent study revealed even higher levels of heavy metal contamination, including in roadside soil (Alabi et al. 2012), especially by lead and copper (Pb: 540.9 mg/kg; Cu: 683.8 mg/kg). It can be concluded that, overall, soil contamination with heavy metals decreases as the distance from the e-waste recycling sites increases (Song & Li 2014a).

Taizhou (located in Zhejiang province) has been the target of most of the studies on heavy metals in the agricultural soil. The most serious soil pollution was found in Luqiao, Taizhou (Bai et al. 2011; Tang et al.

2010a), often exceeding the maximum allowable concentrations as determined by the Chinese national environmental quality standard for soils (the GB 15618–1995 standards, see Annex A: Chinese soil quality standards for more information). Equally, the average concentrations of lead (115.1 mg/kg), zinc (163.4 mg/kg), cadmium and copper in agricultural soils in Luqiao were higher than the Class 1 values (Tang et al. 2010b).

As Taizhou is located in Zhejiang province, the most important producer of rice in China, it was also subject to studies on heavy metal levels in paddy soil. Zhang and Hang (2009) found that paddy soils from Luqiao were heavily contaminated with cadmium (6.4 mg/kg) and weakly contaminated with copper (256.4 mg/kg) and zinc (209.9 mg/kg).

In addition, a study by Fu et al. (2008) indicated that the paddy soil in one village in Taizhou was primarily contaminated by cadmium (1.19 mg/kg), followed by copper (98.8 mg/kg). Equally, the paddy soils in Wenling (Taizhou) were also contaminated with heavy metals including lead and zinc and for some areas potential high-risk levels of cadmium, copper, nickel and zinc were indicated (Zhao et al. 2010, 2011). A study by Tang et al. (2010b) found extremely high levels of contamination by mercury, but also by lead and zinc. The soil samples of the family e-waste recycling workshops in particular showed contamination levels significantly higher than the respective Chinese soil quality standards (see Table 10).

Box 3: The 1995 Chinese environmental quality standards for soil

According to Wang & Shan (2013) these standards urgently need to be revised. There is lack of consideration of human exposure risk. There is a need for covering more contaminants and various land uses. The standards currently focus on farm land, vegetable and tea producing fields, orchards, soil, pastures and natural reserved areas.

More detailed information on the GB15618-1995 soil quality standards are presented in Annex A.

Source: Wang & Shan 2013

4.2.4 Sediments

Sediments can absorb and accumulate pollutants and act as a contamination source even long after the pollution has occurred or abated. Polluted sediments impose negative impacts on aquatic organisms and human beings through the food web (Song & Li 2014a).

Table 11: Environmental pollution of heavy metals in sediment

Pollutants	Sampling time	Sampling site	Location	Sample size	Concentrations in mg/kg	Reference values	References
Pb and Zn	08/2003	Duck pond A, duck pond B, Lianjiang River 1, River 2, River 3, reservoir	Guiyu	-	Pb: 57.7; 53.1; 316; 94.3; 118; 39.4 Zn: 79.6; 84.5; 86.8; 249; 175; 45.2	-	Leung et al. 2006
Pb, Zn and Cu	04/2006	Lianjiang River and Nanyang River	Guiyu	-	Pb: 54.97; 394.5 Zn: 133.72; 482.75 Cu: 66.7; 2153.88	-	Wang et al. 2009a-b
Pb and Cu	06/2007	Nanguan River	Taizhou	-	Pb: 377.33 Cu: 4787.5	-	Chen et al. 2010

Source: adapted from Song & Li 2014a

Table 11 shows the heavy metal sediment pollution in rivers and ponds nearby Guiyu and Taizhou. The first study referred to in the table indicates that the levels of heavy metals at sampling site "Lianjiang River 2" (which was closer to the e-waste recycling site than the other sampling sites) were highest of all sampling sites, except for the lead level. Compared to the control area (reservoir), the sediment pollution of heavy metals of the sampling sites in Guiyu was more serious (Leung et al. 2006).

Wang et al. (2009a) found significantly higher levels of heavy metal contamination in the Nanyang river compared with the Liangjiang River. This held in particular for copper (2153.88 mg/kg), zinc (482.75 mg/kg) and lead (394.5 mg/kg). Also in the Nanyang river in Taizhou very high levels of contamination were measured, among others for lead (377.33 mg/kg) and copper (4787.5 mg/kg) (Chen et al. 2010).

According to Song & Li (2014a) these studies indicate that the heavy metals in the river sediments were mostly from e-waste recycling activities.

4.2.5 Plants

Heavy metal contamination in plant samples is a reflection of the metals' presence in the soil. Heavy metals in food plants can accumulate in the human body through the food chain and as a result impose adverse impacts on human health. Most studies in China on heavy metal contamination of (food) plants have focused on the contamination of rice. Rice is the most important agricultural crop in China. Therefore maintaining its quality is critical to human health (Song & Li 2014a).

Table 12: Environmental pollution of heavy metals in plants

Pollutants	Sampling time	Sampling site	Location	Sample size	Concentrations in mg/kg	Reference values	References
Pb and Cd	08/2009and 10/2010	Sorghum bicolor, Moench and rice stalks at e-waste dump site and roadside	Guiyu	20-30	Pb: 11.41; 18.74 Cd: 2.92; 0.90	-	Alabi et al. 2012
Pb	11/2005	Rice and hull	Taizhou	13	Pb: 0.69	0.20	Fu et al. 2008
Zn	10/2006	Rice grain	Wenling (nearby Taizhou)	96	Zn: 20.69	-	Zhao et al. 2010-2011

Source: adapted from Song & Li 2014a

In Table 12 we have selected a few studies on plant contamination in Guiyu and Taizhou. In Taizhou the mean level of lead in polished rice (0.69 mg/kg) was more than three times higher than the maximum allowable concentration (MAC) (0.20 mg/kg) (NY5115-2002). The average level of cadmium was only slightly higher than the MAC, but the cadmium in 31 per cent of the rice samples exceeded the MAC (0.20 mg/kg). Furthermore, cadmium and lead levels in local rice samples were much higher than in commercial rice samples from the control areas. Heavy metal concentrations were generally higher in rice hulls than in polished rice (Fu et al. 2008).

Zhao et al. (2010-2011) concluded that the enrichment index[8] (from soil to rice) varied significantly with heavy metals in paddy fields. The study also revealed that high levels of soil organic matter and sand increased the accumulation and availability of heavy metals in rice.

[8] The enrichment index is defined as the metal concentration in rice divided by that in soil (Zhao et al. 2010).

Some studies also investigated the levels of heavy metal levels in other plants than rice collected from e-waste recycling sites. Alabi et al. (2012) for instance reported values of heavy metal concentration in plants, which were considerably higher than those in rice, suggesting that these plants had a higher enrichment index than rice. Other studies (not referred to in Table 12) revealed concentrations of cadmium and lead in most vegetables which exceeded the Chinese food safety limit several times (Song & Li 2014a).

4.3 Health impacts

Unsurprisingly the environmental impacts associated with WEEE have translated directly into a serious public health risks and impacts. Many of these risks are already apparent in medical diagnoses and statistical research. Some longer term risks may be yet to develop and will still need to be understood (Grant et al. 2013; ILO 2012). Evidence suggests that WEEE is significantly increasing incidences of chronic disease, threatening not just workers but also current residents and future generations. High prevalence of skin, gastric, respiratory, hematic, neurological, prenatal, natal and infant diseases related to WEEE are becoming increasingly well documented (Geeraerts et al. 2015; Grant et al. 2013; Song & Li 2014b). Health impacts and risks from WEEE can also be indirect, for instance if pollution enters the food and water systems. Contamination already outlined presents opportunities for harmful toxins to accumulate in agricultural crops, livestock and eventually humans (Song & Li 2014a; ILO 2012). In places like Guiyu and Taizhou, where rice is still cultivated, these risks are amplified and high concentrations of toxins found in agricultural soils and vegetation there suggest that this is already a reality (Sepúlveda et al. 2010; Song & Li 2014a).

4.3.1 Sources and routes of exposure

Sources of exposure of e-waste can be classified into three sectors: informal recycling, formal recycling and exposure to hazardous e-waste compounds remaining in the environment (i.e. environmental exposure) (Song & Li 2014b; Grant et al. 2013). Given that illegally imported e-waste is mostly processed in the informal sector, this study is primarily interested in the human health impacts from informal recycling and environmental exposure. In general, people are exposed to e-waste and its hazardous components through inhalation, dietary intake and soil/dust ingestion (Song & Li 2014b; Frazzoli et al. 2010). In the next paragraphs only a selection of figures on exposure is presented, thereby focusing primarily on PBDEs and lead and on the e-waste recycling areas of Guiyu and Taizhou for purposes of illustration.

Dietary intake

According to estimates more than 90 per cent of total human exposure to heavy metals and organic pollutants is from food. Table 13 presents the results from various studies on the dietary intake from PBDEs in Guiyu, Taizhou and Qingyuan. The food groups included in the studies are: freshwater fish, marine fish, shellfish, meat and meat products, viscera, eggs, cereals, vegetables and fruits.

One study showed that Guiyu inhabitants had a PBDEs dietary intake of 931 ng/kg bw[9]/day), thereby exceeding the US EPA's reference dose (100 ng/kg bw/day) multiple times (US EPA, 2008), while Taizhou (44.7 ng/day·kg bw) and Lin'an (1.94 ng/kg bw/day) inhabitants had lower intakes (Chan et al. 2013; see Table 13).[10] Another study of food consumption of local habitants in Taizhou found that the estimated daily dietary intake of PBDEs (3.84 ng/kg bw/day) was higher than in the control groups (1.73 ng/kg bw/day), but much lower than the value in Chan et al. (2013).

[9] bw = body weight

[10] The food consumption data were obtained via semi-quantitative food intake questionnaires.

Table 13: Daily dietary intake from e-waste pollution

Pollutants	Sampling time	Exposure pathways	Exposed group	Sampling site	Daily intake (ng/kg bw/day)[a]	Reference values	References
PBDEs	-	9 food groups	habitants	Guiyu, Taizhou; Lin'an	931; 44.7; 1.94		Chan et al. 2013
PBDEs	-	Chicken meat and eggs	habitants	Wenling	Chicken: 1.8 Eggs: 11.7		Qin et al. 2011
PBDEs	2005	Milk	Breastfed babies	Taizhou	572 ± 839		Leun et al. 2010
PBDEs	11/2011	Duck eggs	habitants	Taizhou; San Men County	3.18-102.48; 0.54		Labunska et al. 2013
PBDEs	-	Chicken and duck	habitants	Qingyuan	1.33		Luo et al. 2009
PBDEs (PBBs)	07/2010	Eggs	habitants	Qingyuan; control areas	200.14; 9.61		Zheng et al. 2012
PBDEs (PBBs, PCBs)	04/2007	7 food groups and water	habitants	Taizhou; Yandang	3.84; 1.73		Zhao et al. 2009
Pb (and Cd)	11/2005	Rice	habitants	Taizhou	Pb: 3.7 µg/kg bw/day	1 µg/kg bw/day [b, c]	Fu et al. 2008

Source: adapted from Song & Li 2014b Note: [a] 1 nanogram = 1 ng = 10^{-9} kg; [b] FAO/WHO's tolerable daily intake; [c] According to the EFSA Panel on Lead in Food, the $BMDL_{01}$ dietary intake value for developmental neurotoxicity in 6 year old children (i.e. blood lead level of 12 µg/L) corresponds to a dietary lead intake value of 0.50 µg/kg b.w. per day (EFSA 2010).

