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Material flow analysis for management of waste TVs from households in urban areas of Vietnam

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ABSTRACT

Electronic waste has become one of the fastest growing waste streams in Vietnam, of which adequate information on its size and its flows is very crucial to efficiently manage it and prevent associated environmental problems. To obtain such information, Material Flow Analysis (MFA) was used to quantify and systematically analyze the flow of obsolete TVs from households in urban areas in Vietnam. The results showed a gradual increase of obsolete TVs during the period 1966–2035. Further investigation showed that 66% of the total obsolete TVs in 2012 was directly reused or reused after repair/refurbishing, 3% was domestically recycled or open burned to recover valuable materials, 9% was illegally exported and the rest of 22% was open dumped. Substance flow analysis showed that 75% of total base metals (i.e., Cu, Al, Fe/steel) contained in obsolete TVs was reused or recycled; the rest (25%) was exported or emitted, representing the loss of materials for the Vietnamese economy. For precious metals (i.e., Au, Ag, Pd), plastic and glass, a larger material leaching was noticed. About 34% was illegally exported (in case of precious metals and plastics) or open dumped (in case of glass). The analysis also revealed the heavy involvement of the informal sector in the TV waste management system, making it more complicated, difficult to control and resulting in potential risks to the environment and human health. Based on the above analysis, an integrated management system was proposed to manage the secondary material source and prevent potential harmful effects.

1. Introduction

E-waste or waste of electrical and electronic equipment (WEEE) is a special kind of waste, which contains both hazardous and valuable substances (Puckett et al., 2002; Huisman et al., 2008; Oguchi et al., 2013). E-waste management therefore should rely on systematic management of its components by an integrated system to prevent hazardous emissions and recover valuable components (Gurauskiene and Stasiskiene, 2011). Moreover, quantification of waste flows and networks is after all the first step in better managing e-waste (Bakhiyi et al., 2018). In this context, material flow analysis (MFA) is a suitable supporting tool for e-waste management that provides foundation for quantification, assessment, improvement or strategic planning (Brunner and Rechberger, 2005). Moreover, since its results can be controlled via simple mass balance of inputs, outputs and stocks (Brunner and Rechberger, 2005), it proves to be a simple yet effective method, and is hence suitable to be applied in the condition of data constraints in both quantity and quality like in developing countries (Streicher-Porte et al., 2007).

MFA has been applied worldwide to cover different aspects of e-waste and e-waste management, such as: e-waste estimation (Jain and Sareen, 2006; Steubing et al., 2010), analyzing e-waste management system or evaluating its performance (Steubing et al., 2010; Lau et al., 2013), defining unknown flows (Kahhat and Williams, 2012; Tran et al., 2016) and analyzing management scenarios to support strategic e-waste management planning (Streicher-Porte et al., 2005).

E-waste management is an emerging challenge in Vietnam (Hai et al., 2015). One of the top hindrances is the lack of information and

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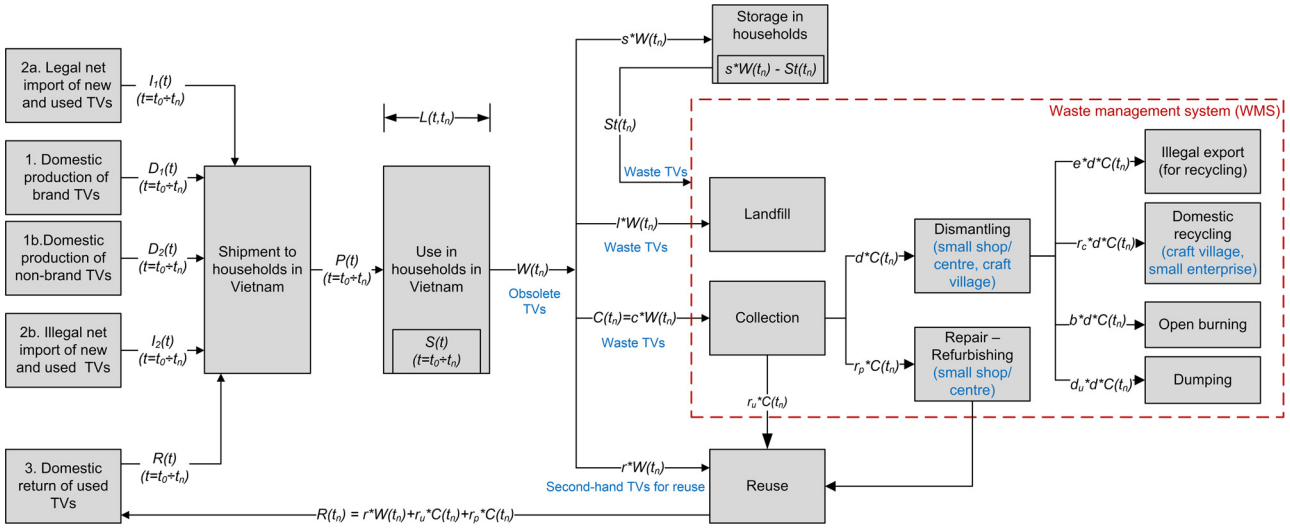

