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ZÁLOHUJME?

STUDIE MATERIÁLOVÝCH TOKŮ PET NÁPOJOVÝCH OBALŮ V ČR ZA ROK 2016

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Project team INCIEN as part of the project Zálohujme – Let's deposit	Ing. Soňa Jonášová, Vojtěch Vosecký, MSc., RNDr. Miloš Polák, Ph.D. Laura Mitroliosová, Ing. Ivana Jenerálová
Author	Institut Cirkulární Ekonomiky, z.ú. ID No.: 04065956 Cejl 37/62, 602 00 Brno – Zábrdovice, Czech Republic
Date	December 2018
Persons involved in the study	Vojtěch Vosecký, MSc., RNDr. Miloš Polák, Ph.D.
Contact regarding the study	Vojtěch Vosecký, MSc. vojtech@incien.org
Contact for media	Ing. Ivana Jenerálová ivana@incien.org
Disclaimer	The project team shall not be held liable for any direct or indirect damage arising out of the use of this document or its content. This document contains the results of research carried out by authors and shall not be regarded as the viewpoint of Karlovarské minerální vody a.s.

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EPR	Extended Producer Responsibility
EKOKOM	Authorized company EKO-KOM a.s.
KMV	Karlovarské minerální vody a.s.
MMW	Mixed municipal waste
DRS	Deposit-refund system(s)
WEP	Waste-to-energy plant

1. INTRODUCTION AND DESCRIPTION OF THE ISSUE

In connection with the recently adopted Circular Economy Package, the company Karlovarské minerální vody a.s. (KMV) is considering the necessary steps to be taken in order to fulfil the objectives of the circular economy within the EU. With respect to ambitiously set recycling targets, in recent years multinational food companies, packaging associations and other stakeholders have been actively considering similarly bold recycling targets for plastic PET bottles.

In the overwhelming majority of European countries, the collective system of Extended Producer Responsibility (EPR) is used to support recycling. However, this system only achieves a limited level and quality of sorting and the subsequent recycling of a given material. This is because it is based on the willingness and capability of people to sort their waste at any given moment. In the case of plastics, it is necessary to further sort the material obtained, only a minor part of which can be subsequently recycled. A '*deposit-refund system'* (hereinafter referred to as "DRS") has frequently been established in order to achieve a greater rate of separation and recycling.

Nevertheless, the actual real-life economic and environmental benefits that would follow on from establishing such system in the Czech Republic needs to be researched. To this end and for the below-mentioned reasons, KMV has decided to investigate in detail the issue of applying a DRS to PET beverage packaging. Therefore, in January 2018, KMV together with INCIEN and the University of Chemistry and Technology (hereinafter referred to as "UCT") announced an initiative called Zálohujme – Let's deposit´ to effectively map how PET beverage packaging is being currently dealt with in the Czech Republic and to suggest steps to make it more efficient.

The following chapters describe in more detail the initial state in the Czech Republic, the chosen research procedures and methods, and present the results of the individual parts of the research conducted by INCIEN, which analyzed the material flows of PET beverage packaging in the Czech Republic.

1.1. Description of the initial state in the Czech Republic:

The obligation to sort and use packaging waste in the Czech Republic was set forth by law in 1991. In 1997, EKO-KOM a.s., an authorized packaging company (hereinafter referred to as "EKOKOM") was established; since then it has introduced the separate collection of packaging waste in 99% of the Czech Republic (EKOKOM, 2017). Since 2002 EKOKOM has been granted a license as the sole operator of the system for separate waste collection for both companies and municipalities operating in the Czech market. A producer who releases a product with packaging material onto the market can decide whether they will satisfy their recycling duties themselves or by delegating responsibility to EKOKOM and paying a fee corresponding to the quantity of products released onto the market.

Limits of the existing system

Until recently, the system functioned very well in the Czech Republic, yet the stagnating rate of plastic separation in recent years shows that the system has apparently reached its limits. In 2016, the rate of plastic separation in the 118,400 containers for plastics covering roughly 85% of the Czech Republic did not change compared to previous years; on the contrary, it dropped from 69% to 68% in the 2015–2016 period (EKOKOM, 2016, 2017). According to the EKOKOM official information, the number of containers for plastic at the same time increased from 118,400 to 144,500 in the 2016–2017 period (Balner, 2018). However, the 2017 results again showed a 69% rate of plastic separation, i.e. an increase of 1% (EKOKOM, 2018).

The problem is that a further increase in capacity for plastic separation requires substantial investment in transport, the purchase of new containers and education of the population, and from the economic point of view this would be inefficient. The strategic analytical document examining the utilization of secondary raw materials states the problem as follows: *"As the recycling rate increases, so does the cost of recycling provision. However, this increase in costs is not directly proportional to the increase in separated waste. The higher the achieved recycling rate, the greater the increase in unit costs for separating one ton of waste."* (EKOKOM, IEEP, VŠE, 2011)

Nonetheless, at the same time, multinational food companies, packaging associations and other stakeholders have in recent years been actively considering ambitious recycling targets for PET bottles (Moye, 2018). Fulfilment of higher targets is usually achieved by the establishment of a DRS. Unlike conventional systems with dispersed responsibility, the DRS is generally set up to motivate the greater separation and subsequent recycling of selected products through economic incentives. In short, the DRS works by charging a small fee on selected beverage packaging when purchased, which is paid back to the customer upon the return of the empty packaging at the place of collection.

Impacts on municipal budgets

International experience shows that the establishment of a DRS on selected beverage packaging can reduce municipal costs on waste collection and sorting (TA Forum, 2017). For example, one study looking into the establishment of a deposit-refund system in Scotland has shown that municipal savings can reach an annual average of CZK 65,000 per 1,000 inhabitants (Reloop, 2017b). At present, the price of non-returnable beverage packaging does not actually include all the costs for collecting, transporting, processing, recycling or disposal of the packaging because the system operator, and consequently the producers themselves, transfers liability for such collection and disposal to customers and municipalities. According to the latest EKOKOM data, the average annual remuneration for waste sorting paid to municipalities in 2017 amounted to CZK 121 per person, while annual municipality costs for separated waste in the same year amounted to CZK 182 per person (EKOKOM, 2018). The data show that municipalities partially fund the collection of separated waste from their budgets, i.e. roughly 33.5% of the total amount.

Problem of littering

There are multiple reasons for considering the implementation of DRS. DRS bring a general reduction of municipal waste, and their establishment prevents illegal dumping and environmental pollution (Dráb & Slučiaková, 2018; European Parliament, 2018; Hnutí Duha, 2002; Hogg, Elliot, & Adrian, 2015). Plastics that do not end up in mixed municipal waste (MMW) or in the separated waste collection system are frequently discarded as litter.

This topic was the subject of previously conducted *littering* analyses carried out in the Czech Republic in 2007. The study, which investigated 24 areas with different population densities and frequency of use in the Czech Republic, showed that 77% of the volume of all beverage packaging found during the analysis consisted of PET beverage packaging. PET bottles accounted for 30% of the average weight of all materials; and, as indicated in Chart 1, PET bottles accounted for 37% of the volume of a total average sample (Přibylová & Štejfa, 2007).

