State of ICT Waste Treatment in Developing Countries and Proposals : Case of Chad

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Abstract *— The consumption of the different products of information and communication technologies produces waste called e-waste that is more or less harmful for the environment and the human being. How is this waste collected and treated in developing countries like Chad? This article answers this question and proposes some ways for an appropriate treatment of this type of waste. Some metals with dangerous properties are presented.*

Keywords *— ICT, waste, environment, heavy metals, waste treatment*

I. INTRODUCTION

Any consumption of a product directly or indirectly leads to the creation of waste. This waste is nothing than the remains of the product that cannot longer be used for reasons of quality or quantity. Concerning the quality, it is when it has decreased and no longer meets the requirements. On the other hand, for the quantity, it is when it is too weak to be used or it is too much to be totally consumed. In both cases, the remainder is waste. Information and Communication Technologies (ICT) are increasingly used in many fields and sectors. The consumption of ICT products (hardware, software or data media) follows the same logic. Indeed, thousands of computers (desktop and laptops) and other ICT devices (tablets, photos, cameras, phones, screens, printers, scanners, fax machines, TVs, digital music players, DVDs, etc.) are sold each year. With the rapid evolution of ICT products (hardware, software or data media), many of these products quickly become obsolete and enter in the world of waste. The case of mobile phones is a good example. Several models of different brands emerge every day and many users change more than one phone in a year. The remainder of ICT products that cannot be used is what we call ICT waste or e-waste.

ICT waste can pose a risk to human and environmental health. Indeed, this waste can be harmful, toxic, irritating, explosive, corrosive, easily flammable, and even infectious. Mixed with household waste, they are a threat to people in charge of waste management, a risk to incinerators and a poison in landfills. As examples, batteries used to power many ICT equipment and LEDs that adorn innumerable ICT objects contain dangerous substances and rare materials. Once worn, they become waste that must be managed with carefulness.

In this work, we will focus on ICT waste and its management in Chad. First, we will present the types of ICT waste that can be found, then we will make a state of the art on ICT waste treatment techniques, then we will expose the situation in Chad, finally we will present possible proposals, suggestions and perspectives of our work.

II. ICT WASTE

Manufacturing ICT products requires enormous resources and produces large quantities of waste. For example, production of a computer takes 240 kg of fuel, 22 kg of chemicals and 1500 litres of water [01] and 98% of these resources turn into waste [02]. We are not interested in this manufacturing waste and carbon dioxide released. We will call ICT waste, any ICT product or any part of an ICT product, acquired and probably used and that cannot be used again in the same situation.

ICT waste is largely derived from Hardware, i.e. hardware part of IT and telecom systems. But they also come from software part and operating supports i.e. consumables needed to exploit information system (ink, barrels, data media such as hard disks, CDs, flash disks, paper, etc.).

We can categorize wastes according to their sources. Thus, we can distinguish:

- Hardware waste;
- Software waste;
- "Storage media" waste.

A. Hardware Waste

It is waste resulting from the consumption of computer and telecommunications equipment. For example, computer shells or telephones and telecom equipments which no longer serve. This waste constitutes the bulk of ICT waste.

B. Software Waste

Soft part of computer systems and telecoms also produces waste. This waste is not as visible as software. But, they saturate ICT systems and can disturb their proper functioning. We specify that this waste consists of software that we do not use and / or that we do not intend to use but that are present on our systems. Examples of such waste include unused

software on systems, obsolete versions of software alongside the versions in use, or old operating systems on computers.

We put in this category, the data and the files present on the machines but with very little chance to be used one day.

We note that this type of waste is in close line with the third type of waste: media waste because it is where software and data are stored.

C. "Storage Media" Waste

Storage media allow retention of software and data. These are hard disks, CD-ROMs, floppy disks, magnetic tapes, USB sticks, etc. After a period of use, these supports can also become obsolete and become waste. Unlike the case of their contents, this waste is palpable like the waste of the "hardware". The case of removable disks that have a shorter and shorter lifetime is an illustration of the generation of these types of waste.

III. CLASSIFICATION OF ICT WASTE

We can classify ICT waste according to their chemical properties and mainly according to their nuisance ability to animal and plant life. Indeed, ICT products contain some chemicals which are harmful to the environment and humans. Among these products, we can mention:

- Cadmium, barium oxide, phosphorus,
- Lead ;
- Berylium;
- Coltan;
- Mercury ;
- Arsenic (in diodes);
- Brominated flame retardants (in screen carcasses);
- Etc.

