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Dynamic modelling of a collection scheme of waste portable batteries for ecological and economic sustainability

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ABSTRACT

Much study in recent years has focused on hazardous waste management, where one of the hazardous waste streams includes portable waste batteries. The main aim of the research is to explore both the short and long term effects of a collection scheme of portable waste batteries on the environment. To this end, a system dynamics model has been built to examine how the physical processes and information flows interrelate in the structure of a dynamic system, and how this structure generates dynamic behaviour over time. A collection scheme in operation in Belgium was used as the case study. The model developed sheds light on the structure of the system and shows that important feedback is missing compared to other types of battery collection models. Firstly, the model showed that the level of the levy on the price is not linked to the achieved collection goal. Secondly, the other missing feedback is between effectiveness of the information campaign and the costs related to these awareness-increasing activities. The model developed could be an important aid for policy makers in assessing the efficacy of policy tools.

1. Introduction

A great deal of research in recent years has focused on hazardous waste management, with special attention being paid to waste batteries since use of these power sources is more widespread than ever before.

The improper handling, use or treatment of batteries can damage ecosystems due to leachate from heavy metals and electrolyte solutions embedded within these products (Kiehne, 2003). But regardless of potential risks, batteries and accumulators are viewed as future sources of energy in electric and hybrid vehicles (Miedema and Moll, 2013) and for storage of renewable energy in micro-generation (McManus, 2012) and in hybrid systems (González et al., 2012). As a result these power sources have significant potential for growth.

Although portable waste batteries only account for around 12% by weight of all batteries placed on the market, they represent up to 98% by unit of all batteries in the market (EPBA, 2013). In addition, the collection and subsequent recycling of waste portable batteries are expensive, while the waste batteries themselves have negative economic value. Both landfill and incineration of waste batteries are generally forbidden. Municipal solid waste often however contains some waste batteries. This can result in cadmium, lead, mercury and dioxin emissions (Bernardes et al., 2004). Consequently, handling of waste portable batteries should involve public policy intervention, with the aim of developing and maintaining a widely-applied and well-financed operational scheme.

Based on the report by the European Portable Battery Association (EPBA, 2013) close to 230,000 tonnes of portable batteries were put on the market in the European Economic Area (EEA) and Switzerland in 2011. However, only 31.3% of these were reported as collected in the same year. The Directive on batteries and accumulators and waste batteries and accumulators (Directive, 2006/66/EC, 2006) obliged rising targets to be met. The target is a 25% collection rate for portable batteries by 2012 and 45% by 2016. The study by (EPBA, 2013) also points out concerns regarding the viability of reaching the 45% target in 2016.

Outside the requirements for producers to be held responsible financially for the net cost of collection and treatment of waste portable batteries, the Directive on waste batteries leaves to each Member State the final decision on how to organize collection of the waste batteries. The following organisational models may be viable depending on the circumstances. They include state fund models, single organization (environmental agreement) models, and competing organisation models (EPBA, 2013).

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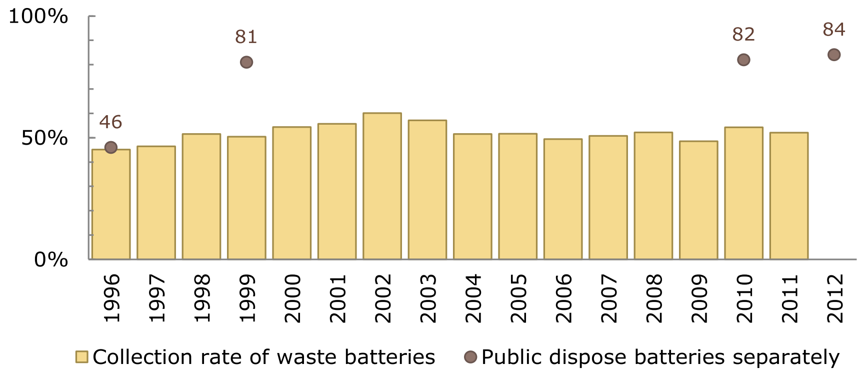

Fig. 1. Collection rate of waste portable batteries (Rapport à l'attention du Parlement wallon, 2012) and public participation in separate disposal of waste batteries in Belgium (EPBA, 2013).