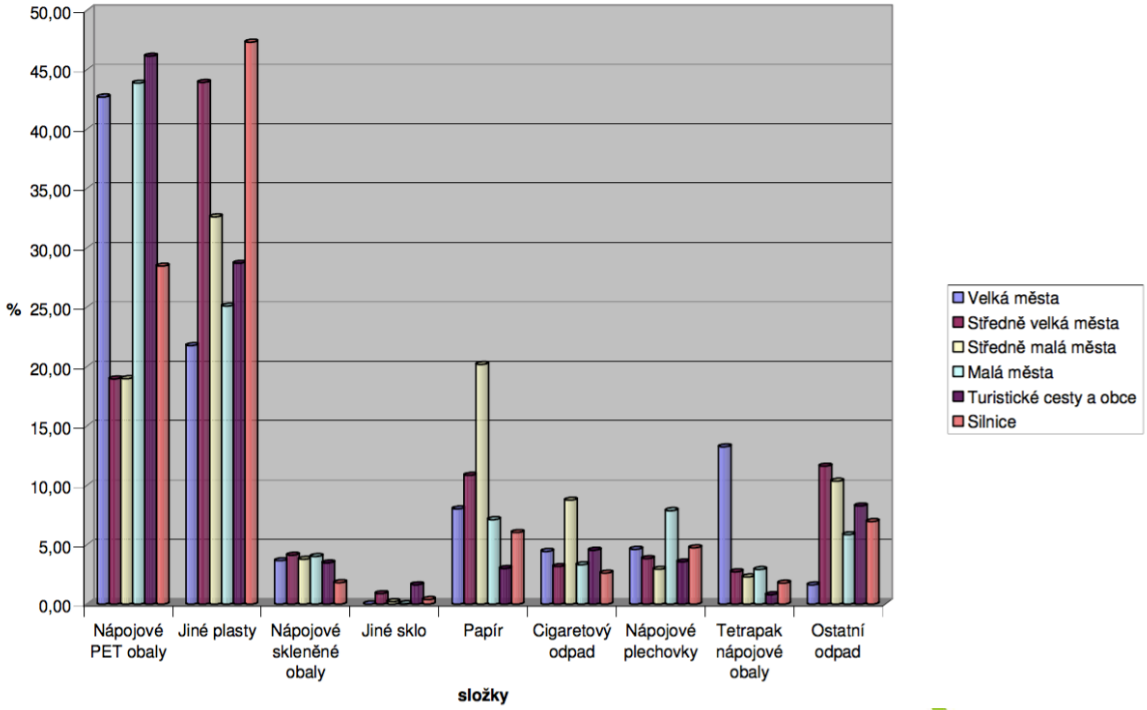

Chart 1: Volumes of monitored waste components. Source: Přibylová & Štejfa (2007)

In addition to its negative environmental impacts, freely tossed out waste is reflected in the costs for waste collection and removal that are usually paid for by a local authority or the administrator of the location. As Přibylová & Štejfa (2007) object: If we succeed in limiting the throwing away of single-use beverage packaging, 77% of the volume of which consisted of PET beverage packing, the cost of tidying up and disposing waste incurred by responsible entities will be considerably reduced.

To this end and for similar reasons, DRS are presently a frequently discussed topic in the global scene, since the use of plastics is increasing hand in hand with the accumulation of plastics in our rivers, seas and oceans. The situation has reached such a point that by 2050 the oceans could contain more plastic than fish (by weight) (Ellen MacArthur Foundation, 2016). Another attractive aspect of the deposit-refund system is general public support; indeed, Chart 2 around 81% of the population in various countries worldwide are in favor of deposit-refund systems. Similarly, 9 out of 10 of Czechs believe that PET bottles should be deposit-bearing, as research carried out by IPSOS (IDNES, 2019) has shown.

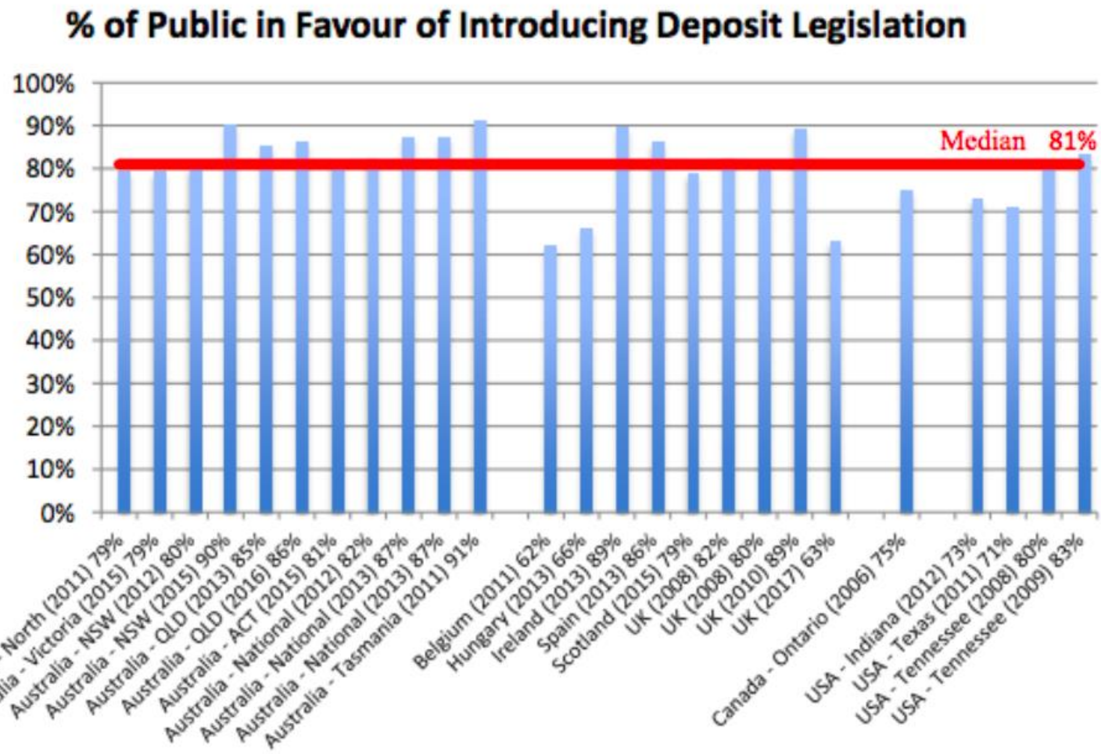

Chart 2: Research on public support for the establishment of deposit-refund systems. Source: Reloop (2016)

Legislation challenges

Current legislative challenges are another reason to analyze the possibilities of deposit-refund systems. With regards to the influence of legislation on handling packaging materials, two draft EU regulations were highly relevant at the time of writing this document, i.e. the Circular Economy Action Package and the Plastic Strategy.