The highest dietary intake of PBDEs from eggs was found in Qingyuan (200.14 vs. 9.61 ng/kg bw/day), many times higher than in the control group (9.61 ng/kg bw/day) or in groups of other exposed sites (11.7 ng/kg bw/day in Wenling and 3.18-102.48 ng/kg bw/day) in Taizhou (Labunska et al. 2013; Qin et al. 2011; Zheng et al. 2012).

Leung et al. (2010) estimated the intake of PBDEs of 6-month-old breastfed babies living on the e-waste site in Taizhou at values between 572 and 839 ng/kg bw/day. These were at least 57 times higher than the intake of babies from the control site (10.1-4.60 ng/kg bw/day) (Leung et al. 2010). Furthermore, the maximum calculated value (2240 ng/kg bw/day) exceeded the US EPA's chronic oral reference dose for penta-BDE (2000 ng/kg/day) (Leung et al. 2010; Jones-Otazo et al. 2005).

Only one study included in the review by Song & Li (2014b) assessed the dietary intake of heavy metals (from rice) (Fu et al. 2008). As lead is concerned, the average daily intake of lead through rice consumption only by a group of habitants in Taizhou was 3.7 µg/kg bw/day, several times higher than FAO/WHO's tolerable daily intake (1 µg/kg bw/day) (Fu et al. 2008).

Inhalation

Dietary exposure is the most important source of human exposure to e-waste. Despite this, several studies have stated that inhalation of contaminated air can be a significant exposure route, in particular for e-waste workers. As no studies have been identified in relation to inhalation of PBDEs and metals from the air, two studies are discussed that looked into PCDD/Fs (see Table 14).

Wen et al. (2011) estimated the total average daily intake of PCDD/Fs in Fengjiang at 62.11 pg WHO-TEQ/kg bw/day for adults and 110.11 pgWHO-TEQ/kg bw/day for children, which substantially exceeds the WHO tolerable daily intake of 1-4 WHO-TEQ/kg·day-1 (WHO 2013). Li et al. (2007) estimated the PCDD/Fs intakes from inhalation based on particulate and gas samples in Guiyu. They concluded that inhabitants from Guiyu were subject to high exposure and high health risk from PCDD/Fs (daily inhalation of 4.5 and 2.54 pgWHO-TEQ/kg bw/day for children and adults respectively) compared with inhabitants from Guangzhou (0.090 and 0.069 pgWHO-TEQ/kg bw/day for children and adults) (Yu et al. 2006). The daily intake doses for children in both studies were almost twice those for adults. It is therefore not surprising that children are the most vulnerable for bad air quality and that for instance 80 per cent of children in Guiyu suffer from respiratory diseases (Li et al. 2007).

Box 4: The toxic equivalency factor

The toxic equivalency factor (TEF) expresses the toxicity of dioxin-like compounds, including PCBs. By using the toxic equivalency factor the toxicity of a mixture of dioxins and dioxin-like compounds can be expressed in a single number – the toxic equivalency (TEQ). The total TEQ is the sum of the concentrations of individual compounds multiplied by their relative toxicity (TEF) (Van den Berg et. Al 2006). The TEQ reports the toxicity-weighted masses of mixtures of dioxin-like compounds.

The WHO-TEQ refers to the universally accepted scheme presented by the World Health Organisation.

Table 14: Daily intake of e-waste pollution through inhalation and other routes

Pollutants	Sampling time	Exposure pathways	Exposed group	Sampling site	Daily intake (pg WHO-TEQ/kg bw/day)[a]	Reference values	References
Inhalation from the air							
PCDD/Fs	07/2006 & 01/2007	Outdoor air	Adults & children	Fengjiang area	Adults: 62.11 Children: 110.11	-	Wen et al. 2011
PCDD/Fs	09/2005	Outdoor air	Adults & children	Guiyu	Adults: 2.54 Children: 4.5	-	Li et al. 2007
Soil/dust ingestion and dermal exposure							
PCDD/Fs	-	Soil/dust	Adults & children	Taizhou; Guiyu	Children: 2.3; 1.982 Adults: 0.363; 0.499	Wenling: Children: 0.0013 Adults: 0.0003	Ma et al. 2008

Source: adapted from Song & Li 2014b. Note: [a] 1 picogram = 1 pg = 10^{-12} kg ; TEQ = toxic equivalents

Soil/dust ingestion and dermal exposure

Ma et al. (2008) assessed the daily intakes of TEQs of PCDD/Fs via soil/dust ingestion and dermal exposure, based on collected soil and dust samples from e-waste recycling facilities. Children and adults living in Taizhou were respectively exposed to 2.3 and 0.363 pg TEQ/kg bw/day (see Table 14). These doses were at least 1200 times higher than those in Wenling, a reference site. The estimated exposure values for children and adults in Wenling were only 0.0013 and 0.0003 pg TEQ/kg bw/day respectively. Ma et al. (2008) assessed as well the daily intakes via soil/dust ingestion and dermal exposure in Guiyu. These were assessed at 1.982 and 0.499 pg TEQ/kg bw/day for children and adults respectively (see Table 14).

4.3.2 Body burdens of e-waste exposure

The presence of pollutants in the environmental media does not necessarily imply significant human exposure to these pollutants. Assessing the level of pollutants in human bodies however can provide direct information about the level of human exposure and the potential public health risks. In recent years many studies in China have clearly indicated a causal relationship between emissions from informal e-waste recycling and dumping activities and the human body burden. These studies commonly include following types of human tissues: placenta, umbilical cord blood, breast milk, blood and serum, urine, hair and other tissues (Song & Li 2014b). For purposes of illustration figures on pollutant levels are only presented in relation to placenta, blood and serum and in relation to selected pollutants (primarily metals such as lead and cadmium). The other human tissues are only discussed briefly in a qualitative way.

Placenta

Table 15 presents several studies which have examined the human body exposure to e-waste in placentas collected after childbirth. These studies compared pollutant levels in placenta from mothers in e-waste recycling towns with those in control towns (Guiyu) with no exposure to e-waste pollution. Concerning the heavy metal levels, these studies concluded that most heavy metal levels in placentas from Guiyu were higher than those in placentas from the control towns, although there were some exceptions. In two studies (Li et al. 2011; Zhang et al. 2011), the cadmium levels in placentas from Guiyu were significantly higher than those from Chaonan. Guo et al. (2010) however did not find a significant correlation as to cadmium levels. As to lead, levels showed significant correlations in the two studies (Guo et al. 2010; Zhang et al. 2011). The total lead value in placentas in Guiyu was circa two times higher compared to the value of the control group in Chaonan (301.43 vs. 165.82 ng/g) (Guo et al. 2010). Zhang et al. (2011) also found lead values about two times higher in Guiyu compared to the control town (Shantou), though the correlation was less significant (521.01 vs. 273.24 ng/g, p = 0.299).

Leung et al. (2010) investigated the PBDE body burdens of women. The ones from the e-waste recycling site (Taizhou) were 19 times higher than those from the control site (19.5 ± 29.9 vs. 1.02 ± 0.36 ng/g fat) (see Table 15).

Table 15: Neonate body burdens (placenta) in Guiyu and Taizhou

Pollutants	Sampling time	Exposed groups	Sampling sites	Human body burden	Reference values	References
Pb, Cd (Cr, Ni)	10/2008-05/2009	220 mother-infant pairs (101:119)	Guiyu; Chaonan	Pb: 301.43; 165.82 ng/g (p = 0.010) Cd: 108.75; 104.15	-	Guo et al. 2010
Cd	2006	423 mother-infant pairs (101:119)	Guiyu; Chaonan	170 ± 480; 100 ± 110 ng/L (p<0.01)	-	Li et al. 2011a
Cd, Pb	10/2008-06/2009	mother-infant pairs (101:119)	Guiyu; Shantou	Cd: 83.99; 51.59 ng/g (p< 0.001) Pb: 521.01; 273.24 ng/g (p = 0.299)	-	Zhang et al. 2011
PBDE	2005	10 women	Taizhou; Lin'an	19.5 ± 29.9; 1.02 ± 0.36 ng/g fat	-	Leung et al. 2010

Source: adapted from Song & Li 2014b.

Blood and serum

Table 16 presents studies on the human body burden in blood and serum as a result of e-waste exposure which focus on heavy metals and lead in particular. It should be noted that several studies have also investigated levels of PBDEs, PCBs and dioxins in blood and/or serum (see e.g. Song & Li (2014b)). All studies presented in Table 16 indicated that the lead levels in the blood of children living in the e-waste recycling areas (Guiyu and Taizhou) were significantly higher than the blood lead levels in the control areas (all $p < 0.01$) and that most blood lead levels exceeded the control standards. According to the diagnostic blood lead level criteria for children as defined by the U.S. Centers for Disease Control (CDC 1991) children with a lead level in their blood equal to or higher than 100 µg/L (or 10 µg/dL) are considered to have an elevated blood lead level. These lead levels were correlated with location of residence, parents' involvement in e-waste recycling, the use of the home as a recycling workshop and the nibbling of toys by children (Song & Li 2014b). It should also be noted that the EFSA Panel for Lead in Food determined the 95th percentile lower confidence limit of the benchmark dose (BMD) of 1 per cent extra risk (BMDL01) of 12 µg/L blood lead as a reference point for the risk characterisation of lead when assessing the risk of intellectual deficits in children measured by the Full Scale IQ score (see 4.3.4 for more details)

Furthermore, Zheng et al. (2008) concluded that both the blood lead levels in Guiyu and the proportions of blood lead levels higher than 10.0 mg/dL increased with the children's age: older children were more likely to have higher blood lead levels than younger children. They also discovered that the blood lead levels of children aged 5, 6 and 7 years in Guiyu were significantly higher than those in Chendian (all $p < 0.01$).

Table 16: Human body burden in blood and serum

Pollutants	Sampling time	Exposed groups	Sampling sites	Average human body burden (γg/L) ± Standard deviation	US CDC ref. level ((γg/L)[a]	References
Pb (and Cd)	-	246 children aged 3-8	Guiyu	73.0 (43.3-154.3); no statistical analysis	100	Yang et al. 2013
Pb (Cu and Cd)	-	104 persons (48:56)	Southeast China	114.9 vs 91.04 (p<0.01)	100	Wang et al. 2011a
Pb (Cd, Cu, Cr, Hg and PCBs)	-	76 workers and habitants (40:36)	Taizhou vs control area	150.63 ± 184.41 vs 84.37 ± 33.81	100	Zhang et al. 2012
Pb	2004	226 children (165:61)	Guiyu vs Chendian	153.0 ± 57.9 vs 99.4 ± 40.5 (p<0.01)	100	Huo et al. 2007
Pb	2006	278 children aged 1-7 (154:124)	Guiyu vs Chendian	131.7 ± 59.8 vs 100.4 ± 48.5	100	Zheng et al. 2008
Pb	01-02/2008	303 children aged 3-7 (153:150)	Guiyu vs Chendian	144.3 ± 69.3 vs 87.2 ± 43.4 (p<0.01)	100	Liu et al. 2011
Pb	09-11/2004	226 children aged 1-6 (165:61)	Guiyu vs Chendian	153.0 ± 57.9 vs 99.4 ± 40.5 (p<0.01)	100	Xu et al. 2006
Pb	2006	136 children aged 3-6 (85:51)	Guiyu vs Chendian	117.8 vs 89.3 (p<0.01)	100	Han et al. 2007
Pb	-	226 children aged 1-6	Guiyu vs	153.0 vs 57. 9 (p<0.01)	100	Peng et al.

