Resources, Conservation and Recycling 117 (2017) 183–194

Contents lists available at ScienceDirect

Resources, Conservation and Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

Comprehensive analysis and quantification of national plastic flows: The case of Austria

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ARTICLE INFO

Article history:
Received 24 February 2016
Received in revised form 20 July 2016
Accepted 12 October 2016
Available online 11 November 2016

Keywords:
MFA
Plastics
Austria
Resource management
Waste management
Uncertainty

ABSTRACT

Plastics have been increasingly used in a wide range of applications, generating important waste streams, but overall information on their flows through society is generally not available. Therefore, the national plastic flows in Austria were analyzed and quantified from the production stage up to the waste management stage, for the reference year of 2010. To achieve this, material flow analysis was used to set up a model quantitatively describing the Austrian plastics budget, and the quality of the data sources was assessed using uncertainty characterization. The results show that about 1.1 million tonnes (132 kg/cap·a ± 2%) of primary plastics were produced in Austria, whereas about 1.3 million tonnes (156 kg/cap·a ± 5%) of plastics products were consumed. Roughly one third of the consumed amount contributed to net stock increase in all consumption sectors, and about half of this increase occurred in building and construction, whereas packaging waste constituted approximately half of total post-consumer wastes (70 kg/cap·a ± 4%). Of the total waste amount (including traded and production waste, 91 kg/cap·a ± 3%), the majority was incinerated in waste-to-energy plants or in the cement industry (46% and 21% respectively), whereas the rest was mainly recycled mechanically or chemically (21% and 10% respectively). The results identify the major national flows and processes of plastics, and evaluate the overall data availability for quantifying these flows. Furthermore, the increasing amounts of plastic wastes, due to large stocks having been built up in sectors with long product lifetimes, necessitate assessing which processing capacities are needed and which treatment priorities are to be set in waste management.

1. Introduction

Plastics have become one of the most used materials globally, showing a stronger growth over the past 50 years than any other engineering material (Allwood et al., 2011), and reaching a global production of more than 300 million tonnes in 2014 (PlasticsEurope, 2015). This is due to the key properties this class of materials possesses: they are inexpensive, lightweight, strong, and very durable. The diversity of the numerous general purpose and specialty high performance polymers means that they are used in a vast range of products and applications, whereas the inclusion of various additives can modify the properties and enhance the performance to make the polymers even more versatile (Murphy, 2001; Thompson et al., 2009).

This combination of the use of many different polymers with various additives makes that in general, plastics form a highly complex resource stream which leads to large and very diverse material flows into society. However, this causes a number of environmental concerns as well. The vast majority of plastics are synthetized from non-renewable fossil resources, which leads to the fact that around 4% of the annual petroleum production is converted into plastics, whereas an additional 3–4% is needed for the energy supply during production (Al-Salem et al., 2009; Hopewell et al., 2009). At the other end of the life-cycle of plastics, waste flows have become increasingly important. The durability of the polymers causes accumulation of improperly discarded items in the natural environment, particularly in marine habitats (Barnes et al., 2009; Browne et al., 2011), where they can cause physical problems for organisms such as entanglement and ingestion (Gregory, 2009), whereas monomers, oligomers, and the included additives of the plastic itself, as well as adsorbed hydrophobic contaminants from the surroundings, can be transferred to organisms and have biolog-

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http://dx.doi.org/10.1016/j.resconrec.2016.10.017
0921-3449/

ical consequences as well (Teuten et al., 2009). Proper management of waste plastics can therefore contribute to reducing both resource consumption and environmental impacts.

This is recognized by the European Commission, which in their circular economy strategy pushes for increased recycling rates of wastes in general, as well as for various materials in packaging wastes, including plastics (EC, 2015). However, to understand what potential for recycling is available to justify these targets, detailed knowledge on the current situation of material flows and stocks is needed. This kind of knowledge is quite well established for some materials, with more than 350 studies published on more than 1000 individual elemental material cycles, especially on metals (Chen and Graedel, 2012), e.g. steel (Hatayama et al., 2010), aluminium (Buchner et al., 2014), and copper (Spatari et al., 2002). However, for plastics, information from government and industry is much sparser, and therefore only limited research on the cycles of individual polymers, or plastics in general, has been performed. The main publications describing flows and/or stocks of plastics in a country or region are subsequently shortly described.