Plastic Strategy

As part of the final version of the so-called European Plastics Strategy, at the end of 2018 the EU presented an agreement focusing on a series of measures whose principal target is plastic single-use products. The particular products listed in the regulation represent 70% of trash contained in European seas. Greater activity on the part of producers is expected: they will have to become more involved in cleaning up, and besides the ban on some single-use plastic products, by 2029 they will have to ensure the collection of 90% of single-use plastic beverage bottles, with an interim target of 77% in 2025. According to the EU and experts, the implementation of DRS is precisely the kind of measure required to achieve a 90% level of separation; as of today no other system has proven itself capable of achieving such a high figure. It has been estimated that the highest level of recycling that could be achieved in countries without DRS – once losses during sorting have been factored in – is 70% (Eunomia Consulting ltd. & ICF, 2018; European Parliament, 2018).

Circular Economy Action Package

A significant change in waste handling is also being brought by a series of EU regulations as part of the long-awaited Circular Economy Action Package. In April 2018 the European Parliament adopted the drafts of four directives from the Circular Economy Action Package, and Member States now have two years to transpose them into national legislation. The EU expects that the Package, which fundamentally changes the provisions of the directives regulating waste, packaging, landfill and WEEE/bateries/ELV, will ensure the faster transformation into a circular economy. The package means greater recycling, limits on packaging materials, less landfilling and, for example, greater utilization of secondary raw materials.

Recycling quotas for individual packaging materials are one of the pillars of the Circular Economy Action Package, as described in Table 1Table 1.

Table 1: CE Action Package Targets. Source: Bourguignon (2016)

	Year 2025	Year 2030
All packaging materials	65%	70%
Plastic	50%	55%
Wood	25%	30%
Metals	70%	80%
Glass	70%	75%
Aluminum	50%	60%
Paper and cardboard	75%	85%

These recycling quotas, especially for aluminum and plastic packaging, will be highly relevant to the present situation in the Czech Republic. For example, the new targets for aluminum and plastic, with a new method of measurement, could be a problem for the Czech Republic.

Up until now, methods for measuring recycling rates have not been uniform across the EU, and so represent a very important point of the package. Measurement methods are now being introduced at the outlet from waste sorting plants and specifically at the inlet to processors, which is a significant departure from the existing methods widely used in the Czech Republic, where energy recovery, for example, is included in the recycling rate, as well.

This fact will make it harder to reach new recycling quotas. Not only will the quotas for some packaging be higher than they have been previously, they will also be measured at the outlet of waste sorting plants, i.e. when packaging is sent to a recycling plant – fulfilling this quota will be a challenge in the case of plastic and aluminum packaging in the Czech Republic.

This fact pertains particularly to the Czech Republic because the existing system of plastic collection and recycling tends to report the estimated total weight of separated waste in containers, rather than that what is actually recycled. According to the latest information from practice during 2018, about 50% of the quantity of separated plastics in the Czech Republic transported from villages and towns to waste sorting lines ends up as discard for the production of solid alternative fuels as early as the first sorting stage, or in landfills, or in waste-to-energy plants (WEP) (Ministry of Environment, 2018).

Recycling quotas

Although the DRS for beverage packaging represents a complex issue, it nonetheless offers one of the most effective solutions for coping with the aforesaid challenges, thanks to its achieving an average rate of return of > 90% and the recycling of products in the EU (see Chart 3). The main reason behind the higher redemption rate achieved in the DRS is that the system motivates customers to sort selected products through economic incentives. A small financial fee is charged on selected beverage packaging when purchased, and paid back to the customer upon the return of the empty packaging to the place of collection. At present, systems for the take-back of single-use beverage packaging work successfully for 120 million of EU citizens.

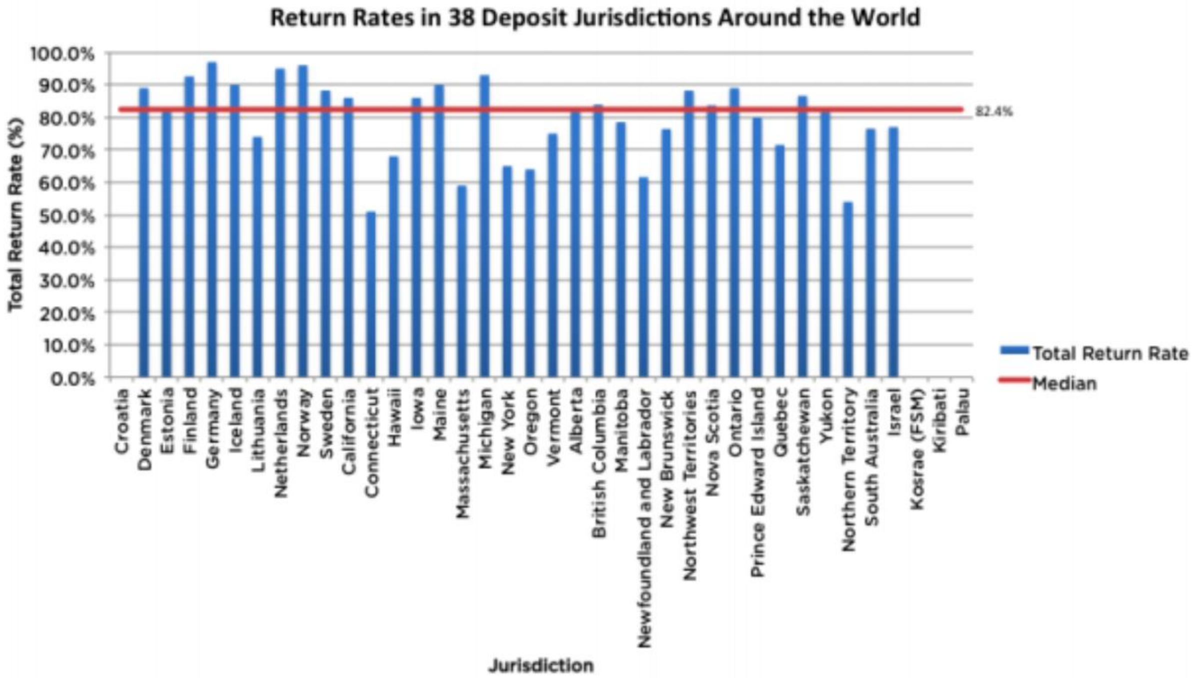

Chart 3: Return rates of beverage packaging after introducing deposit-refund systems around the world. Source: Reloop (2017a)

Despite the apparent positive results in many aspects, it is now necessary to conduct a careful analysis of both the current state and the proposed solution. In regard to how we fund the entire system of sorting and recycling packaging materials, if, for example, PET beverage packing were removed from containers for separated waste, we would be justified in expecting waste sorting lines to suffer negative impacts.

PET beverage packaging actually represents the main source of income for those companies whose primary income comes from sorting and the subsequent sale of sorted commodities (especially plastics). Another relevant issue also involves funding the entire EPR (Extended Producer Responsibility) system, which would lose a substantial part of its resources if PET bottles were removed. In addition, in the Czech Republic there is a concern that the collection rate of other plastics would drop with the implementation of a deposit-refund. Such fears might be unfounded, however: in Germany, for example, the recycling rate of plastic packaging has been steadily rising since 2005 (deposits on PET bottles were introduced in 2003) (Eurostat, 2018).