		(165:61)	Chendian			2005
Pb	06/2010	178 children aged 11-12 (108:70)	Luqiao vs Chun'an	6.97 vs 27.8 (p<0.01)	100	Wang et al. 2012a
Pb	-	138 persons (59:79)	South China (exposed vs control)	99.83 vs 92.25 (p<0.01)	100	Zhang et al. 2007

Source: adapted from Song & Li 2014b. Note: The EFSA Panel for Lead in Food determined the 95th percentile lower confidence limit of the benchmark dose (BMD) of 1 per cent extra risk ($BMDL_{01}$) of 12 µg/L (B-Pb) as a reference point for the risk characterisation of lead when assessing the risk of intellectual deficits in children measured by the Full Scale IQ score (see 4.3.4 for more details).

Other human tissues

Studies on pollutant levels in umbilical cord blood found that newborn babies from Guiyu are exposed to e-waste and have a serious human body burden of pollutants. Several studies also found significantly higher levels of pollutants in hair samples from inhabitants of e-waste recycling towns and e-waste workers. Some studies also found significantly higher levels of heavy metals in urine samples from e-waste workers compared to samples from control groups (Song & Li 2014b).

4.3.3 Health impacts

Many studies have been conducted on the health impacts of exposure to e-waste in China. The majority of select studies reviewed by Grant et al. (2013) showed associations between exposure to e-waste and physical health outcomes, including lung function, physical growth, reproductive health, thyroid function and changes in cellular expression and function. Negative associations were also shown for blood lead levels and IQ in children. Outcomes were mainly reported from Guiyu and Taizhou.

Lung function

Zheng et al. (2013) examined associations between exposure to heavy metals (amongst others chromium and nickel) and lung function in 144 schoolchildren (aged 8–13 years) from Guiyu and from Liangying, a control town with no evidence of e-waste recycling. Boys aged 8 and 9 years living in Guiyu had a lower forced vital capacity[11] than those living in Liangying (1859 mL vs 2121 mL, p=0.03). Significant negative correlations were found between blood chromium concentrations and forced vital capacity in children aged 11 and 13 years and serum nickel concentrations in children aged 10 years (Zheng et al. 2013; Grant et al. 2013).

Physical growth

Two studies showed that children living in the e-waste recycling town of Guiyu had significantly lower weight, height and body-mass index than children living in the control area Liangying (Zheng et al. 2013; Huo et al. 2007). One study also found negative correlations between height and weight on the one hand and concentrations of manganese in blood and nickel in serum on the other (Zheng et al. 2013). The other study however did not show adverse effects of lead on growth in young children (Huo et al. 2007).

[11] Forced vital capacity (FVC), also called "forced expiratory vital capacity" (FEVC), is the volume change of the lung between a full inspiration to total lung capacity and a maximal expiration to residual volume and whereby the exhalation is done forcefully. The preceding maximal inhalation does not need to be done forcefully. (Source: www.spirxpert.com/indices5.htm)

Reproductive health

In most studies reviewed by Grant el. 2013 consistent effects of e-waste exposure have been found with increases in spontaneous abortions, stillbirths, and premature births, and reduced birth weights and birth lengths (Guo et al. 2012; Wu et al. 2011, 2012; Xu et al. 2012). Adverse birth outcomes have been associated with increased exposures to PAHs and POPs, including PBDEs, PCBs and perfluoroalkyls (Guo et al. 2012; Wu et al. 2012). The principal exception is the lack of association between exposures to metals and adverse birth outcomes (Guo et al. 2010).

Mental health outcomes

In two studies lead was investigated as the main chemical agent associated with mental health outcomes resulting from e-waste exposure (Liu et al. 2011). In one study researchers assessed temperament in children (Liu et al. 2011), in the other researchers generated neonatal behavioural neurological assessment scores (Xu et al. 2012). It was found that children in Guiyu had higher concentrations of lead in their blood than children living in towns with no e-waste recycling (Liu et al. 2011; Xu et al. 2012).

Neonates (newborn babies) had increased concentrations of lead in cord blood and meconium. These were correlated with the mother's involvement in e-waste recycling, time spent living in Guiyu before and during pregnancy, time spent in e-waste recycling facilities while pregnant, and the father's involvement in e-waste recycling activities (Li et al. 2008a). Neonatal behavioural neurological assessment scores differed considerably among the babies in Guiyu and those in the control town (Li et al. 2008a). Increased concentrations of lead were associated with abnormalities in temperament scores (Liu et al. 2011) and low neonatal behavioural neurological assessment scores (Li et al. 2008a).

Thyroid function

The studies reviewed by Grant et al. 2013 showed that reported effects on thyroid-stimulating hormone (TSH) were not consistent.

DNA damage

Most studies identified Grant et al. (2013) as studies including health outcomes at cellular level found that inhabitants of e-waste recycling towns or e-waste recycling workers had greater DNA damage than those living in the control town (Yuan et al. 2008; Liu et al. 2009; Chen et al. 2010; Wang et al. 2011a). According to Grant et al. (2013) the studies however do not have the power to exclude other contributory factors next to e-waste exposure. A study by Li et al. (2008b) reported significant differences in lymphocytic DNA damage in newborn babies from Guiyu and newborn babies from the neighbouring fishing town Chaonan. Newborn babies from Guiyu had greater DNA damage than did neonates from Chaonan. Significant correlations between chromium levels in blood and DNA damage in neonates (Li et al. 2008b).

Intelligence quotient

One study investigated the educational outcomes of e-waste exposure whereby lead was analysed as the main chemical agent (Wang et al. 2012a). The effects of lead levels in blood on intelligence quotient (IQ) in children aged 11 and 12 years were assessed. The children were from the e-waste recycling town Luqiao in Thaizou, the tinfoil manufacturing area Lanxi and the control town Chun'an. As no significant differences in IQ were recorded among the three sites, the results from the three individual site samples were combined. 38.9 per cent of the children from Luqiao and 35.1 per cent of the children from Lanxi had blood lead levels above 10 µg/dL, whereas all examined children from Chun'an had levels below 10 µg/dL. Wang et al. (2012) associated health risks for intellectual function in children with blood lead levels below 10 µg/dL with a decrease in IQ levels. Every 1 µg/dL increase in blood lead level resulted in a 0.71 point decrease in IQ (Wang et al. 2012a).

Discussion

E-waste contains a unique combination of persistent hazardous substances. Other sources of exposure are however difficult to rule out, in particular in China. In studies that accounted for confounding variables, researchers still found important associations between e-waste exposure and adverse outcomes in exposed populations. Even when other variables such as age and smoking were accounted for, e-waste exposure came out as an independent risk factor (Grant et al. 2013).

4.3.4 Case: elevated lead levels in human body and IQ scores of children

All data presented in the previous sections suggest that the contaminant levels in different environmental media at and nearby e-waste recycling sites are significantly higher than those at reference sites. As a result e-waste recycling workers and people living at or nearby e-waste recycling sites are subject to increased health risk. Long-range transport of e-waste-derived pollutants, e.g. through the food chain, can also subject inhabitants of adjacent regions to unintended health risks (Ni & Zeng 2013). In the following paragraphs we undertake an effort to asses these health risks more in detail in relation to lead as a major pollutant arising from informal e-waste recycling and dumping in China and its impacts on the neurological development of children in terms of IQ scores.

Hazard identification and characterization

It is well known that heavy metals (such as lead) persist in the environment and lead to poisoning at low concentrations through bioaccumulation in plants and animals or bioconcentration in the food chain (Song & Li 2014a; see also previous sections). Oral ingestion of contaminated food has been proved to be an important pathway for the transfer of lead (and other metals) from the environment to the human body. Children in particular are amenable to heavy metal exposure due to high gastrointestinal uptake and the permeable blood-brain barrier (Ogunseitan 2013). The high concentrations of toxic metals in dust will pose a severe health threat to children, due to the involuntary or direct ingestion of contaminated dust particles via the ‘‘hand to mouth’’ pathway (Song & Li 2014a). In human bodies lead interferes with behaviour and learning abilities; copper results in liver damage; and chronic exposure to cadmium increases the risk of lung cancer and kidney damage (Grant et al. 2013; Song & Li 2014a).

In its scientific opinion on lead in food the EFSA Panel on Contaminants in the Food Chain identified the developmental neurotoxicity in young children, cardiovascular effects and nephrotoxicity in adults as the basis for its risk assessment of lead in food (EFSA 2013). As to developmental neurotoxicity in young children, the EFSA Panel determined the 95th percentile lower confidence limit of the benchmark dose (BMD) of 1 per cent extra risk ($BMDL_{01}$) at 12 µg/L (B-Pb) as a reference point for the risk characterisation of lead when assessing the risk of intellectual deficits in children measured by the Full Scale IQ score. For this benchmark dose level (BMDL) of 12 µg/L (B-Pb), the EFSA Panel has calculated a corresponding dietary intake: the $BMDL_{01}$ dietary intake value for developmental neurotoxicity in 6 year old children corresponds to a dietary lead intake value of 0.50 µg/kg bw per day (EFSA 2013).

Risk characterisation

From the previous chapters we learned the following on lead: it was estimated that inhabitants of Taizhou had a dietary intake of 3.7 µg/kg bw per day through consumption of rice only. This exceeds the EFSA dietary lead intake value for developmental neurotoxicity in children several times and does not even take into account consumption of other food (e.g. which may contain lead (or other pollutants), other exposure routes such as inhalation of air and soil/dust ingestion, the latter being in particular of relevance for children. It is very likely that similarly high values (or even higher values) would have been measured in Guiyu (and other informal e-waste recycling towns), given the relatively high concentrations of lead found in several environmental media such as air, dust and soil and in rice and other plants (e.g. vegetables) in Guiyu and surroundings (see 4.2). Furthermore, very high average blood lead levels have been found in

children in Guiyu (and Taizhou) (see Table 16), which exceeded the $BMDL_{01}$ of 12 µg/L multiple times, with most blood lead levels significantly higher than 100 µg/L (or 10 µg/dl). Based on this, we can conclude that almost all children living in informal e-waste recycling centers such as Guiyu (and Taizhou) are or have been subject to lead exposure which exceeds the $BMDL_{01}$ intake level of 0.50 µg/kg b.w. per day for neurodevelopmental effects (the benchmark dose approach is explained in Box 2 on page 18). This implies that potentially all children living in these informal e-waste recycling areas have been affected in their neurological development. Assuming that 70 per cent of the villages/neighborhoods of Guiyu are engaged in informal e-waste recycling and that this has remained stable over the years, it is estimated that 22,400 children (16,000-25,600) born in the period 1995-2013 have had blood lead levels exceeding the $BMDL_{01}$ and as a result have been affected in their neurological development. This implies that 22,400 children (16,000-25,600) have been subject to a drop in intelligence as a result from informal e-waste recycling and dumping (see Box 5 for more details on the calculation of the number of children affected).