We can categorize e-waste according to the main types of metals (chemical elements): heavy metal e-waste and rare metal e-waste.

A. *"Heavy Metals" E-waste*

Heavy metals like mercury, cadmium, lead, etc. are present in many ICT materials. Most materials containing printed circuit boards have such products. Some heavy metals are used as flame retardants and serve to reduce the flammability of plastics in printed circuit boards, housings, motherboards, connectors, printer cartridge, keyboards and wiring. Among these metals, we have bromine and polyvinyl chloride, their derivatives and their combinations (polybrominated biphenyls (PBB), polybrominated diphenyl ethers (PBDE), tetrabromobisphenol-A (TBBPA) and hexabromocyclododecane (HBCD). Polyvinylchlorides are used for covering housings and wiring. However, the molecular composition of polyvinylchloride contains chlorine, a product that can pose carcinogenic risks when incinerated under unsuitable conditions.

These heavy metals pose risks to human health and the environment if they are not managed properly. Even, incinerated at insufficiently high temperatures, plastics and other hydrocarbons can combine with halogens to form dioxins and furans that are responsible for various toxic effects, including immunotoxicity, disturbances in thyroid and steroid hormones and reproductive functions [03].

A. Some Heavy Metals in ICT

We briefly present here some of these metals presenting a danger.

1) ***Lead:*** Lead is incorporated into the glass of the cathode ray tube (shields) to protect the user from radiation. The quantity of lead varies between 0.4 and 3 kg for a screen, depending on the size and the year of manufacture, the conventional average is 1.36 kg. Lead is a bioaccumulative metal; it can cause health problems mainly by attacking the nervous system, kidneys and blood. Soluble lead, or lead oxide, is particularly problematic: it can be dissolved in water and cause contamination of surface or ground water.

The toxic effects of lead can occur in many parts of the body, although the nervous system is more sensitive, particularly in young children whose brain and nervous system are developing. At high concentrations in young children, it can cause encephalopathy (swelling of the brain) and even death. The toxic effect of lead can also be manifested by anemia by inhibiting enzymes responsible for the synthesis of one of the constituents of hemoglobin [04]. Like most metals, lead can also induce various pathologies in the kidneys although this kind of toxicity is now rarer [05, 06].

2) Mercury: Mercury is used for the manufacture of some ICT equipment for backlighting. For example, flat screens contain between 0.12 mg and 5 mg of mercury. The vaporization of metallic mercury and dimethyl mercury is dangerous and can lead to fire triggering in landfills. The toxic manifestations of mercury vary according to its nature. Chronic exposure to metallic mercury in the form of vapor mainly causes symptoms in the central nervous system such as tremors or depressed mood, but can also lead to proteinuria in the kidneys [06]. It can also cause hypertrophy of the thyroid gland and gingivitis. As for inorganic mercury, its target organ is the kidney where it can induce nephritis, which is an inflammation of the kidney. Organic mercury, mainly methylmercury, targets the central nervous system [05, 06] where it can notably cause paresthesia (tingling, numbness, etc.), ataxia or neurasthenia.

3) Cadmium: Cadmium is a metal which is resistant to corrosion, malleable and ubiquitous in the earth's crust.

Cadmium is widely used in the NiCd battery sector and also in the manufacture of pigments, the stabilization of plastics such as polyvinyl chloride (PVC) and the plating of metal parts to prevent corrosion. It is a non-essential metal to humans. Once absorbed, it disperses in the body; the highest concentrations are found mainly in the kidneys, bones and lungs. Cadmium has a particular affinity for the kidney, because kidney has an insufficient endogenous synthesis of metallothioneins to capture it all. Then, it is accumulated in the form of Cd^{2+} ions and can cause tubule damage leading to proteinuria [07] that can ultimately lead to kidney failure. The first manifestations of renal toxicity occur when the urinary cadmium concentration reaches 10 µg/g of creatinine. Cadmium is also considered as a carcinogenic agent [06, 08, 09].

4) Benzene: Benzene is a highly flammable and volatile liquid. It is used in several industries, including the electronics industry, as a degreaser of components for which the highest purity is sought. In chemical industry, it is a starting product for many syntheses (synthesis of phenol, styrene, aniline, nitrobenzene, cyclohexane) which are themselves intermediates products used for the manufacture of plastics, dyes, textiles etc. It is a substance that irritates the eyes, the skin and the respiratory tract. It can lead to clinical signs during acute exposures. Benzene can have effects on the bone marrow and can cause cancer [3, 10, 11].