Therefore, the subject of this study, as well as of many other studies described below, is what would be the real economic and environmental benefits of implementing a DRS in the Czech Republic. The basis for any decisions on the potential benefit of a DRS for PET beverage packaging, however, shall be an in-depth overview of the actual flow of PET beverage packaging. Only after a careful mapping of material flows has been performed will it be possible to draw conclusions as to economic and environmental benefits of alternatives to the existing system. Because no study mapping the material flows of selected beverage packaging exists today in the Czech Republic, the following chapters investigate the current flow of PET beverage packaging – from being released onto the market, through sorting, removal to being placed in processing capacities.

2. DETAILS OF THE INITIATIVE 'ZÁLOHUJME – LET'S DEPOSIT'

2.1. Procedure and methods

The analytical part of the project 'Zálohujme – Let's deposit' has been and is being carried out in several stages. The resulting report consists of three analytical documents, each of which evaluates different aspects of the existing and alternative systems for the collection and handling of PET and aluminum beverage packaging in the Czech Republic.

- As part of the project, INCIEN investigated **general documents, motivations and reasons for changing the existing system,** and has used the knowledge gained to **map the material flow of PET packaging in the Czech Republic.** This material flow is in divided in detail into several main stages, i.e. from placement on the market to transformation into a new product.

- An additional document is the **analysis of the economic impacts of the introduced deposit-refund system on PET and aluminum beverage packaging made**, which was produced by Eunomia Research & Consulting Ltd.

- The last document comprises an **analysis by UCT comparing the environmental impacts of the existing and alternative systems for collecting and processing PET and aluminum beverage packaging**.

This set of documents will serve as a comprehensive overview of the possibilities of the existing system and of potential steps for making it more efficient. The table below describes in detail the individual documents and who created them.

Table 2: Description of the partial steps of the analytical part of the project

Research methods	Detail	Supplier of services	Contact
MFA	The output is an overview of the total flow of PET bottles in the Czech Republic, i.e. from their release onto the market through to waste management and their transformation into a new product.	INCIEN	**Project Manager:** Vojtěch Vosecký, MSc. (vojtech@incien.org) **Project Communications Manager:** Ing. Soňa Jonášová (sona@incien.org) **MFA expert** RNDr. Miloš Polák, Ph.D. (milospolak@seznam.cz)
Cost-Benefit Analysis	The output is a proposal for, and a calculation of the economic impacts of, a deposit-refund system for PET beverage bottles and beverage cans in the Czech Republic that would attain a 90% return rate.	Eunomia Research & Consluting, Ltd.	**Project Lead** Chris Sherrington (Chris.Sherrington@eunomia.co.uk) **Project Manager** Orla Woods (Orla.woods@eunomia.co.uk)
LCA	The output is an assessment of environmental benefits and shortcomings of the deposit-refund system for PET bottles and cans compared to the existing system.	UCT Prague, Faculty of Environmental Technology	**LCA Research Lead** Doc. Ing. Vladimír Kočí, Ph.D. (Vlad.Koci@vscht.cz)

3. MATERIAL FLOW ANALYSIS OF PET BOTTLES IN THE CZECH REPUBLIC IN 2016

In terms of investigating material flows, data regarding the number and amount of beverage packaging released onto the market is essential. Only by having a correct estimate as to how much PET beverage packaging is launched into the market is it possible to calculate the effectivity of the entire system. In addition, the quantity of beverage packaging in the Czech market is also used as a key figure for designing the DRS properly, assessing its economic impacts on principal stakeholders, as well as its environmental impacts in comparison with the existing system.

A *Material Flow Analysis* (MFA) is a systematic approach to evaluating flows and stocks of materials within a defined system in a given space and time (Brunner & Rechberger, 2004). An MFA provides a complete and consistent set of information about total flows and stocks of a given material within the selected system. The term '*material*' in an MFA symbolizes or represents the concepts of substances and goods. MFA is the most frequently used method in fields such as environmental management, industrial ecology, natural resource management and waste management.

According to Brunnera & Rechbergera (2004), there are two kinds of resources, i.e. natural and **anthropogenic resources.** Natural resources include, for example, minerals, water, air, information, soil or biomass (including plants, animals and people). Anthropogenic resources are resources that have been created or transformed by people, e.g. cultural heritage, technologies or the arts.

These resources occur in the '*anthroposphere*', i.e. in households, agriculture, healthcare and infrastructure, etc. Thanks to the mass-scale mining of rocks and minerals, natural resources are transformed into anthropogenic ones. In some cases, this transformation is so distinct that the magnitude of anthropogenic flows has already exceeded that of natural flows. For example, the flow of cadmium associated with human activity is three to four times higher than the natural (geogenic) flow caused by erosion, weather, mobility or volcanic activity (Brunner & Rechberger, 2004). This is also why the present era is referred to as the Anthropocene by some scientists, since human activity has become a global geophysical force and a driving mechanism of global environmental changes (Crutzen, 2002; Steffen, Crutzen, & McNeill, 2007).

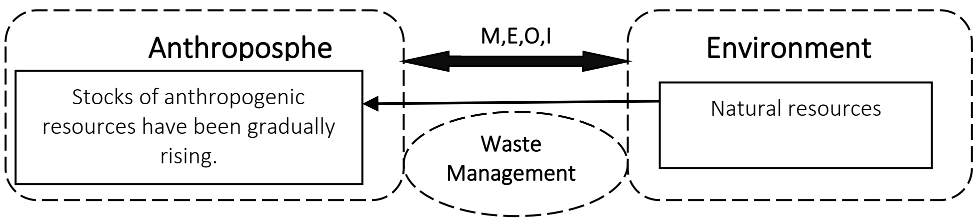

Figure 1: Exchange of flows of materials (M), energy (E), organisms (O) and information (I) between two systems – the "anthroposphere" and "environment". Source: adapted according to Brunner and Rechberger (2004)

Waste management takes place in the boundary between the anthroposphere and environment, see Figure 1. As human society increases its consumption, the amount of waste being produced is similarly increasing, and its composition is changing over time. The very earliest aim of waste management was to ensure basic hygiene conditions and prevent epidemics. Nevertheless, significant changes in the production, quantity and quality of waste took place during the 20th century. At present, waste management is a concept that integrates several waste-handling methods, such as landfilling, energy recovery, material recovery, waste re-use or prevention.

3.1. Main objective

The main objective of this partial report is to theoretically describe and quantify the material flows of PET bottles. The partial objectives are as follows:

1. To specify the system of flows of the materials and stocks of PET bottles using well-defined terms.
2. To reduce system complexity while preserving the value of results for the process of decision-making.
3. To use the MFA results to identify potential accumulations/losses of utilizable resources.
4. To present the results clearly and comprehensibly.

3.2. STAN software

STAN software was used to provide the graphical illustration and additional calculations of unknown material flows (Oliver Cencic & Rechberger, 2008). STAN (derived from subSTance flow ANalysis) is a freeware developed for MFA purposes in compliance with the Austrian standard ÖNorm S 2096 (*Material flow analysis – Application in waste management*).

This software enables users to create an MFA graphical model with predefined components (processes, flows, system boundaries, text fields, etc.) in which known data (material flows and stocks, volume flows and stocks, concentrations, transfer coefficients) for various layers (goods, substance, energy) and periods can be entered or imported. In addition, STAN enables users to automatically make additional calculations regarding unknown flows. All flows are illustrated using a *Sankey diagram*, so that the flow width proportionally corresponds to its value. Graphics can be printed and exported, and the widely used Microsoft Excel is utilized as an import/export tool. STAN also makes it possible to automatically combine uncertainties. The calculation algorithms are based on mathematic tools such as data reconciliation, error propagation and gross error detection.