Breivik et al. (2014) estimate the amounts of e-waste treated in the informal recycling sector at 1,350 kt/year (550-2,000) and 4,900 kt/year (3,600-7,200) in Guiyu and China respectively. Assuming that the ratio between the amounts treated in Guiyu and in China as a whole is the same as the ratio between the number of children affected in Guiyu and in China as a whole, it is roughly estimated that around 81,300 children (58,000-93,000) in China born in the period 1995-2013 have been affected in their neurological development as a result of the informal recycling of e-waste.

These are likely to be conservative estimates as long-range transport of e-waste-derived pollutants such as lead, e.g. through the food chain, can also subject inhabitants of adjacent regions to unintended health risks (Ni & Zeng 2013; Huo et al. 2007). In fact in many control areas blood lead levels of children were mostly also significantly higher than the $BMDL_{01}$ of 12 µg/L used by the EFSA Panel as a reference point for assessing the risk of intellectual deficits in children (see Table 16). Huo et al. (2007) for instance indicated that children's blood lead levels in rural control areas nearby Guiyu were also higher than blood lead levels in nearby urban areas (such as Zhongshan City and Shenzhen City). According to Huo et al. (2007) this was very likely the result of lead contamination having spread from Guiyu to the nearby rural control area by dust, river and air.

Box 5: Estimate of children affected by lead poisoning as a result of informal e-waste recycling

Based on the population numbers of Guiyu for 2003 and 2013 (Wang et al. 2013), the urban population growth rates in China, the overall Chinese population growth rates and overall birth rates for China, the number of children born in Guiyu in the period 1995-2013 have been estimated/calculated (see **Annex B: Guiyu population statistics** for details on these calculations**)**. The resulting number is about 32,000 children. Given that 20 of Guiyu's 28 villages are engaged in informal e-waste recycling (Wang et al. 2013), it is assumed that ca. 70 per cent of these children are affected, thereby assuming that those 20 villages represent 20/28 or ca. 70 per cent of Guiyu's overall population. Given uncertainties about the proportion of children living in these villages in combination with the likelihood that children from villages in Guiyu which are not engaged in e-waste recycling are also subject to blood lead levels higher than 12 µg/L, lower and upper bound assumptions are being applied: respectively 50 and 80 per cent of Guiyu's children are being affected. The default estimate would be 22,400 children, while the lower bound and upper bound estimates would be 16,000 and 25,600 respectively.

Epidemiological studies indeed show that exposure to lead during the early stages of children's development is linked to a drop in intelligence. Studies suggest that for each 10 µg/dl (microgram per decilitre) of blood lead, IQ is reduced by at least 1-3 points (Morgan 2013 in: University of Bristol 2013). This small effect on many individuals could be a significant burden to society, with reduced overall intellectual performance and resulting economic losses (University of Bristol 2013).

Assuming that all 81,300 children (58,000-93,000) exposed to lead as a result of living in e-waste recycling areas in China had average blood lead levels of 12 µg/dl (or 120 µg/l) of blood lead – conservative estimates based on the body burden figures from Table 16 – and assuming that for each 10 µg/dl of blood lead, IQ is reduced by 2 points (see above), it is roughly estimated that for the population of children living in informal e-waste recycling areas and born in the period 1995-2013 the intelligence has dropped with 195,120 IQ points (139,200-223,200). Based on data from the studies referred to in Table 16 it is roughly assumed that 50 per cent of the blood lead originates from informal e-waste recycling and dumping activities. This means that the children living in e-waste recycling areas in China **lost** about **97,560 IQ points (69,600-111,600)** as a result of these activities. This amounts to an **average reduction of intelligence of 1.2 points per child**. It should be noted that these figures provide an initial order of magnitude estimate.

4.4 Economic impacts

The focus of this section is on economic losses to the EU and to the EU e-waste recycling sector in particular. The economic impacts in China are only briefly touched upon. In section 4.1 of this report it was estimated that ca. 1.16 million tonnes of e-waste have been shipped illegally from the EU to China in 2012. This estimate built further on Zoeteman's estimate of 0.74 million tonnes of illegal imports of e-waste from the EU in China (Zoeteman et al. 2009). If one assumes a linear increase of annual imports in China from the EU between 2005 and 2012, **the average annual import in the period 2005-2012 amounts to 0.95 million tonnes**. These figures are used as a basis for estimating the economic impacts on the EU e-waste recycling sector and the Chinese informal e-waste collection and recycling sector. In order to give estimates for the economic impacts resulting from overall illegal exports from the EU, one might start working from following figures: in 2005 and 2012 respectively 1.9 and 2.98 million tonnes of e-waste have been exported from the EU (according to our estimates produced in section 4.1 of this report).

4.4.1 In Europe

Economic loss to the EU waste recycling sector

The illegal export of e-waste has also led to a point where the legitimate modern recycling facilities in the EU cannot obtain the expected amount of WEEE (Geeraerts et al. 2015). For instance, the UK recycling industry anticipated an annual volume of 1.5 million tonnes of WEEE to be processed once the WEEE Directive had entered into force in the UK. However, in reality the actual quantity was only a third of this amount two years after the Directive's entry into force (UNODC 2013).

In a 2012 report Amec estimated that the overall economic impact of illegal waste exports from the UK is £8.7 million (€10.7 million), including a £5.1 million (€6.2 million)[12] loss in profits to WEEE treatment facilities in the UK. As Amec recognised the inherent uncertainties in their estimates, it suggested that the true economic cost of illegal exports could be considerably higher (Amec 2012). These estimates of economic loss built further on Amec's estimates of total UK waste exports in 2012 (15 million tonnes), of total illegal waste (between 0.6 and 1.7m tonnes) and the share of WEEE illegal exports (0.5-0.6 million tonnes) (Amec 2012). Based on these 2012 figures and our estimate of overall illegal e-waste exports from the EU in 2012 (see Box 6), a rough and simple extrapolation is made for the EU as a whole. If 0.5-0.6 million tonnes of illegal e-waste exports from the UK in 2012 correspond with a £5.1 million loss in profits to the UK recycling industry, **2.98** million tonnes of illegally exported e-waste from the EU in 2012 might correspond roughly with **£25.3 million to £30.4 million loss in profits to the EU recycling industry**

[12] The Eurostat's annual average exchange rates for 2012 have been used to convert GBP to Euros (available at: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ert_bil_eur_a&lang=en).

(€31.2 million – €37.5 million)[13] (assuming that the ratio between tonnes of illegal exports and loss to the industry is the same for the UK and the EU). If one looks at the illegal e-waste **exports to China only** (**1.16** million tonnes in 2012), the **EU recycling industry** might have **lost £9.86 million to £11.83 million in profits in 2012 (€12.2 million - €14.6 million**). To put this into perspective, the EU e-waste recycling market earned revenues of US$1.3 billion in 2012 (or €1.012 billion) and is estimated to earn US$1.79 billion (or € 1.39 billion) in 2020 (Frost & Sullivan 2013).

Box 6: Estimates of e-waste export from EU and China import from EU in 2012

Section 4.1 presented the following estimates of e-waste volumes exported from the EU to China:

- According to the StEP project 9,918,000 tonnes of e-waste have been generated in the EU in 2012 (StEP 2015c).
- The amount of illegally exported e-waste from the EU in 2012 was estimated to be around **2.98 million tonnes**.
- According to UNODC (2013) in 2012 8 million tonnes of WEEE were imported into China.
- The volume of illegally exported e-waste from the EU into China amounted to **1.16 million tonnes** in 2012.

It should also be noted that many European based "recyclers" of e-waste act as brokers for China bound WEEE and thus profit from this illegal trade.

If larger volumes of e-waste would have been treated within the EU, it would have helped EU companies to become more competitive. The EU recycling sector currently suffers from a lack of available material to treat and recycle. The volumes that now are being shipped illegally to China (and other developing countries) could have helped EU companies to compete with e.g. Chinese companies which process significant amounts of e-waste (BIO IS 2010).

According to the WEEE Forum (2013) the average intrinsic value of WEEE was about € 300 per tonne.[14] Building further on this figure the **economic value lost to the EU** as a result of illegal **exports to China** (1.16 million tonnes in 2012) is roughly estimated at **€ 348 million for 2012** only. The **economic value lost** to the EU as a result of **all illegal exports out of the EU** (2.98 million tonnes in 2012) is estimated at **€ 892 million for 2012**.

A major part of the economic value lost to the EU arising from illegal e-waste exports relates to the **loss of precious metals in these exports**. Metals are one of the main elements that can be extracted from WEEE, recycled and treated for re-use in new devices. Gold is one example of such a precious metal. Each year millions of mobile phones are discarded and exported that contain significant amounts of gold (next to many other precious metals). According to the European Recycling Platform about two grams can be recovered from 10 kilograms of discarded mobile phones, which is the amount of gold that is required to produce a wedding ring. Furthermore, the conventional way to get these two grams is to refine 10 tonnes of gold ore (ERC 2014), of which the extraction and refining is significantly more harmful to the environment and the climate.

[13] The Eurostat's annual average exchange rates for 2012 have been used to convert GBP and USD to Euros (available at: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ert_bil_eur_a&lang=en).

[14] According to INTERPOL one tonne of e-waste is valued at US$500 and if the differences in the numerous types of e-waste are taken into consideration an average figure of US$375 per tonne can be estimated (UNODC 2013).

Job loss in the EU waste recycling sector

The illegal exports are likely to present a potential loss of jobs in enterprises treating e-waste, through the decrease of the quantities of e-waste having to be treated in the EU. The loss of jobs resulting from illegal e-waste exports outside of the EU can be calculated using an approach whereby the lost total turnover for the EU e-waste recycling sector is divided by the sector's labour intensity (i.e. the level of turnover per full time equivalent (FTE) job).

However, the potential loss of jobs can also be calculated using coefficients for FTE jobs for diverting 1,000 tonnes of e-waste from landfill, incineration or illegal export. For WEEE, however, only two coefficients have been identified in the literature. The first one is from a 2004 study by the London South Bank University (LEPU 2004) which calculated that for every 1,000 tonnes of waste recycled per year in London, 6 jobs would be gained across the entire waste chain. The collection and sorting of WEEE, however, provided the biggest employment opportunities, with a total of 40 jobs being created per 1,000 tonnes of material processed (LEPU 2004). This implies that **1 job** would be created per **25 tonnes** of e-waste processed.

The second coefficient is from a 2013 study for the Coalition for American Electronics Recycling (CAER) (DSM 2013). According to this study, every extra 172,000 pounds (78,018 kg or roughly **78 tonnes**) of e-waste processed in the United States which is not exported outside of the US, would generate a **new job**. This estimate represents only those jobs directly involved in processing the added e-waste. Additional indirect and induced jobs generated by spending of employees associated with the (new) direct jobs in e-waste recycling would also be generated. Typically indirect and induced jobs increase twofold the number of direct jobs established. It should be noted that this estimate is based among others on the assumption that the smelting of shredded circuit boards and other materials containing precious metals would continue to take place primarily outside of the US, as would recycling of significant quantities of CRT glass (DSM 2013).