5) Bromine: Bromine is a chemical used in the production of flame retardants that serve to reduce the flammability of plastics in printed circuit boards and certain computer and telephones components. Bromine is toxic to humans and has several side effects of contact or ingestion. Exposure to bromine has various health problems: liver, kidney and skin damage, eye irritation and cancer [12]. Bromine in the atmosphere can reduce the amount of ozone, which can be negative for the environment [13].

6) Chlorine : Chlorine is present in the molecular composition of polyvinyl chloride used for coating housings and wiring. Chlorine has a toxicity closely related to its powerful oxidant properties. This toxicity makes it possible to obtain drinking water by destroying the bacteria, however this substance is also toxic for humans. Chlorine is a severe irritant to the eyes, and respiratory tract.

Bronchopulmonary sequelae are possible after exposure to high concentrations. Repeated exposures cause skin disorders, irritation of the ocular mucosa and chronic bronchitis [14]. However, chlorine is not considered as carcinogenic in humans [15].

B. *"Other Metals" E-waste*

Other metals used in the manufacture of ICT products are found in e-waste. Someone may be unhealthy for the environment and humans. We present below some examples of these metals.

1) Copper: Copper is a metal with particularly high thermal and electrical conductivities and is, like the majority of metals, ubiquitous not only in the earth's crust at levels between 5 mg/kg and 70 mg/ kg [01], but also as trace elements in all animals and plants. Copper has been used for a very long time because of its exceptional properties. The construction, electrical and electronic products and general products sectors are major consumers of copper [16].

Excessive inhalation of copper-containing dust can lead to nasal and eye irritation, headaches, nausea and diarrhea. Ingestion may also occur. The symptoms are mainly related to the gastrointestinal system such as abdominal pain and vomiting. Ingestion of water exceeding 3 mg Cu/L leads to liver necrosis [17]. Hepatic toxicity is explained by the saturation of lysosomes where copper is complexed with metallothioneins. Since these organelles cannot metabolize them further, the excess copper would migrate to the nucleus where it would cause increased oxidative damage [17].

2) Zinc: Zinc is one of the most abundant metals in the earth's crust, ranging from 0.9 mg/kg to 169 mg/kg [18]. In its metallic form, it has a bluish-white appearance, is resistant to corrosion and is insoluble in water, although many of its forms, especially those complexed with sulfur, are soluble in water. Today, the majority of zinc is used in the process of galvanizing steel, iron and many other metals to make them resistant to corrosion.

Acute intoxication by ingestion of zinc is relatively rare; it causes gastrointestinal problems and diarrhea. Chronic inhalation of zinc may lead to problems with copper deficiency manifesting as a decrease in the number of erythrocytes [18]. An acute inhalation of zinc oxide may cause symptoms associated with metal fever: chest pain, fever, nausea, coughing, shivering, and leukocytosis.

3) Lithium: Lithium is a soft metal, the lightest of solids. It is used to manufacture batteries (electrolyte in an electrochemical accumulator) for cameras, watches, laptops, etc. However lithium in reaction with combustible substances and water can cause an explosion whose smoke is irritating and toxic. Inhalation may cause burning sensation, coughing or difficulty breathing [19].

4) Coltan: Coltan is an abbreviation for a colombio-tantalite mineral. It is the combination of two minerals, Colombium or niobium and Tantalum. It is the latter that makes coltan so important. Coltan has been highly sought in recent years and is involved in the manufacture of mobile phones, computers, GPS, satellites, remote-controlled weapons, plasma televisions, video game consoles, space rockets, missiles, cameras, etc. It is a strategic resource, essential to the development of ICTs [20].

Although tantalum oxide is inert, its inhalation into fine particles causes pneumological diseases [21].

5) Arsenic: Arsenic is a tasteless, odorless chemical element naturally present in the soil. Arsenic is used in industry (paints, dyes, dyes, printing, electronics ...) to prevent the formation of defects (oxygen bubbles). Ingestion of inorganic arsenic for a long time may lead to chronic arsenic poisoning (arsenicism). The effects, which may take years to appear, depending on the level of exposure, include skin lesions, peripheral neuropathy, gastrointestinal symptoms, diabetes, renal system disorders, cardio-vascular diseases and cancers. Organic arsenic compounds, which are abundant in seafood products, are less harmful to health and are rapidly eliminated by the human body [03]. They are rapidly absorbed by the respiratory route (in the form of vapors or dust), digestive route and also cutaneous one. In divided form, arsenic is a moderately flammable and slightly explosive product [22]. Some salts of arsenic can cause severe eye burns. An irritant action (dermatitis) is observed after skin contact [23].