3.3. MFA basic definitions and terms

The following definitions and terms have been adopted from Brunner and Rechberger (Brunner & Rechberger, 2004):

Substance is any (chemical) element or chemical compound. All elements and substances are characterized by their own unique and identical structure, and are therefore homogenous (e.g. N, C, Cu, NH_4^+, CO_2). In contrast, drinking water, for example, is not a substance because it consists of substances such as pure water, calcium, magnesium, etc. According to MFA, PVC is not a substance either, because it consists of polyvinylchloride and certain additives.

A **Good** is defined as a tangible object with a positive or negative economic value. A good is made up of one or more substances. Examples of goods include drinking water, minerals, concrete, TV sets, automobiles, garbage, etc. The words *merchandise, product* or *commodity* can be used as synonyms.

Material serves as an umbrella term identifying both substances and goods in MFA. Material within this analysis refers to *"PET bottles".* A PET bottle or PET bottles are defined in the concept of a PET beverage bottle in the segment of soft drinks, ciders and both alcoholic and alcohol-free beer, irrespective of the distribution channel. Here, the broader meaning of PET bottles is not included (e.g. the utilization of PET bottles for oils, milk and drugstore articles is omitted).

Process is defined as the transformation, transport or storage of materials. Materials are transformed in primary production processes such as in the mining or extraction of metals from ores. Consumption processes in households transform goods into wastes and emissions. Other examples of process include: the metabolism of a city, man or an animal; the activity of a household (e.g. waste separation) or an enterprise (e.g. waste incineration, landfilling, paper making, etc.); a process in the environment (e.g. in the atmosphere, hydrosphere or pedosphere); and a service (e.g. collection of municipal waste). Usually, a process is defined as *a black box* process, meaning that internal processes inside the black box are not taken into account. Only the inputs and outputs are of interest. If an internal process is important and should be included into the MFA, it must be divided into 2 or more sub-processes, see Figure 2.

Stock is the total amount of material that is available in stock for the given process. There are two types of different stocks:

1. for example, waste in a waste incinerator – new waste corresponds to increased stock, incineration leads to stock reduction.
2. for example, a building as part of infrastructure – a new building leads to a stock increase, while a demolition leads to stock reduction.

Flow is defined as the "material flow rate", for example, the ratio of material per the period of time that it takes the material to flow through a conductor, for example, a water pipe. The physical unit of a flow may then be given in kg/sec or t/year, etc.

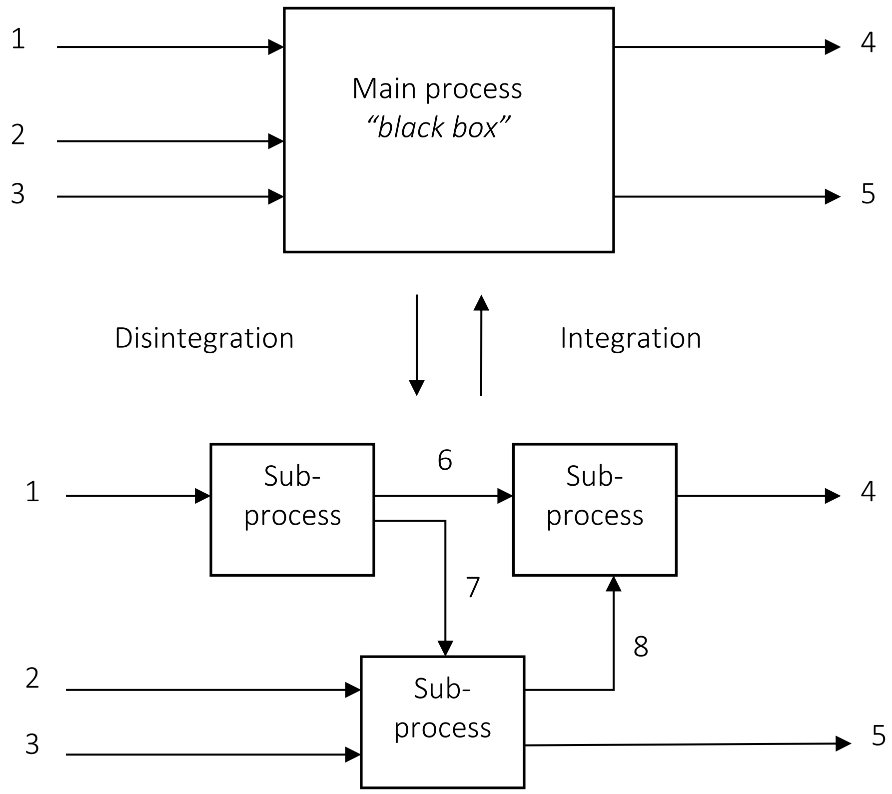

Figure 2: Integration and disintegration of the main process defined as a black box process in MFA. If an internal process is important, it must be divided into sub-processes. Source: adapted according to Brunner and Rechberger (2004)

Transfer Coefficient (TC) describes the presence of material (goods or substances) in the given process, i.e. transfer of the material to the output flow *j*. The sum of all transfer coefficients for all output flows shall equal to 1 (provided that the transfer of material to stocks is also included in outputs).

System is defined by a group of elements and by the interaction between these elements. In MFA, system components are referred to as processes or flows. An enterprise (e.g. a waste incinerator), a region, a state or a household, etc., can represent a system. In an MFA system, each good is clearly defined according to the process by which it originated and its final purpose.

System boundaries are defined in space and time (temporal and spatial system boundaries). For an anthropogenic system such as an enterprise, city or state, periods of 1 year are the most frequently used for reasons of data availability. Spatial system boundaries are usually fixed by the geographical area in which the processes are located. Flows entering the system are called *imports*, while flows leaving the system are called *exports*. Flows within the system that enter individual processes are called *inputs*, while flows that leave the process are called *outputs.* A general MFA model for PET bottles is shown in the following chart, see Figure 3:

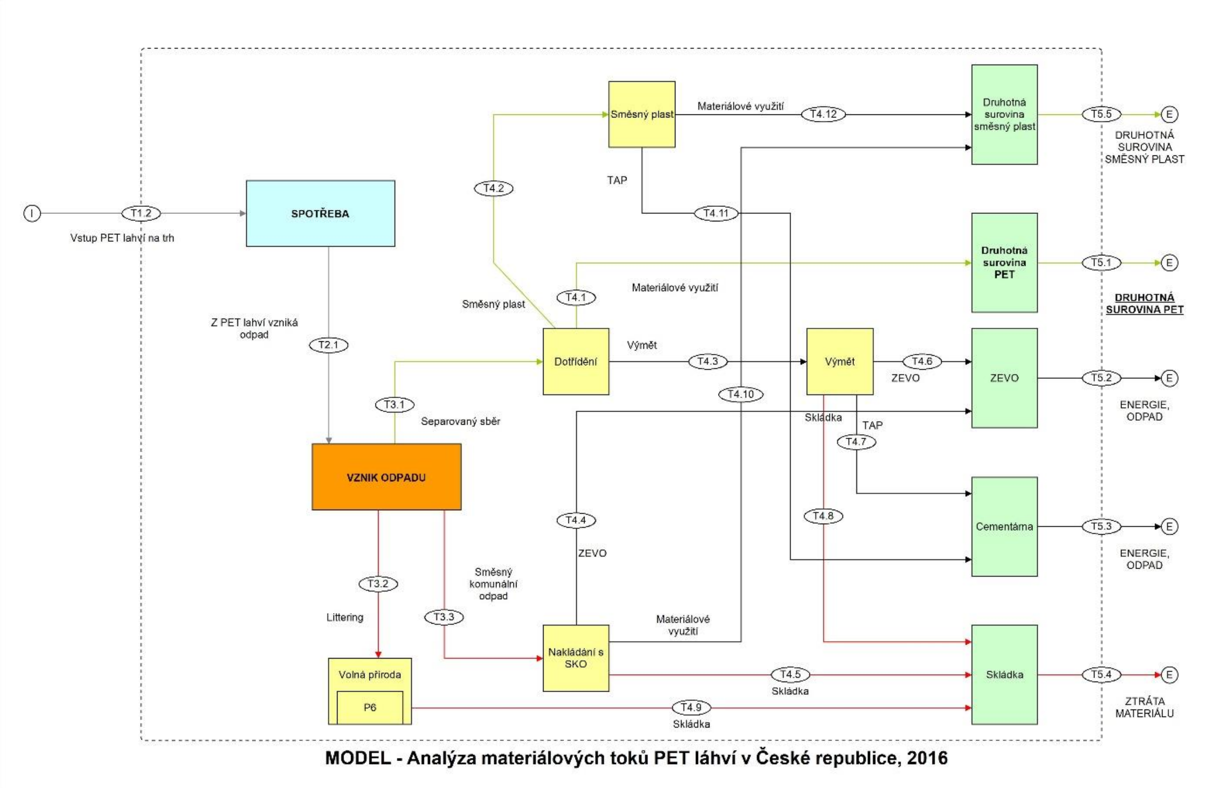

Figure 3: A general MFA chart for PET beverage packaging. Source: INCIEN, 2018

3.4. Uncertainties and assumptions

It is often the case that individual measurements, interviews, or historical resources represent the only data available. In such cases, uncertainties need to be 'roughly estimated' by analyzing the source of the data (Brunner & Rechberger, 2004). For our system analyzing the material flows of PET bottles, in most cases these uncertainties were estimated professionally. To combine uncertainties, STAN software applies the mathematical method of 'error propagation', or 'propagation of uncertainties' (Oliver Cencic & Rechberger, 2008).

It is assumed that the uncertainties in an MFA of PET bottles will feature a normal Gauss distribution. This is referred to as *standard uncertainty*, or also *standard error* (O. Cencic, 2018). In Czech, the term 'standardní nejistota' is used. Depending on the method of evaluation, standard uncertainties are classified as follows:

- Standard uncertainties, type A (u_a) – obtained from the repeated measurements of a quantity (a statistical analysis of a set of measured values). Values decrease with an increasing number of repeated measurements. The cause is unknown.

- Standard uncertainties, type B (u_b) – obtained in a manner other than by the statistical processing of the results of repeated measurements. These are evaluated for individual sources of uncertainty identified for a particular measurement. Their values do not depend on the number of repeated measurements (like systematic errors of measurement). They originate from various sources. The joint action of individual type B uncertainties is expressed by a resulting standard uncertainty, type B.

Unlike uncertainties, type A, where the causes of random errors are deemed as being generally unknown, uncertainties, type B are bound to be known, identified sources.

In connection with the MFA of PET bottles, we use the standard uncertainty, type B.

3.5. Procedure

To make matters clearer, we have divided our research activities into two parts – Part 1, i.e. MFA 1, is focused on investigating PET bottle flow from release onto the market through to final operations such as landfilling, WEP or littering, or being transformed into a secondary raw material. Part 2, i.e. MFA 2, is focused on investigating PET bottle flow from the moment in which '*baled'* PET bottles are transported from the waste sorting line for processing (i.e. *'flaking'*), whether in the Czech Republic or abroad. In MFA 2, we have also focused on the next step, i.e. on the transformation of PET flakes into a new product, while at the same time distinguishing once again whether this took place in the Czech Republic or abroad. As a result, we have obtained an overview of the total flow of a PET bottle – from being released onto the market to its transformation into a new product and subsequent re-entering the market. Individual findings are described in the following pages.