Although effectiveness in performance of the various collection schemes was demonstrated to be the major influence on collection rates up to 2016 (EPBA, 2013), little attention has been paid to studying the dynamic relations between and among the actors involved in the collection schemes.

The dynamics of waste management is defined by Seadon (2010) where each component of the waste management system is closely interlinked and can influence others. Applications of modelling were shown in the sector of health care waste by Chaerul et al. (2008), municipal solid waste by Chen and Chang (2010), construction and demolition waste by Yuan et al. (2012) and waste from energy production by Yu and Wei (2012).

The main aim of the research is to explore both short and long term effects on the environment of a collection scheme for portable batteries. For this purpose in mind, a system dynamics model has been built to examine how the physical processes and information flows interrelate in the structure of a dynamic system, and how this structure generates dynamic behaviour over time. A collection scheme then in operation in Belgium was used as the case study.

The paper starts with the background information about the study region. The paper then outlines methodological framework, on which a system dynamics model is developed and described. In the last part, the validation of the model is carried out and the results are presented and discussed.

Although the system dynamics model was based on the Belgium case study, its general application to other countries and collection schemes is also discussed.

2. Background information

Belgium was selected as the study region due to the abundance of historical data on physical processes (portable batteries placed on the market, portable batteries collected) and information flows (represented by data from public surveys) for the time period of 1996–2011. Moreover, a detailed analysis on the interaction between and among the various parameters was available from the research by EPBA (2013).

In Belgium one of the oldest centralized collection programs for waste portable batteries, named also as, single organization model has been in operation since 1996. The collective battery management program is monitored by the Belgian battery organization (BEBAT). The program was based on an environmental agreement between and among three regional governments and associations. The operation of BEBAT is financed by a government mandated fee or levy, which is set by law and is included in the price of the battery. Consequently, it is paid by consumers.

The "polluter-pays" principle is an integral part of the waste legislation in Belgium, where producers are obliged to pay an eco-tax of 0.5 euro per battery unless they reach a collection rate defined by the government. The collection rate was set as 45% in 2010. It rose to 50% in 2012 (EPBA, 2013).

Retailers and distributors of batteries are obliged to take back waste batteries free of charge. Participation by municipalities in the waste collection scheme is not compulsory.

Although, the BEBAT achieved 84% of public participation in 2012 and a dense network of collection points (on average one active collection point for 450 residents), the collection ratio of portable waste batteries has remained stagnant at around 50%. See Fig. 1.

The data shown in Fig. 1 give an overview of the dynamic problems present in the sector. Despite high public awareness the collection rate is stagnating. The model developed shows the dynamics that underline the system's behaviour.

3. Methodology

In this study, a model was created using the system dynamics methodology. The system dynamics methodology was introduced by Forrester (1958). Currently this framework is used as a tool assessing the system. It identifies the means for a reduction of energy consumption (Blumberga et al., 2014), cleaner production (Dong et al., 2012), and better allocation of investment funds (O'Regan et al., 2006).

The selected methodology identifies the interaction between and among physical activities, information flows and policy measures, thus revealing the dynamical nature of the variables. The main structure of the system dynamics model is described by causal loops, where the causal loops define the feedback mechanisms within the system under study (Forrester, 1961); see Fig. 3. The diagram of causal loops has been converted to a stock–flow diagram in order to obtain a quantitative mathematical model. See Figs. 4–6.

The battery collection model has three sectors: *portable battery flow*, *financing* and *public participation*. These sectors include a number of sub-sectors given in Fig. 2.

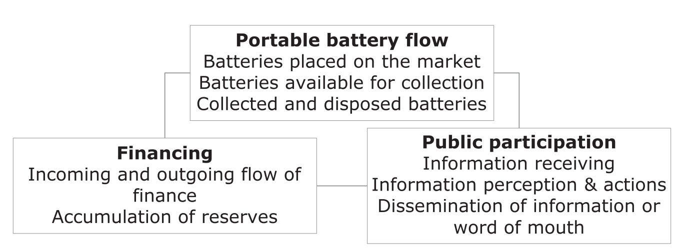

Fig. 2. The structure of battery collection model.