Fig. 1. General scheme of the TV life cycle and waste TV management in Vietnam. In this graph, t_0 and t_n are the initial year that TVs entered the market and the evaluation year, respectively. $I_1(t)$, $D_1(t)$, $D_2(t)$, $I_2(t)$, $R(t)$ are respectively the legal net import, the domestic production of brand TVs, the domestic production of non-brand TVs, the illegal net import of new and second-hand TVs and the domestic return of second-hand TVs in year t. $P(t)$, $S(t)$ and $W(t)$ are the quantity of TV sales, in stock and become obsolete in year t. $L^{(p)}(t, t_n)$ is the lifespan profile of TVs sold in year t, presenting their probabilistic obsolescence rate in year t_n. $St(t_n)$ is the 'leaching' flow from storage (hibernate stock) in year t_n. $C(t_n)$ is the total waste TVs collected in year t_n. s, l, c, r, d, r_p, r_u, e, b, r_c, d_u are the coefficients, which respectively represent the fraction that enters storage, landfill, collection, (direct) reuse, dismantling, repair/refurbishing, reuse after functional checking, illegal export (for recycling), open burning, domestic recycling and dumping.

inventory data on waste generation and current management practices, which are prerequisite inputs to frame an appropriate management system. Together with a rapid growth in e-waste quantity, existing improper e-waste management practices (e.g., open burning for metal recovery, open dumping) have caused many environmental and human health issues (Tue et al., 2013; Hai et al., 2015). These lead to an urgent demand for: (i) more comprehensive but concrete and quantitative information on e-waste generation and e-waste management system; and (ii) holistic and practical solutions to prevent toxic emissions and effectively manage valuable material resources present in this waste stream. However, most of the available studies mainly provide qualitative information to depict an overview on e-waste, its treatment and management in Vietnam (Huynh and Lee, 2007; URENCOs, 2007; Hai et al., 2015; Tran and Salhofer, 2016; Yoshida et al., 2016). There is some quantitative information on the current e-waste collection and treatment practices, but they are still disaggregated and some are outdated (URENCOs, 2007). Systematic analyses of the material flows of some specific e-waste (e.g., discarded home appliances (Nguyen et al., 2017), the e-waste transboundary flows between Vietnam, China and Cambodia (Shinkuma and Nguyen, 2009)) are mainly at qualitative level. The application of MFA as a quantitative assessment tool is limited to estimate the amount of e-waste generation (Nguyen et al., 2009; Tran et al., 2014). Recently in the study of Tran et al. (2016), it is used to estimate the unregistered inflow of TVs into the Vietnamese market. Moreover, so far no material flow analysis for e-waste on substance level has been done for Vietnam.

Therefore, this study aims to apply MFA as an analytical tool at both goods and substance level to support e-waste management in Vietnam. More specifically, MFA is used to quantify the obsolete electrical and electronic equipment (EEE) generation and its future projection, and qualitatively and quantitatively analyze the flow of e-waste and its substances within the current e-waste management system. The results are then used to evaluate the current system, identify the bottlenecks; and define potential improvements and management plans based on the integrated waste management strategy. This is done via a case study on obsolete TVs generated from households in urban areas of Vietnam. TVs are selected as the study object because they are the most common and affordable home appliance in Vietnam (GSO, 2016b). Waste TVs hence dominate the waste stream of household appliances (Nguyen et al., 2009) and their contribution to the national e-waste is expected to be high. The case study is conducted for urban areas mainly because of data availability. Moreover, the consumption rate of TVs in households in urban areas is higher than in rural areas (GSO, 2016b).

2. Material and methodology

MFA is a tool to systematically analyze the flows and stocks of materials of a certain system, which is defined in time and space (A more detailed explanation on MFA can be consulted in section A of the supporting information (SI)).

With the ultimate aim of supporting e-waste management in Vietnam, the system boundary of the studied system in this case is set corresponding to the Vietnamese national border. Moreover, life cycle thinking is applied to thoroughly assess all processes involved in the EEE life cycle within Vietnam, from EEE supply and consumption, obsolete EEE generation to the WEEE treatment and final disposal (Gurauskiene and Stasiskiene, 2011). Particularly, MFA is applied in a three-step analysis. First, the TV life cycle is qualitatively investigated to identify all related processes and flows. Second, MFA is used to analyze the cycle of TV supply, consumption and discarding to estimate the amount of obsolete TVs from households in urban areas. Third, MFA is used to quantitatively analyze the flows of obsolete TVs and their materials in the waste management system. The results of this step are then used to evaluate the waste TV management system in Vietnam.

2.1. Qualitative analysis of the TV life cycle

In this step, information from all available sources (e.g. literature, national reports/data, previous research) are collected to depict a general scheme of the TV life cycle and waste TV management system (Fig. 1). The time factor is also employed in mathematical expressions of the flows to present their dynamic nature as well as to properly define their distribution within different processes and the correlation between them.

Moreover, in this study, an EEE is considered as obsolete when it is no longer used by its owner, whereas, an obsolete EEE is considered as waste when it is discarded by its owner without intention of reuse (StEP Initiative, 2014). Accordingly, the obsolete EEE that is sold or given to