4. MFA 1 – JOURNEY OF A PET BOTTLE FROM ITS RELEASE ONTO THE MARKET TO THE FINAL OPERATIONS OF WASTE MANAGEMENT

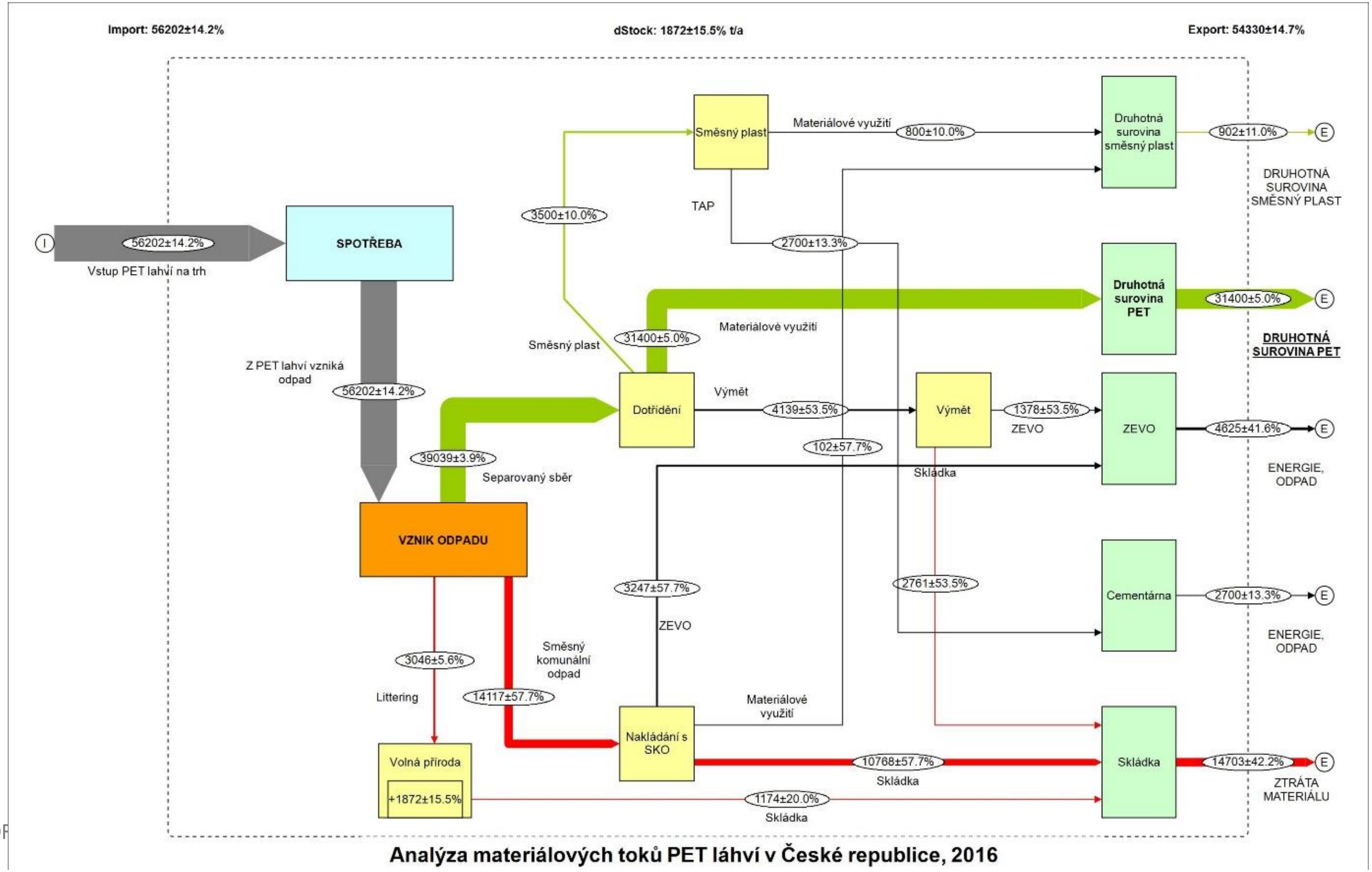

Figure 4: Chart of the material flows of PET bottles for 2016, from release onto the market to the final operations of waste management

4.1. MFA 1 – Results

The following data (for 2016) can be regarded as the main results of MFA 1.

- In 2016, around 56,202 tons of PET bottles (+/- 14.2%) were released onto the marked.
- Approx. 39,039 tons of separated PET bottles, or 69.5% of the total quantity released onto the market (+/- 3.9%) ended up in containers for separated waste.
- This implies that 17,163 tons of PET bottles, or 30.5% of the total quantity released onto the market, did not end up in separated collection, but in mixed municipal waste (MMW) or as litter in the natural environment or in public places.
- Around 14,117 tons of PET bottles (+/- 57.7%), or 25.1% of the total quantity released onto the market, ended up in MMW.
- Hence, around 3,046 tons of PET bottles (+/- 5.6%), or around 5% of the total quantity released onto the market, ended up as litter in the natural environment or in public places. It is assumed that around 1,872 tons (+/- 15.5%) are accumulated in the natural environment and are not cleaned up every year.
- 31,400 tons of PET bottles (+/- 5%), or 55.9% of the total quantity released onto the market, were transported from waste sorting lines for recycling as a secondary PET raw material.
- Thus, around 24,800 tons of PET bottles, or 44.1% of the total quantity of PET bottles released onto the market, were not handed over for transformation into PET flakes.
- This implies that 6,839 tons of PET bottles, or 12.1% of the total quantity released onto the market, get lost in the process of further sorting in waste sorting lines. The losses are particularly caused by the properties of material that are not suitable for separate sorting within separate single-stream PET waste (color, labels, contamination), but also by the quality of work carried out and the technological possibilities of manually sorting waste. Material loss also includes the utilization of PET bottles in the form of solid alternative fuel (SAF) in cement plants.
- Around 2,700 tons of PET bottles (+/- 13.3%), or 4.8% of the total quantity released onto the market, ended up as SAF in cement plants.
- Around 4,625 tons of PET bottles (+/- 41.6%), or 8.2% of the total quantity released onto the market, ended up in waste-to-energy plants (WEP).
- Around 14,703 tons of PET bottles (+/- 42.2%), or 24.7% of the total quantity released onto the market, ended up in landfills.
- Approx. 902 tons (+/- 11%) of PET bottles, or 1.6% of the total quantity released onto the market, ended up in bales of mixed plastic intended for further material recovery.

4.2. MFA 1 – Explanation of results

MFA 1 focuses on the flow of PET bottles in 2016, i.e. from the release of the total quantity onto the market, through to interaction with the consumer, and the subsequent journey of a PET bottle to waste management. Here, we focus on a description and quantification of results – those cases in which the consumer decides to throw away their PET bottle freely in the natural environment or in public place (‘*littering*’), or those in which the consumer decides to place a PET bottle in MMW, or in containers for separated waste collection. Additionally, we focused on the journey of a PET bottle within waste management, the material losses encountered in various processes, up as far as the final processing of PET bottles, when they are transported for recycling, landfilling or energy recovery in WEP and cement plants.

4.2.1. MFA 1 – Explanation of results – Release onto the market

The total weight or quantity of PET bottles released onto the market in a given year is considered a base figure for the research. This is the total quantity of PET bottles that physically enter the market in the Czech Republic.

The original EKOKOM data from January 2018, indicating that the total PET bottle sorting rate amounted at least 74% in 2016, would imply that the weight of all PET bottles released onto the market amounted to around 52,813 tons. For its calculation, EKONOM used the total amount of PET packaging (60,750 tons); however, this number included soft foils (4,570 tons), or packaging with a volume above 5 liters (330 tons). According to EKOKOM, PET bottles, drugstore articles, blisters and boxes should have accounted for the remaining 55,850 tons. Based on the EKOKOM data, 5% of the total quantity of PET packaging (i.e. approx. 3,037 tons) are accounted for by these very blisters and boxes, etc.; thus, PET bottles should logically have accounted for the remaining 52,813 tons (Müllerová, 2018).

This figure differs, however, from Ministry of Environment sources, which for the same year indicate 65,164 tons as the total weight of waste generated from single-stream PET packaging released onto the market. This is 4,414 tons more than EKOKOM suggests (Trylč, 2018). At the time of finalizing the study, the research team was waiting for an official explanation of the aforesaid discrepancies from EKOKOM.

In addition, the Ministry of Environment estimated the total weight range between 50,000 and 53,000 tons (Trylč, 2018). Using calculation methods according to CZ-NACE records, EKOKOM then arrived at the conclusion that around 48,200 tons of PET bottles had been released onto the market in 2016 by organizations registered under the following codes of economic activities:

Table 3: CZ-NACEs included in the category of single-use sales packaging, solid hollow PET plastics released onto the market in 2016. Source: Balner (2018)

Code	Name of economic activity
159000	Beverage production
159600	Beer production
159800	Bottling of mineral and drinking water, and production of alcohol-free drinks

Thus, the variability of data on the quantity of PET bottles released onto the market in 2016 is relatively large. What we can be sure of is that there are no exact statistics or records on the quantity of PET bottles released onto the market in the given period. For MFA, however, this is an essential input that affects the size of other flows within the entire analysis. Nevertheless, MFA also enables us to calculate the probable quantity of PET bottles released onto the market provided we know the quantity of the separated collection of PET bottles and the quantity of PET bottles in mixed municipal waste (MMW). The estimation procedure according to the following assumptions is shown below.

Release onto the market = Separated collection + Quantity of PET in MMW + Littering

- According to the calculation, the collections of separated PET bottles amounted to 39,039 tons in 2016 (Balner, 2018).
- The quantity of PET bottles in MMW amounted to 1% in 2016 (Balner, 2018).