It was decided to apply the most conservative coefficient, which is the one from the American study: **1 job per 78 tonnes** (DSM 2013). Compared to the LEPU 2004 coefficient, it is a more recent figure and it has been determined in a study fully focused on the (US) e-waste recycling industry. Assuming that a similar ratio applies to the EU e-waste recycling industry, the illegal export of e-waste from the EU in 2012 might represent a **potential loss** of about **38,000 full time equivalent (FET) recycling jobs in the EU**. Assuming a typical multiplier of 2, these direct recycling jobs would result in another **38,000** indirect[15] and induced jobs[16], for a total of **76,000 jobs**. The **illegal export to China** in particular represents a potential loss of about **14,900 FTE jobs** and another **14,900 indirect jobs**, for a total of **29,800 jobs.**[17]

4.4.2 In China

The economic impact of the illegal exports of e-waste from the EU (and other developed countries) is the creation of an industry, made up mostly of informal enterprises in China which process e-waste, attempting to generate profit from the resale of copper, steel, aluminium, gold and computer chips. There,

[15] Indirect jobs are created as the recycling industry supports other economic activity by purchasing goods and services from other types of business establishments (such as office supply companies, accounting and legal firms, etc.) (FoE 2010).

[16] Induced jobs are jobs 'induced' or generated as a result of the spending by both direct and indirect employees in the local economy.

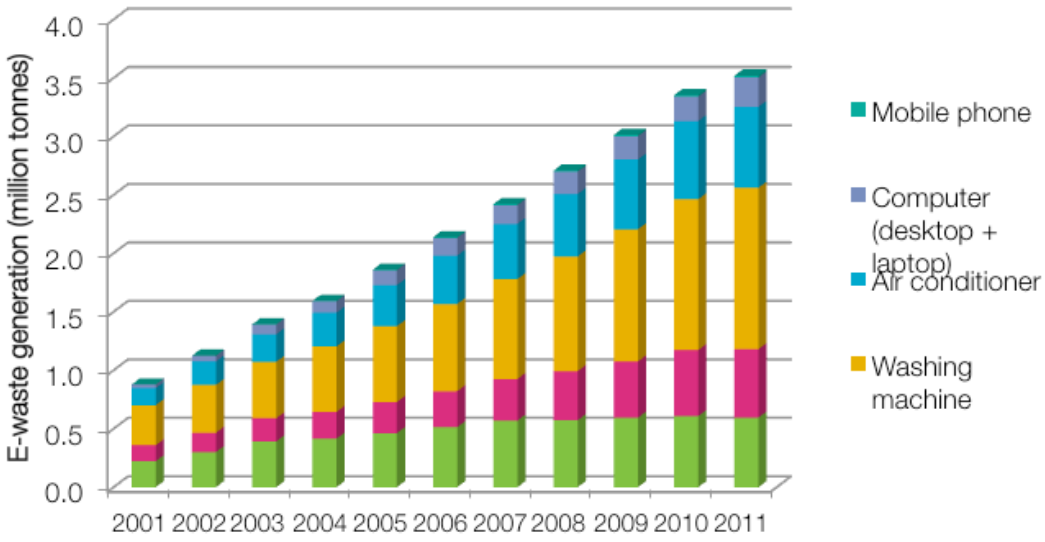
[17] Alternatively, multipliers could be applied from a 2010 study by Friends of the Earth UK (FoE 2010). In this study indirect and induced (loss of) employment has been estimated by applying separate multipliers for indirect and induced jobs: a multiplier of 1.50 to calculate the indirect jobs resulting from direct employment in the recycling sector and a multiplier of 1.75 to calculate the induced jobs. The authors of the FoE study consider these multipliers as conservative, as these are lower than those commonly used in other economic sectors (FoE 2010).

potential in resource reutilisation and for income generation, allow WEEE to be perceived as an economic opportunity. Whilst environmental and health impacts are generated mostly by recycling practices, there exist complex value chains, at various stages of which the economic value of waste is extracted.

This has seen Guiyu, for example, transform from a poor rice growing village into a highly dynamic and for some lucrative economic hub, processing up to 150 million tonnes of WEEE each year (Hicks et al. 2005). According to Wang et al. (2013) Guiyu is home to more than 300 companies and 3,000 individual workshops that are involved in the recycling of e-waste, with nearly 100,000 migrant labourers fuelling the business. Those engaged on dismantling and processing e-waste earn an average wage equivalent of US$1.50 per day (ILO 2012). About 150 million tonnes of electronic components are being recycled with an output value of nearly 1.56 billion yuan (approximately €0.19 billion)[18], accounting for more than 90 per cent of the town's industrial output value (ILO 2012). Wang et al. (2013) estimate that around 250,000 workers work in the informal e-waste recycling sector in China as a whole (see also Breivik et al. 2014).

It should be noted however that the situation in Guiyu (and other traditional recycling areas) seems to have changed in recent years as a result of governmental initiatives to regulate informal recycling activities and to clean up the local environment (Personal Communication 2015). In addition, domestically generated WEEE has become increasingly important for the informal e-waste recycling sector over the years (see Figure 3) and as a result the share of e-waste from the EU and other parts of the developed world seems to be decreasing. The picture is however not fully clear as most English publications on Guiyu are several years old. It is not fully clear either to what extent illegal imports of e-waste from the EU and elsewhere have been effectively reduced since the Chinese government started to control imports more strictly under the Green Fence program (see for more details: Geeraerts et al. 2015).

Figure 3: Generation of e-waste in China 2001-2011 (in million of tonnes)



Source: Balde et al. 2015

Given that the informal recycling of illegally imported e-waste has resulted in substantial environmental and health effects, China has suffered and will suffer economic losses as well. To give one example: given that around 81,300 children (58,000-93,000) in China born in the period 1995-2013 are very likely to have

[18] The Eurostat's annual average exchange rates for 2012 have been used to convert CNY to Euros (available at: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ert_bil_eur_a&lang=en).

been affected in their neurological development (as they all had blood lead levels of more than 100 γg/L (or 10 g/dL) (see section 4.3.4), given that studies suggest that for each 10 µg/dL of blood lead, IQ is reduced by at least 1-3 points (Grosse et al. 2002) and given that a decrease of 1 IQ point in children can be associated with a decrease of later productivity of about 2 per cent (EFSA 2010), the informal recycling of e-waste in China has and will lead to **significant economic losses** as a result of **reduced overall intellectual performance**.

4.5 Conclusions

Quantifying the illegal export of e-waste from the EU (to China) is especially challenging as there is very little clear information upon which estimates can be based (given the illegal nature of these e-waste shipments). Nevertheless an attempt has been made to come up with estimates for 2005 and 2012. For these years it was estimated that around 0.74 and 1.16 million tonnes of e-waste have been imported in China from the EU. These estimates are based on reliable estimates of the volumes of WEEE generated in the EU and assumptions about the percentage of WEEE that is being exported from the EU and the percentage of WEEE from the EU that is being imported in China. Given the uncertainty surrounding these 'guesstimates', it is suggested to work with minimum and maximum EU export scenarios and minimum and maximum import in China scenarios.

The illegal export of e-waste from the EU to China has resulted – through the intensive informal recycling of e-waste in China – in the release of large amounts of contaminants in the local environment such as heavy metals, PBDEs, PCDD/Fs, PBCs, CFCs and PAHs. It has caused in particular high concentrations of heavy metals (such as lead, cadmium, mercury, copper, zinc, etc.) in the surrounding air, dust, soils, sediments and plants. The exceedance of various national and international environmental quality standards imposes significant negative effects on the environment.

The potential annual emissions of some environmental contaminants associated with e-waste imported illegally in China from the EU were estimated. These estimates are based on concentrations in components of Swiss e-waste and on the estimates of the 2005 and 2012 illegal imports in China from the EU. To give one example: it was estimated that respectively 10 and 16 tonnes of PCBs from EU e-waste were potentially released in the Chinese environment in 2005 and 2012.

Given the scale and complexity of the e-waste problem, it was within the context of this project not possible to quantify the total environmental impacts from informal e-waste recycling in China or in particular areas of China, not to mention the impacts from the informal recycling in China of the millions of tonnes of e-waste imported annually from the EU (i.e. the share of EU-borne e-waste impacts within the overall impacts from informal recycling in China). This resulted among others from uncertainties about the sources of the contamination in recycling areas and control areas and in particular from the exact shares of these sources in the overall contamination. It should however be noted that many studies were able to indicate that certain pollution cases were mainly originating from e-waste recycling activities.

Given the above and in particular given the complexity of the environmental impacts from e-waste recycling and dumping, the report presents only select data. It focuses mostly on the environmental impacts (i.e. pollution levels) related to heavy metals and lead and zinc in particular. And mostly studies investigating or results regarding adverse environmental impacts in Guiyi and Taizhou, as the most representative locations for informal e-waste recycling, are being referred to.

As to health impacts, this study demonstrates that illegal exports from the EU are significantly increasing incidences of chronic disease in China, threatening not just workers but also current residents of e-waste recycling areas and adjacent regions and future generations. Illegal exports from the EU result (through the informal recycling and dumping) in high prevalence of skin, gastric, respiratory, hematic, neurological, prenatal, natal and infant diseases in China. As to health impacts, figures on the routes of exposure, on the human body burden and on scientifically established associations and/or causal links between e-waste exposure and several kinds of diseases and other health impacts are presented. As with environmental effects, only select figures were presented, primarily in relation to heavy metal contamination in Guiyu and

Taizhou. Select scientific studies (in China) show associations between exposure to e-waste and physical health outcomes such as:

- decreased lung function (i.e. lower forced vital capacity);
- decreased physical growth of children (i.e. lower weight, height and body-mass index);
- reduced reproductive health (i.e. increases in spontaneous abortions, stillbirths, and premature births, and reduced birth weights and birth lengths);
- changes in cellular expression and function (i.e. increased DNA damage).

Negative associations were also shown for blood lead levels and IQ in children.

A more detailed quantification has been carried out for the impacts of lead poisoning resulting from e-waste exposure on children's neurological development, expressed in terms of children's IQ scores. Based on data from various studies it was concluded that almost all children living in informal e-waste recycling centers such as Guiyu and Taizhou are or have been subject to lead exposure which exceeds the $BMDL_{01}$ intake level of 0.50 µg/kg b.w. per day as determined by the EFSA Panel on Contaminants in the Food Chain for neurodevelopmental effects. This implies that potentially all children living in these informal e-waste recycling areas have been affected in their neurological development. It is estimated that roughly 22,400 children (16,000-25,600) born in Guiyu in the period 1995-2013 have had blood lead levels exceeding the $BMDL_{01}$ and as a result have been subject to a drop in intelligence as a result from informal e-waste recycling and dumping. For China as a whole it is conservatively estimated that **around 81,300 children (58,000-93,000) born in the period 1995-2013** have been **affected in their neurological development** as a result of e-waste exposure. It was subsequently estimated that these **children in China lost about 97,560 IQ points** (69,600-111,600) as a result of informal e-waste recycling and dumping activities. This amounts to an **average reduction of intelligence of 1.2 points per child**. It should be noted that these figures provide an initial order of magnitude estimate. More accurate estimates might be generated on the basis of more detailed data on among others the number of children exposed to e-waste or on blood lead levels in children and the contribution of e-waste exposure to these blood lead levels, if those data could be retrieved.

Similar quantifications could be done for other pollutants, for other health impacts and for other groups of people (children vs. adults, e-waste workers vs. inhabitants, inhabitants of e-waste recycling towns vs. inhabitants of adjacent regions). Neither have health impacts in the longer term been quantified. As a matter of fact, some longer term risks may be yet to develop and will still need to be understood.