IV. Treatment of ICT waste in Chad

By waste treatment we mean the process from waste collection to destruction that can result in recycling or annihilation.

The problem of waste treatment in Chad is very delicate in all areas. Households and even businesses have trouble for managing their waste. Many of them dump their waste in the streets, gutters or rivers that coexist or cross city.

Projects in the direction of waste treatment have been initiated. Examples include the municipality N'djamena with the project "*N'Djamena Nadif*" aimed at collecting and disposing of city waste in a responsible way and the cases of some companies like "*Bobby Ville Propre*" that are trying to collect and to treat the waste. But the results are minimal.

Many ICT waste are confused with other wastes and do not include specific measures for their treatment. The main processes for managing end-of-life ICT products are identified in [24] and their links are shown schematically in Figure 1.

We present below the collection and treatment of ICT waste in Chad.

A. *ICT Waste Collection in Chad*

At present, there is no recommended procedure for collecting ICT waste that we know. Each person or organization does what he can and what seems good to him. The indications of some manufacturers present on ICT products are not taken into consideration for lack of waste management policy of these products but also for lack of a recycling centre. A palpable example is that of printer inks or toners on which guidelines for their management after exhaustion are given, but which, in practice, end up in household waste or strew some street arteries in cities.

B. *Current ICT Waste Management in Chad*

In developed countries, guidelines have been established for the management of ICT waste. An example is the European Parliament and Council Directive on Waste Electrical and Electronic Equipment (WEEE), which was defined in 2002 and recast in 2012 [25]. This Directive imposes obligations on the collection, treatment, disposal and financing of household and business WEEE. In Chad, the treatment of even household waste is difficult. Few households collect their waste and deposit it in garbage bins put at their disposal by municipalities. However, most households take care of the collection of their waste and treat it in a natural way by depositing them in corners of the street and burning them. Overall, the population is poorly supplied by means of collection. There is an absence or insufficiency of waste collection sites. Few garbage bins are placed for waste collection. The population is also less aware of the process of collecting and sorting waste.

With regard to ICT waste, few special actions are undertaken for their treatment. They are confused with household waste in most cases.

Cleaning companies such as "*N'djamena Nadif"*, "*Bobby Ville Propre*" " collect the waste and place it in fields outside the cities in the open air or bury it in the quarries or burn it. These practices are not without consequences for the population: the air is polluted by harmful gases that emanate from the waste; lakes, rivers and Groundwater are not spared. Livestock and agriculture are also threatened because fields needed for agriculture are used for landfills of this waste. Leaves and herbs used as feed for livestock are also polluted and do not develop normally due to various chemicals from ICT and other products. In other words, animal and plant populations are all subject to intoxication through air, water and food.

The employees of these cleaning companies work in deplorable and dangerous conditions, without sufficient protection for the hands and feet or for the face. They are exposed to gases, acid solutions, toxic fumes and contaminated ash from dismantling or destruction of this waste.

V. Proposals for waste treatment techniques

We propose as ICT waste treatment techniques in Chad taking into account the environmental, technological and social realities, the reuse and the establishment of a waste treatment structure collaborating with the producers of ICT products and other recycling centres.

Indeed, ICT products like other products can be subject to various consumption at different levels. Companies and organizations, after having used these products for a while, can pass them on to other organizations such as educational institutions, associations or organizations of general interest that can use them. This will reduce the amount of waste.

Having an ICT waste treatment centre becomes more than necessary. This centre must be endowed with the means necessary for its work. It must not work alone, because the country does not have all the skills on the whole chain of waste treatment. It must therefore collaborate with major manufacturers of ICT products (HP, IBM, Cisco, Oracle, etc.) to take back some obsolete products for recycling or redesign for another use.

In addition, we must promote the collection and sorting of waste to households and businesses to facilitate the treatment of waste.

Finally, we encourage the shared use of some ICT resources like what is done in the Cloud. Users do not have to buy the resources for themselves, but they can use those of their peers for a fair fee.