A static material flow analysis (MFA) for Austria was established for 1994 by Fehringer and Brunner (1997), determining the flows and stocks of total plastics as well as specifically for polyethylene (PE) and polyvinylchloride (PVC), and for 2004 by Bogucka and Brunner (2007), who compared these results with data for Poland. Furthermore, Joosten et al. (2000) used supply and use tables to examine the flows of plastics in the Netherlands in 1990, whereas Patel et al. (1998) analyzed past flows of plastic production and consumption in Germany from 1976 to 1996, and used various scenarios to forecast future waste volumes and plastic stocks until 2050. Similarly, Mutha et al. (2006) studied past plastic flows in India from 1960 to 2000, and estimated future developments until 2030 using the national relationships of per capita plastics consumption with the respective gross domestic product (GDP), combined with projections on the development of the GDP in India. On the level of single polymers, Kuczenski and Geyer (2010) conducted an MFA of polyethylene terephthalate (PET) in the United States (US) over the period of 1996–2007, whereas Nakamura et al. (2009) determined the flows of PVC in Japan in 2000 using input-output analysis. Finally, Kleijn et al. (2000) used the case of PVC in Sweden to examine the delaying mechanisms of stocks with respect to waste production in a dynamic MFA, using various scenarios regarding the distribution of input streams and life spans of the products.

These analyses provide valuable understanding on the regional material flows of plastics. However, the mentioned studies present MFAs that are 10 to 25 years old, do not always present the full overview of plastic flows from chemical industry up to and including waste management, and do not distinguish different sectors of plastics consumption. Furthermore, some use a limited amount of different data sources, mainly relying on trade statistics, and none of the studies take data uncertainties into consideration, so no assessment of the quality of the data and subsequently of the robustness of the results can be made.

The aim of this paper is therefore to build on, update and expand the previous work of Fehringer and Brunner (1997) and Bogucka and Brunner (2007), and thus establish the plastics budget of Austria in 2010 to investigate plastics production, use and associated waste flows. Due to constraints in data availability, as data sources are usually updated rather infrequently and not all data are available on an annual basis, 2010 was chosen as the reference year. The data sources needed for the analysis of the Austrian plastics budget are provided, including data quality evaluation and uncertainty assessment, to enable future updates of the system for resource accounting to be done more easily. The model illustrates the structure of the processes and flows of plastics in Austria with a high resolution, which enables a thorough understanding of production, demand and waste generation of plastic materials in Austria. This serves as a basis to identify opportunities for increasing overall resource efficiency through effective waste management, and thus reduce negative impacts from production and consumption of plastics.

2. Materials and methods

To achieve the above stated aim, a model of all relevant processes, and the flows that connect these processes, is set up and quantitative information is provided, using material flow analysis. Furthermore, the uncertainties of the mass flows are characterized, assessing the quality of the data sources, to provide probable ranges with the best estimates of the results, and to highlight potential limitations of these applied data sources. These methods are described more in detail in the following sections.

2.1. Material flow analysis

Material flow analysis comprehensively assesses the flows and stocks of materials through a system that is defined in space and time. It is used to connect and quantify the sources, pathways, and intermediate and final sinks of the material in physical units. The calculations are based on the law of conservation of matter, by using a material balance to compare all inputs, stocks, and outputs of a process. The analysis can be carried out on the level of goods (e.g. wood), or on the level of specific chemicals (e.g. carbon, usually called substance flow analysis, SFA) (Brunner and Rechberger, 2004; van der Voet, 2002). Furthermore, different ways exist to model the system's flows and stocks, from static modelling, representing a snapshot of the material flow system, over the modelling of time-series in the past to keep track of flows and stocks, to dynamic modelling, where time is included as a modelling parameter to predict future behavior of the system (van der Voet, 2002; Zoboli et al., 2015). The procedure of an MFA begins with defining the goals, and selecting the relevant substances, system boundaries, and processes. Subsequently, the mass flows and substance concentrations are determined, considering the uncertainties, and finally the results are presented. This procedure should be carried out iteratively, to continuously check, refine and optimize the results (Brunner and Rechberger, 2004).

The STAN software was used to describe and analyze the system with a standardized method (Cencic and Rechberger, 2008). This software is applied widely for material flow analysis (e.g. Beretta et al. (2013); Chancerel et al. (2009); Yoshida et al. (2013)), is made specifically for conducting an MFA, and is freely available (from stan2web.net). The software has a graphical user interface to build up the model with different layers (goods and substances) and over multiple time periods. It allows for the consideration of data uncertainties, unknown flows can be calculated by balancing the system, and the associated uncertainties of these calculated values are determined using Gaussian error propagation, assuming normally distributed variables. Furthermore, data reconciliation can be performed by the software, provided that more information is available than is required for solving the mass balance equations (i.e. overdetermined system of equations). Data reconciliation resolves conflicts between uncertain input values by forcing the values to comply with given mass balance constraints. The inverses of the variances are used as a weighting factor, resulting in highly uncertain values being changed more strongly relative to less uncertain flows (Laner et al., 2015a). Finally, the material flow results are presented in a Sankey style diagram, to be able to easily recognize the relative size of the individual flows.