As to the economic impacts of illegal exports of e-waste, it is estimated that the 2.98 million tonnes of illegally exported e-waste from the EU in 2012 correspond roughly with **€ 31.2 million to € 37.5 million loss in profits to the EU e-waste recycling industry**. This figure relates to the overall EU exports. If one looks at the e-waste **exports to China only** (1.16 million tonnes in 2012), the **EU recycling industry** is estimated to have **lost € 12.2 million to € 14.6 million in profits in 2012**. These figures should be considered initial order of magnitude estimates, as they were generated on the basis of a simple and rough extrapolation of an estimate for the UK only to Europe as a whole. Thereby the assumption was made that the ratio between the volumes of illegal exports and the loss to the industry is the same for the UK and the EU as a whole.

Assuming that the average intrinsic value of WEEE is about € 300 per tonne, the **economic value lost to the EU** as a result of illegal **exports to China** is roughly estimated at **€ 348 million for 2012** only. The **economic value lost** to the EU as a result of **all illegal exports out of the EU** is estimated at **€ 892 million for 2012**. This estimate too is an initial order of magnitude estimate and may be further fine-tuned on the basis of a revised average intrinsic value of WEEE. The value of € 300 per tonne refers to the average value of WEEE, whereas more precise figures might be generated for those WEEE categories that are being shipped to and recycled in China.

As to the impact on jobs, the illegal export of e-waste from the EU in 2012 is estimated to represent a **potential loss** of about **38,000 FTE recycling jobs in the EU**. Assuming a typical multiplier of 2, these direct recycling jobs would result in another **38,000 indirect and induced jobs**, for a total of **76,000 jobs**. The **illegal export to China** in particular is estimated to represent a potential loss of circa **14,900 FTE jobs** and another **14,900 indirect and induced jobs**, for a total of **29,800 jobs.** Our findings provide an initial order of magnitude estimate of the potential loss of recycling jobs and indirect and induced jobs in the EU.

5 Monetary analysis

5.1 Environmental impacts

The illegal export of e-waste is indirectly (through the informal recycling and dumping) leading to severe impacts on the environment, compromising among others the river and ground water quality and as a result depriving inhabitants from clean access to drinking water. Different estimates have shown that lead levels in water have been 8 times higher than the local drinking water standard (0.05 mg/L) (Robinson 2009). The two main rivers flowing through Guiyu, the Liangjiang and the Nanyang, are or used to be directly exposed to different parts of the e-waste processing chain. For example, the Nanyang had a number of acid leaching sites on its banks. The water and sediments in the rivers have been found to contain high levels of heavy metals (Greenpeace 2008). In Guiyu, the presence of pollutants (such as heavy metals) in surface and groundwater has created many years ago a market for drinking water to be delivered from neighbouring towns (Hicks et al. 2005). This resulted in direct costs for Guiyi's inhabitants, as they were required to buy expensive drinking water instead of using water from the river or from ground water resources. In the meantime tap water pipelines have been constructed in Guiyu giving inhabitants access to clean drinking water. More recently, the local government in Guiyu has started with soil remediation, due to the presence of heavy metals and other chemicals in the soil originating from e-waste recycling (Personal Communication 2015).

The impacts of e-waste exports/recycling on the aquatic environment can thus be monetised by estimating/calculating the (actual) direct costs for buying drinking water, by calculating the (actual) costs for constructing water supply infrastructure (drinking water pipelines) and by calculating the (potential and/or actual) costs for remediating contaminated soil in Guiyu. The additional cost that need to be incurred to mitigate the negative impacts of contaminated soil and water resources are site specific. Data from the WHO (2004) on the cost of water supply improvement can help illustrate the magnitude of these costs. According to this estimate, a supply based on piped water approximately amounts to annual cost of US$9.95[19] (approximately €10.77)[20] per person supplied (WHO 2004). This is a broad estimate for the Asian region and includes investment costs and the cost of operation and maintenance over the economic life of piped water infrastructure of 40 years. Accordingly, **the construction of a piped water supply for Guiyu from 2005 onwards would have led to additional annual cost of US$1,333,300 ($9,95 x 134,000) (approximately €1,443,590)**[21] i.e. the estimated population in 2005. However, if water resources planners accounted for the expected population growth in Guiyu, the supply systems would have to be dimensioned accordingly. For example, **supplying water to the estimated population in 2013 would lead to higher expected additional annual cost of US$1,492,500 (US$9.95 x 150,000) (approximately €1,615,959**)[22].

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[19] This refers to USD year 2000.

[20] The Eurostat's annual average exchange rates for 2000 have been used to convert USD to Euros (available at: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ert_bil_eur_a&lang=en).

[21] Given that the original estimate refers to USD in year 2000 the Eurostat's annual average exchange rates for 2000 have been used to convert USD to Euros (available at: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ert_bil_eur_a&lang=en).

[22] Given that the original estimate refers to USD in year 2000 the Eurostat's annual average exchange rates for 2000 have been used to convert USD to Euros (available at: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ert_bil_eur_a&lang=en).

5.2 Health impacts

Some of the health impacts in China arising from illegal e-waste shipments (and informal recycling and dumping in particular) have direct economic costs and others can usefully be represented by economic or monetary values to help communicate the importance of preventive and remedial action. In section 4.3 the impacts of lead exposure on children's neurological development in terms of IQ change have been quantified. It was estimated that around 81,300 children (58,000-93,000), born in 1995-2013 in the Chinese informal e-waste recycling areas, have been affected in their neurological development as a result of the informal recycling of e-waste (see paragraph 4.3.4). It was subsequently estimated that the intelligence of these children had collectively dropped with **97,560 IQ points** (69,600-111,600), which amounts to an **average loss of intelligence of 1.2 points per child** due to lead exposure originating from informal e-waste recycling and dumping (see paragraph 4.3.4).

A monetary valuation of these impacts on children's IQ might include an assessment of: opportunity costs in terms of *lost productivity* (i.e. decreased current value of expected lifetime revenues); *direct resource educational costs* related with compensatory education; opportunity costs of *lost income during remedial compensatory education*; *medical treatment costs*; and, *disutility* resulting from human development disabilities (Hunt 2011).

Given time and resource constraints and limited availability of or access to Chinese data, it was not possible within the context of this project to estimate or calculate these direct costs and opportunity costs. Figures from other studies however have been identified which may give an indication of the scale of these costs. Schwartz (1994) for instance related a 1 point reduction in IQ to a 4.5 per cent increase in the risk of failure to graduate from high school. Grosse et al. (2002) studied economic benefits from projected improvements in worker productivity from the reduction in children's exposure to lead in the US and estimated that each IQ point raises worker productivity by 1.76 to 2.38 per cent using a causal model of cognitive ability and economic productivity and they estimated from there an economic benefit. Therefore, a **decrease of 1 IQ point** in children can be associated with a **decrease of later productivity** of about **2 per cent** (EFSA 2010). Applying this to our case, it can be estimated that **about 81,300 children** (58,000-93,000) will suffer on average a **decrease of later productivity of about 2.4 per cent** as a result of exposure to contamination from e-waste recycling.

Hunt (2011) identified two studies which estimated the **medical treatment costs** for children with elevated blood lead levels (the treatment was chelation therapy)[23] (see Table 17). In order to estimate the medical treatment costs in China, it might be sensible to start working from a range of values that correspond to the lowest and highest values given in the Mathtec Inc study: USD 428 and 4,400 per child respectively (2000 prices). These figures obviously need to be adapted to the situation in China if one wants to use these for estimating the medical treatment costs. It also needs to be figured out to what extent and which medical treatment lead-poisoned children get in China.

Table 17: Estimates of medical treatment costs incurred by lead-poisoned children

Study	Cost element	Impact valued	Cost per child (USD, 2000)
US EPA (1985)	Medical costs	Preventing blood levels rising to 25 µg/dl or above	1531
Mahtec Inc (1987)	Medical costs; screening/education programmes; opportunity costs of	Blood level > 40 µ/dl; EP level > 53 µg/dl	4398
		Blood level > 40 µ/dl; EP level 35-53 µg/dl	2196

[23] Chelation therapy is a medical procedure with the aim to remove heavy metals from the body.

parents time	Blood level 21-40 µ/dl; EP level 33-53 µg/dl	1016
	Blood level 21-40 µ/dl; EP level 0-32 µg/dl	428
	Blood level 0-20 µ/dl; EP level > 33 µg/dl	565
	Blood level 0-20 µ/dl; EP level 0-32 µg/dl	428

Source: adapted from Hunt 2011

Scasny et al. (2008) provide a review of the available evidence of the **opportunity costs** next to the **costs** accrued by **remedial education**. They started from the guidance provided by the US Environmental Protection Agency (US EPA 1997) and arrived at cost estimates as presented in Table 18. The US EPA study combines the value of lifetime revenue with the estimate of percent salary loss per IQ point and subtracts the direct education and opportunity costs to result in a total net impact of IQ loss on revenue of USD 2,505 or USD 3,410 per IQ point (depending on which estimates of percent salary loss per IQ point are being applied) (US EPA 1997).

Table 18: Loss in earnings and education costs from IQ loss

	USD
Loss in earnings (LE)	4,090
Costs of education (CE)	267
Opportunity costs while in school (OC)	531
Total (LE-CE-OC)	3,292

Source: adapted from Hunt 2011 and Scasny et al. 2008

Based on a literature review on IQ valuation Spadaro and Rabl (2004; 2008) arrived at a **unit value of USD 18,000 per IQ point** (including adjustment for purchase power parity).

5.3 Economic impacts

5.3.1 Economic loss to the EU e-waste recycling sector

In fact, the economic loss to the EU e-waste recycling sector had already been monetised in paragraph 4.4.1 by extrapolating a figure for the UK to the EU as a whole. As a result it was roughly estimated that **2.98** million tonnes of illegally exported e-waste from the EU in 2012 represent roughly **£25.3 million to £30.4 million loss in profits to the EU recycling industry (€ 31.2 million – € 37.5 million)**[24]. If one looks at the illegal e-waste **exports to China only** (**1.16** million tonnes in 2012), the **EU recycling industry** might have **lost £9.86 million to £11.83 million in profits in 2012 (€ 12.2 million - € 14.6 million**). To put this into perspective, the EU e-waste recycling market earned revenues of US$1.3 billion in 2012 (or € 1.012 billion) and is estimated to earn US$1.79 billion (or € 1.39 billion) in 2020 (Frost & Sullivan 2013) (see paragraph 4.4.1 for more details).

Building further on an estimate from the WEEE Forum (2013) of the average intrinsic value of one tonne WEEE (about € 300), the **economic value lost** to the EU as a result of illegal exports to **China** (1.16 million

[24] The average historical exchange rates for 2012 have been used to convert from USD and Pound to euro (http://www.oanda.com/currency/historical-rates).

tonnes in 2012) was estimated at **€ 348 million for 2012** (see paragraph 4.4.1). The economic value lost to the EU as a result of all illegal **exports out of the EU** (2.98 million tonnes in 2012) is estimated at **€ 892 million for 2012**.

The economic value lost to the EU arising from illegal e-waste exports might also be estimated through a bottom-up approach whereby the monetary values of the different components and/or materials (including the precious metals) contained within these exports is estimated and these values are aggregated. Or at least the value of some precious materials lost might be assessed (e.g. gold, silver and palladium).