VI. SUGGESTIONS

ICT waste is detrimental to humans and environment. It is crucial to look at its management appropriately. Measures can be taken upstream and downstream of the use of ICT products. Upstream, we will focus on the importation of these products and the responsibility of producers. Downstream, we will consider a responsible behaviour of the users of these products and the means of being able to treat their waste well.

It is important to ensure the quality of imported ICT products (quality assurance services). Some developed countries send some of their end-of-life ICT products to developing countries (including Chad). This seems profitable for the latter, but in the long run, it becomes a risk for those countries that do not always have the means to manage the waste of these products. Indeed, recycling and disposal of these products in poor countries is rudimentary and poses serious health and environmental problems. For example, deteriorating water quality can lead to serious illness. Chad and other developing countries must not only enact laws on the quality of imported ICT products but must enforce these laws.

Developed countries must also respect the good conventions they have ratified, in particular the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal adopted in 1989 and revisited in 1995, which ban the export of hazardous waste from EU countries, OECD and Liechtenstein signatories to the Convention, to all other member countries [26]. It is desirable for developing countries to support the European Parliament's Directive on WEEE and the Limitation of Hazardous Substances (LSD - RoHS) which imposes a substitution of several metals (lead, mercury, cadmium ...) as well as inhibitors of flames (PBB and PBDE) in all new electrical and electronic equipment. Producer empowerment envisioned by some countries is also to be encouraged. The aim is to make manufacturers and importers of ICT equipment responsible for the entire life cycle of their products. The principle is that manufacturers facilitate the recycling and dismantling of their products by limiting the use of resources, pollution and the volume of waste.

For a clean collection of ICT waste, it is desirable to define the collection procedure and set up a local structure in companies and have at least one company collecting this waste. This last one will have among others tasks to :

- go to companies for the collection of ICT waste;
- sort this waste;
- propose some of this waste to a second use in educational or associative institutions;
- send some part of this waste to specialized companies for recycling;
- and proceed to clean disposal of the rest.

As a perspective, we are planning a survey to learn more about the practices of the population regarding the management of ICT waste at the individual level and the consequences.

VII. CONCLUSION

ICT waste management is a process that requires skill and adequate means. Chad, like most developing countries, is late in defining a management policy for this kind of waste. Chadian companies in charge of waste management do not distinguish ICT waste from other waste. The concept of waste sorting is not anchored in households and businesses. It is enviable to sensitize the population to this concept and to set up structures endowed with material resources and skills for an appropriate treatment of ICT waste with a vision to emphasize reusing and recycling of ITC products. The landfilling and burning of ICT products must be the last resort, to reduce the risk of pollution of the fauna and flora. Liquid substances must be drained and collected by qualified persons for recycling prior to disposal at indicated site.

Therefore, producers must use materials that are less harmful to human health and the environment; for example, the use of magnesium-based alloys instead of lead.

Finally, with the speed of obsolescence of ICT equipment, is it not essential to have a good system for treating ITC waste in every country?

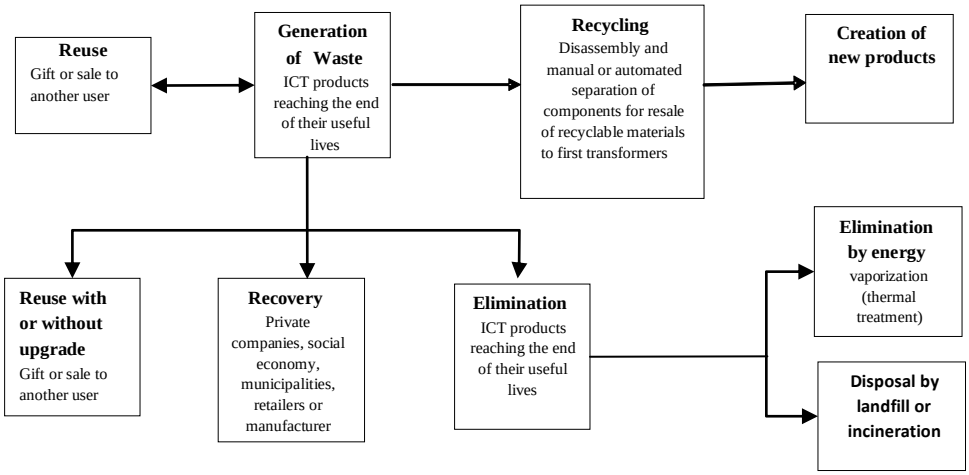

Figure 1: End-of-Life ICT Product Management Processes [24]

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