The **high intrinsic value** of the **precious metals** contained in e-waste can be demonstrated by following figures: according to Johnson (2011) the average mobile phone and DVD player contain around £15 (or €17.19) and £28 (or €32.09) of precious metals respectively and overall WEEE contains precious metals worth around £1 (or €1.146) for every kilogram of discarded electronic equipment (if September 2011 values are being applied) (Johnson 2011). Using the September 2011 values for these precious metals, the **value of precious metals within WEEE exported from the EU** in 2011 is roughly estimated at about **€ 3.23 billion** for all exports and about **€ 1.26 billion for exports to China only** (assuming 2.82 million tonnes of e-waste were exported illegally from the EU in 2011 and 1.1 million tonnes to China only, see table in Annex B: Guiyu population statistics). It should be noted that the accuracy of these estimates is difficult to assess with any degree of certainty. These estimates are however reliable as 'order of magnitude' estimates.

5.3.2 Job loss in the EU e-waste recycling sector

In paragraph 4.4.1 it was assessed that the illegal export of e-waste from the EU in 2012 might represent a potential loss of about 38,000 full time equivalent (FET) direct recycling jobs in the EU and another 38,000 indirect and induced jobs, for a total of 76,000 jobs. The illegal export from the EU to China in particular was estimated to represent a potential loss of about 14,900 FTE jobs and another 14,900 indirect jobs, for a total of 29,800 jobs. In economic terms, the loss of jobs implies the loss of economic value that could be generated in the e-waste recycling sector in Europe. Data limitations, especially in terms of separate statistical data for e-waste recycling (as a subsector of within the waste collection, treatment and disposal sector (including materials recovery) only allow rough assessments of these economic losses. According to Eurostat figures, the average annual economic value added per employee amounted to € 52,344 for the EU-27's waste and materials recovery sector (NACE Division 38) (Eurostat 2015). Thus, **direct employment losses of 14,900 FTE in the e-waste recycling sector imply an annual loss of economic value added of around € 780,000,000** (€ 52,344 per FTE employee x 14,900 FTE = 779,930,952). However, these values need to be treated with caution, as the e-waste recycling sector will differ in its characteristics form the aggregate waste collection, treatment and disposal sector. Nonetheless, the figures are indicative of considerable economic impacts.

5.4 Conclusions

The **environmental impacts** in China arising from illegal e-waste imports from the EU have not been monetised in full. We have illustrated these impacts by focusing on the environmental impacts of informal e-waste recycling and dumping on the aquatic environment in Guiyi town. These impacts have been illustrated by estimating the (actual) direct costs for constructing water supply infrastructure (drinking water pipelines) in order to substitute locally contaminated water supply resources in Guiyi. **To supply the estimated current population in Guiyu, the additional annual cost amount to around**

US$1,500,000 (approximately €1,630,000)[25]. This is a conservative and lower-bound value, as the supply infrastructure would likely to take into account further population growth in the area.

As to the **health impacts**, we have undertaken an effort to monetise the loss of intelligence in the group of children that were born in the Chinese informal e-waste recycling areas in the period 1995-2013. A monetary valuation of these impacts on children's IQ might have included an assessment of: opportunity costs in terms of *lost productivity* (i.e. decreased current value of expected lifetime revenues); *direct resource educational costs* related with compensatory education; opportunity costs of *lost income during remedial compensatory education*; *medical treatment costs*; and, *disutility* resulting from human development disabilities. However, given time and resource constraints and limited availability of or access to Chinese data, it was not possible within this study to estimate or calculate these costs. In order to estimate the medical treatment costs in China for instance, it is suggested to start working from a range of values that correspond to the lowest and highest values given in a study done in the US: USD 428 and 4,400 per child respectively (2000 prices). These figures obviously need to be adapted to the situation in China if one wants to use these for estimating the medical treatment costs. It also needs to be figured out to what extent and which medical treatment lead-poisoned children get in China.

As to the **economic impacts**, the loss in profits for the EU e-waste recycling sector arising from illegal e-waste exports had already been monetised earlier in the report, by extrapolating a figure for the UK to the EU as a whole. The economic value lost to the EU had also been monetised earlier, thereby building further on an estimate of the average intrinsic value of one tonne WEEE. In addition, the **value of precious metals** within WEEE exported from the EU was estimated for 2011, building further on 2011 information indicating that every kilogramme of WEEE overall contains precious metals worth around € 1.146. As a result this value was estimated to be about **€ 3.23 billion** for **all exports** from the EU and about **€ 1.26 billion** for **exports to China** only**.** It should be noted however that the accuracy of these estimates is difficult to assess with any degree of certainty. These estimates are however reliable as 'order of magnitude' estimates.

The **direct job loss** for the EU e-waste recycling industry has been monetised by multiplying the number of jobs lost with average economic value added per FTE employee in the sector. **It amounts to an annual loss of around € 780 million of value added for the EU-27.**

[25] Given that the original estimate refers to USD in year 2000 the Eurostat's annual average exchange rates for 2000 have been used to convert USD to Euros (available at: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ert_bil_eur_a&lang=en).

6 Conclusions

6.1 Summary of the extent of impacts

6.1.1 Illegal exports of e-waste from the EU

It was estimated that for 2005 and 2012 respectively around 0.74 and 1.16 million tonnes of e-waste have been imported in China from the EU.

6.1.2 Environmental impacts

The illegal export of e-waste from the EU to China has resulted – through the intensive informal recycling of e-waste in China – in the release of large amounts of contaminants in the local environment such as heavy metals, PBDEs, PCDD/Fs, PBCs, CFCs and PAHs. It has caused among others high concentrations of heavy metals such as lead, cadmium, mercury, copper and zinc in the surrounding air, dust, soils, sediments and plants.

The potential annual emissions of some environmental contaminants associated with e-waste imported illegally in China from the EU were estimated. It was for instance estimated that respectively 10 and 16 tonnes of PCBs from EU e-waste were potentially released in the Chinese environment in 2005 and 2012.

Given the complexity of the e-waste problem, the report presents only select data as to the environmental impacts of the e-waste crime. The focus was mostly on the environmental impacts (i.e. pollution levels) related to heavy metals and lead and zinc in particular. And mostly studies investigating or results regarding adverse environmental impacts in Guiyi and Taizhou, as the most representative locations for informal e-waste recycling, are being referred to.

As to the monetisation of the **environmental impacts** in China, we have focused on the impacts of informal e-waste recycling and dumping on the aquatic environment in Guiyi town. These impacts have been monetised by estimating the (actual) direct costs for constructing water supply infrastructure (drinking water pipelines) in Guiyu. **To supply the estimated current population in Guiyu, the additional annual cost amount to around US$1,500,000 (approximately €1,630,000)**[26]. This is a conservative and lower-bound value, as the supply infrastructure would likely to take into account further population growth in the area.

6.1.3 Health impacts

As to health impacts, this study demonstrates that illegal exports from the EU are significantly increasing incidences of chronic disease in China, threatening not just workers but also current residents of e-waste recycling areas and adjacent regions and future generations. Illegal exports from the EU result (through the informal recycling and dumping) in high prevalence of skin, gastric, respiratory, hematic, neurological, prenatal, natal and infant diseases in China.

In order to demonstrate the health impacts, figures on the routes of exposure, on the human body burden and on scientifically established associations and/or causal links between e-waste exposure and several kinds of diseases and other health impacts are presented. As with environmental effects, only select figures were presented, primarily in relation to heavy metal contamination in Guiyu and Taizhou.

[26] Given that the original estimate refers to USD in year 2000 the Eurostat's annual average exchange rates for 2000 have been used to convert USD to Euros (available at: http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ert_bil_eur_a&lang=en).

Select scientific studies (in China) show associations between exposure to e-waste and physical health outcomes such as:

- decreased lung function (i.e. lower forced vital capacity);
- decreased physical growth of children (i.e. lower weight, height and body-mass index);
- reduced reproductive health (i.e. increases in spontaneous abortions, stillbirths, and premature births, and reduced birth weights and birth lengths);
- changes in cellular expression and function (i.e. increased DNA damage).

Negative associations were also shown for blood lead levels and IQ in children.

A more detailed quantification has been carried out for the impacts of lead poisoning resulting from e-waste exposure on children's neurological development, expressed in terms of children's IQ scores. Based on data from various studies it was concluded that almost all children living in informal e-waste recycling centers such as Guiyu and Taizhou are or have been subject to lead exposure which exceeds the $BMDL_{01}$ intake level of 0.50 µg/kg b.w. per day as determined by the EFSA Panel on Contaminants in the Food Chain for neurodevelopmental effects.

This implies that potentially all children living in these informal e-waste recycling areas have been affected in their neurological development. It is estimated that roughly **22,400 children** (16,000-25,600) born **in Guiyu** in the period **1995-2013** have had blood lead levels exceeding the $BMDL_{01}$ and as a result have been subject to a **drop in intelligence** as a result from informal e-waste recycling and dumping.

For **China** as a whole it is conservatively estimated that **around 81,300 children (58,000-93,000) born in the period 1995-2013** have been **affected in their neurological development** as a result of e-waste exposure.

It was subsequently estimated that these **children in China lost about 97,560 IQ points** (69,600-111,600) as a result of informal e-waste recycling and dumping activities. This amounts to an **average reduction of intelligence of 1.2 points per child**.

As to the **monetisation** of the health impacts, we have undertaken an effort to monetise the loss of intelligence in the group of children that were born in the Chinese informal e-waste recycling areas in the period 1995-2013. Given time and resource constraints and limited availability of or access to Chinese data, it was not possible within the boundaries of this study to monetise this. In order to estimate the medical treatment costs in China for instance, it is suggested to start working from a range of values that correspond to the lowest and highest values given in a study done in the US: USD 428 and 4,400 per child respectively (2000 prices). These figures obviously need to be adapted to the situation in China if one wants to use these for estimating the medical treatment costs. It also needs to be figured out to what extent and which medical treatment lead-poisoned children get in China.

6.1.4 Economic impacts

As to the economic impacts of illegal exports of e-waste, it is estimated that the 2.98 million tonnes of illegally exported e-waste from the EU in 2012 correspond roughly with **€ 31.2 million to € 37.5 million loss in profits to the EU e-waste recycling industry**. This figure relates to the overall EU exports.

If one looks at the e-waste **exports to China only** (1.16 million tonnes in 2012), the **EU recycling industry** is estimated to have **lost € 12.2 million to € 14.6 million in profits in 2012**.

Assuming that the average intrinsic value of WEEE is about € 300 per tonne, the **economic value lost to the EU** as a result of illegal exports to China is roughly estimated at **€ 348 million** for **2012** only.

The economic value lost to the EU as a result of all illegal exports out of the EU is estimated at **€ 892 million** for **2012**.

In addition, the **value of precious metals** within WEEE exported from the EU was estimated for 2011, building further on 2011 information indicating that every kilogramme of WEEE overall contains precious metals worth around € 1.146. As a result this value was estimated to be about **€ 3.23 billion** for **all exports** from the EU and about **€ 1.26 billion** for **exports to China** only**.**

As to the impact on jobs, the illegal export of e-waste from the EU in 2012 is estimated to represent a **potential loss** of about **38,000 FTE recycling jobs in the EU**. Assuming a typical multiplier of 2, these direct recycling jobs would result in another **38,000 indirect and induced jobs**, for a total of **76,000 jobs**. The **illegal export to China** in particular is estimated to represent a potential loss of circa **14,900 FTE jobs** and another **14,900 indirect and induced jobs**, for a total of **29,800 jobs.**

Table 19: Overview of estimated economic impacts in the EU for 2012

Loss in profits for the EU recycling industry	Arising from illegal EU exports to China		€ 12.2m - € 14.6m	
	Arising from total illegal EU exports		€ 31.2m - € 37.5m	
Lost economic value to the EU	Arising from illegal EU exports to China		€ 348m	
	Arising from total illegal EU exports		€ 892m	
Potential job loss in the EU (FTE)	Arising from illegal EU exports to China	*Direct jobs*	14,900	29,800
		Indirect and induced jobs	14,900	
	Arising from total illegal EU exports	*Direct jobs*	38,000	76,000
		Indirect and induced jobs	38,000	

The **direct job loss** for the EU e-waste recycling industry has been monetised by multiplying the number of jobs lost with the annual wage in the EU waste recycling (and reuse) industry. It amounts to annual losses of around € 780 million of value added in this sector.

Finally, it should be noted that most of our quantification and monetisation efforts in this report provide initial order of magnitude estimates.

6.2 Major gaps and research needs

6.2.1 Quantitative analysis

Quantifying the illegal export of e-waste from the EU (to China) is highly challenging as there is very little clear information upon which estimates can be based (given the illegal nature of these e-waste shipments). The estimates are based on reliable estimates of the volumes of e-waste generated in the EU and assumptions about the percentage of e-waste that is being exported from the EU and the percentage of e-waste from the EU that is being imported in China. Especially in relation to these percentages more in-depth research could be undertaken. More research could also be undertaken into the (sub)volumes of the different e-waste categories that are being shipped out of the EU and imported in China.

Given the uncertainty surrounding these 'guesstimates', it is suggested to work with minimum and maximum EU export scenarios and minimum and maximum import in China scenarios.

The potential annual emissions of some environmental contaminants associated with e-waste imported illegally in China from the EU have been estimated. These estimates are based on concentrations in components of Swiss e-waste and on the estimates of the 2005 and 2012 illegal imports in China from the EU. Further research could be undertaken to update the estimates of concentrations of certain

environmental contaminants of e-waste and to extend these estimates to other contaminants – figures are only available for a select number of contaminants.

Given the scale and complexity of the e-waste problem, it was within the context of this project not possible to quantify the total environmental impacts from informal e-waste recycling in China or in particular areas of China, not to mention the impacts from the informal recycling in China of the millions of tonnes of e-waste imported annually from the EU (i.e. the share of EU-borne e-waste impacts within the overall impacts from informal recycling in China). This resulted among others from uncertainties about the sources of the contamination in recycling areas and control areas and in particular from the exact shares of these sources in the overall contamination. It should however be noted that many studies were able to indicate that certain pollution cases were mainly originating from e-waste recycling activities.

As a result, the report presents only select data as to the environmental impacts of the e-waste crime. The focus was mostly on the environmental impacts (i.e. pollution levels) related to heavy metals. And mostly studies investigating or results regarding adverse environmental impacts in Guiyi and Taizhou, as the most representative locations for informal e-waste recycling, are being referred to.

Also in relation to the health impacts select figures were presented, primarily in relation to heavy metal contamination in Guiyu and Taizhou. Figures on the routes of exposure, on the human body burden and on scientifically established associations and/or causal links between e-waste exposure and several kinds of diseases and other health impacts are presented.

As to the estimates of the number of children subject to a drop in intelligence and of the total loss of intelligence, it should be noted that these provide an initial order of magnitude estimate. More accurate estimates might be generated on the basis of more detailed data on among others the number of children exposed to e-waste or more detailed data on blood lead levels in children and the contribution of e-waste exposure to these blood lead levels, if those data could be retrieved.

Similar quantifications could be done for other pollutants, for other health impacts and for other groups of people (children vs. adults, e-waste workers vs. inhabitants, inhabitants of e-waste recycling towns vs. inhabitants of adjacent regions).

Neither have health impacts in the longer term been quantified. As a matter of fact, some longer term risks may be yet to develop and will still need to be understood.

The estimates of the loss in profits for the EU e-waste recycling industry should be considered initial order of magnitude estimates, as they were generated on the basis of a simple and rough extrapolation of an estimate for the UK only to Europe as a whole. Thereby the assumption was made that the ratio between the volumes of illegal exports and the loss to the industry is the same for the UK and the EU as a whole. These estimates of the loss in profits could be further fine-tuned by applying the methodology used to generate the estimate for the UK to the EU as a whole. This obviously requires more detailed research into the economic parameters of the EU e-waste recycling industry.

The estimate of the total economic value lost to the EU (based on the assumed average intrinsic value of WEEE per tonne) too is an initial order of magnitude estimate and may be further fine-tuned on the basis of a revised average intrinsic value of WEEE. The value of € 300 per tonne refers to the average value of WEEE, whereas more precise figures might be generated for those WEEE categories that are being shipped to and recycled in China.

6.2.2 Monetary analysis

In this study the **environmental impacts** in China arising from illegal e-waste imports from the EU have not been monetised in full. We have focused on the impacts of informal e-waste recycling and dumping on the aquatic environment in Guiyi town, by estimating the costs for constructing water supply infrastructure (drinking water pipelines) in Guiyu. In future research, attempts could be made to monetise these impacts on the aquatic environment for China as a whole.

As to the monetisation of the **health impacts**, we have undertaken an effort to monetise the loss of intelligence as a result of lead poisoning in the group of children that were born in the Chinese informal e-waste recycling areas in the period 1995-2013. An attempt was undertaken to estimate the medical treatment costs in China. However, only a range of values was identified from studies in the US. Future research might be carried out to investigate the actual costs of medical treatment in China and to investigate to what extent lead-poisoned children get medical treatment in China and if so what type of treatment. Future research might also gather data to monetise other costs than medical treatment costs, such as opportunity costs in terms of *lost productivity* (i.e. decreased current value of expected lifetime revenues); *direct resource educational costs* related with compensatory education; opportunity costs of *lost income during remedial compensatory education*; and, *disutility* resulting from human development disabilities. Future research may also look into monetising health impacts from other environmental contaminants than lead, from overall e-waste exposure or from certain exposure routes. For instance the monetisation of health impacts from air pollution resulting from informal e-waste recycling could be looked into further.

As to a review of gaps in the analysis and the research needs in relation to monetising economic impacts, we refer to the previous section – i.e. the section on the quantitative analysis. As indicated earlier in the report, the quantitative analysis of the economic impacts (in particular the loss of profits to the EU e-waste recycling industry and the lost economic value to the EU) was in fact a monetary analysis.

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Annex A: Chinese soil quality standards

The Chinese soil quality standards, also called GB1568-1995 standards, were put into effect in 1996 with the main aim to prevent soil pollution and to protect soil functions, eco-environment, agricultural and forestry production and human health.

The soil quality standards include the following three classifications (Wang G. & Shan Y. 2013):

1. Class 1 standards:
    - Soil background level
    - Nationally wide background values based
    - Cover natural conservation areas, drinking water source areas etc.
    - Based on more than 400 samples
2. Class II standards:
    - Ecological and environmental effects based
    - Cover farm land, fields of vegetable and tea production, orchard soil
    - Healthy plant growth and safe food quality
    - No potential effects on water bodies
3. Class 3 standards:
    - Soil of higher adsorption capacity/background levels
    - Healthy growth of trees/plants, no hazard to environment
    - Use experimental data based on soil of higher adsorption capacity and artificially contaminated soils

Table 20: The GB1568-1995 Chinese soil quality standards

Contaminants	Class-1	Class-2			Class-3
	Background	<6.5	6.5 - 7.5	>7.5	>6.5
Cd	0.20	0.30	0.30	0.60	1.0
Hg	0.15	0.30	0.50	1.0	1.5
Ni	40	40	50	60	200
As Paddy	15	30	25	20	30
Dry land	15	40	30	25	40
Cu [a] Agri.	35	50	100	100	400
Frui.	-	150	200	200	400
Pb	35	250	300	350	500
Cr [b] Paddy	90	250	300	350	400
Dry land	90	150	200	250	300
Zn	100	200	250	300	500
HCH [c]	0.05		0.50		1.0
DDT [c]	0.05		0.50		1.0

[a]: 'Agri.' represents agricultural soils, and 'Frui.' represents fruit farm soils.
[b]: In case soil CEC < 5cmol(+) kg^{-1}, the standard values will be half values of the listed.
[c]: HCH (hexachlorocyclohexane), values are the sum of 4 isomers;
[d]. DDT (Dichloro-diphenyl-trichloroethane), values represent the sum of DDT, DDD and DDE.

Source: Wang G. & Shan Y. 2013

Annex B: Guiyu population statistics

Table 21: estimates of inhabitants and number of children born in Guiyu

Year	Estimated number of habitants Guiyu	Crude birth rates for China (per 1000 hab.)[a]	Children born in Guiyu	Crude death rates for China (per 1000 hab.)[a]	People dying in Guiyu	Population proportion under 15 [b]	Population under 15
1995	95,000	17	1,615	7	665	29	27,550
1996	99,000	17	1,683	7	693	28	27,720
1997	103,000	17	1,751	7	721	28	28,840
1998	107,000	16	1,712	7	749	27	28,890
1999	112,000	15	1,680	6	672	26	29,120
2000	116,000	14	1,624	6	696	26	30,160
2001	120,000	13	1,560	6	720	25	30,000
2002	125,000	13	1,625	6	750	24	30,000
2003	**130,000**	12	1,560	6	780	22	28,600
2004	132,000	12	1,584	6	792	21	27,720
2005	134,000	12	1,608	7	938	20	26,800
2006	136,000	12	1,632	7	952	20	27,200
2007	138,000	12	1,656	7	966	19	26,220
2008	140,000	12	1,680	7	980	19	26,600
2009	142,000	12	1,704	7	994	19	26,980
2010	144,000	12	1,728	7	1,008	18	25,920
2011	146,000	12	1,752	7	1,022	18	26,280
2012	148,000	12	1,776	7	1,036	18	26,640
2013	**150,000**	12	1,800	7	1,050	18	27,000
Total			31730		16184		
Average	127,211		1670				27,802

Source: own representation, World Bank, WHO Global Health Observatory Data Repository and Wang et al. 2013. Note: As no population statistics were available for Guiyu to the project team, except for the number of habitants in 2003 and 2013 (Wang et al. 2013), the number of habitants for the other years in the period 1995-2013 have been estimated/calculated starting from these 2003 and 2013 figures, thereby applying urban population growth rates for the period 1995-2013 (assuming Guiyu has been growing very fast in that period) and applying roughly the population growth rates in China as a whole for the period 2003-2013 (assuming that population growth had slowed down somewhat in that period). The number of children born annually in Guyiu have been estimated/calculated by applying the crude birth rates from China (per 1000 habitants) (figures from The World Bank) to the population estimates. [a] Source: The World Bank; [b] Source: WHO Global Health Observatory Data Repository.

Table 22: overall and urban population growth rates in China

Year	Population growth rates China	Urban population growth rates China
1995	1,1	4,2
1996	1	4,1
1997	1	4
1998	1	3,9
1999	0,9	3,8
2000	0,8	3,6
2001	0,7	4,1
2002	0,7	4,2
2003	0,6	4,1
2004	0,6	4
2005	0,6	3,9
2006	0,5	3,7
2007	0,5	3,5
2008	0,5	3,4
2009	0,5	3,3
2010	0,5	3,3
2011	0,5	3,2
2012	0,5	3,1
2013	0,5	2,9

Source: own representation and The World Bank