According to scientific estimates, at a sorting rate of 70%, littering accounts for about 5% of the total quantity of PET bottles released onto the market (Raadal, Iversen, & Modahl, 2016).

PET bottles in MMW

According to EKOKOM, 2,069,800 tons of MMW was produced in 2016. These are audited records of municipalities integrated in the EKOKOM system. The data only apply to domestic waste; MMW originated from companies and sole traders is not included. The total production of MMW originated from both municipalities and companies is given in ISOH, an official database of the Ministry of Environment. According to ISOH, 2,820,913 tons of MMW were produced in 2016 (Waste code 200301 – Mixed municipal waste).

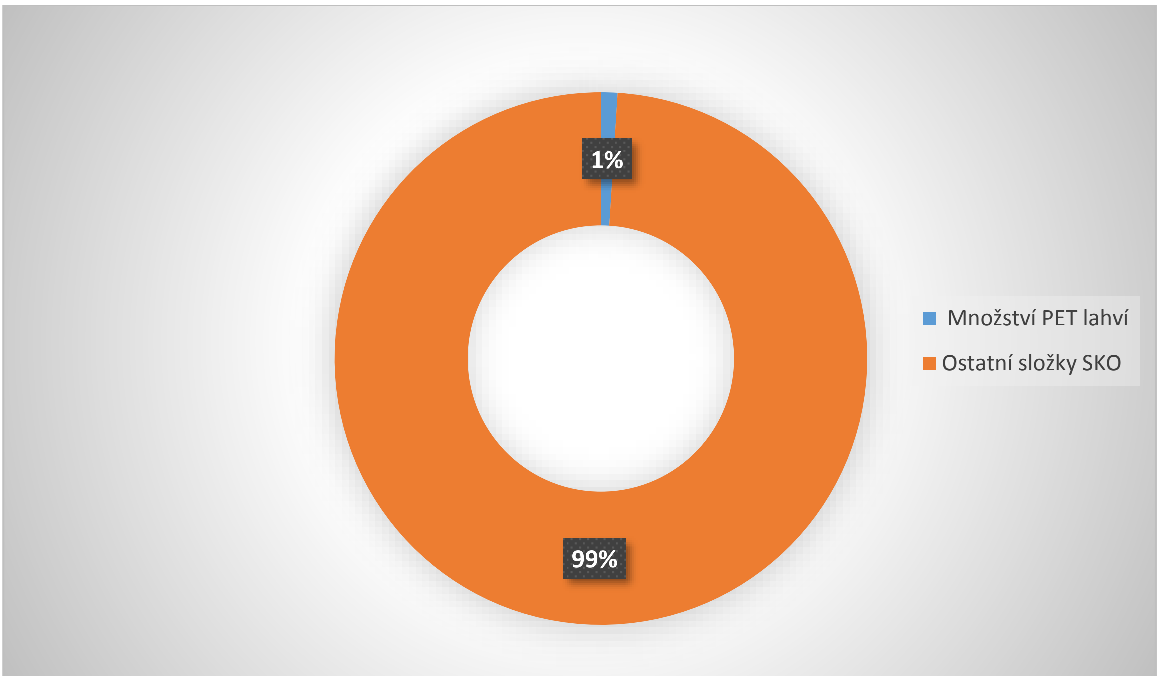

Chart 4: QUANTITY OF PET BOTTLES IN MMW in 2016. Source: Balner (2018)

According to EKOKOM, the specific weights of PET bottles in separated collection and in MMW are 20 kg/m3 and 40 kg/m3, respectively. EKOKOM attributes this variation to the fact that PET bottles in MMW are heavily fouled by other remaining waste and can be wet. Therefore, in EKOKOM's view the weight of PET bottles in MMW should be multiplied by a correction coefficient of 0.5 (Balner, 2018). However, we think that in this case the data for specific weight is not relevant. The specific weight of PET bottles depends on how much a PET bottle has been pressed or stepped upon. Although the specific weight will change, the weight of PET bottles does not change in relation to the total weight of MMW. Nevertheless, MMW analyses show that individual waste components are contaminated to a certain extent by other waste such as ash or the remains of fruit and vegetables, whereas sometimes they are very clean, see Figure 6.

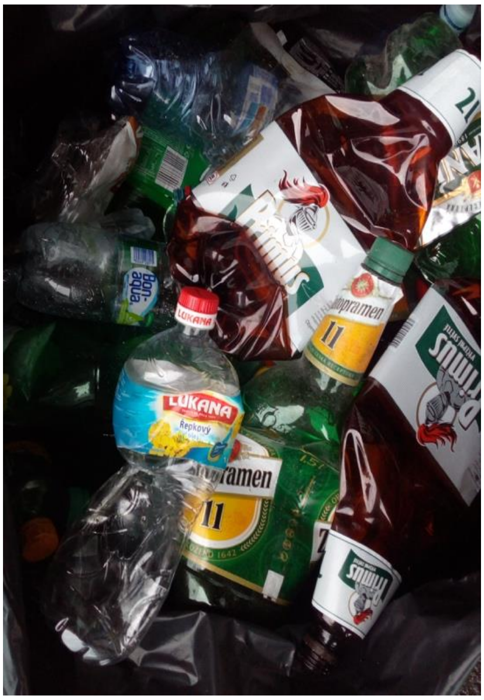

Figure 5: Samples of PET bottles subject to a physical analysis of MMW made by INCIEN. Source: INCIEN (2018)

It is estimated that impurities and other materials that get stuck on a PET bottle in MMW amount to 23% (estimated correction coefficient is 0.77). **Hence, the 1% of total weight of PET bottles in MMW can be decreased by 0.23% down to 0.77% due to impurities.**

➢ We therefore consider the estimate based on EKOKOM data as the minimum value for the quantity of PET bottles in MMW: 2,069,800 t * 0.77% = 15,937 tons.

➢ We therefore consider the estimate based on the official ISOH database as the maximum value for the quantity of PET bottles in MMW: 2,820,913 t * 0.77% = 21,721 tons.

➢ For comparison, the quantity of PET bottles in MMW in Austria, for example, with 8.7 million inhabitants, amounts to 14,884 tons (32% of the total quantity released onto the market) (Van Eygen, Laner, & Fellner, 2017).

➢ In Slovakia, with approx. half number of inhabitants compared to the Czech Republic (5.4 million), the estimated quantity of PET bottles in MMW (10,000 tons) and littering (2,637 tons) amounts to approx. 12,637 tons (Dráb & Slučiaková, 2018).

➢ Thus, it is appropriate to assume that the quantity of PET bottles in MMW and littering in the Czech Republic should not essentially differ from that in Austria, nor should it be lower than in Slovakia.

➢ The actual calculation of the quantity of PET bottles = the mean value between the minimum and maximum, i.e. (15,937 + 21,721)/2 = 18,829 (+/- 2,892) tons. Release onto the market (95%) = separated collection + quantity of PET in MMW = 39,039 (+/-3.9%) tons + 20,785 (+/-15.4%) tons = **59,824 tons (+/-5.9%)**, see Figure 6.

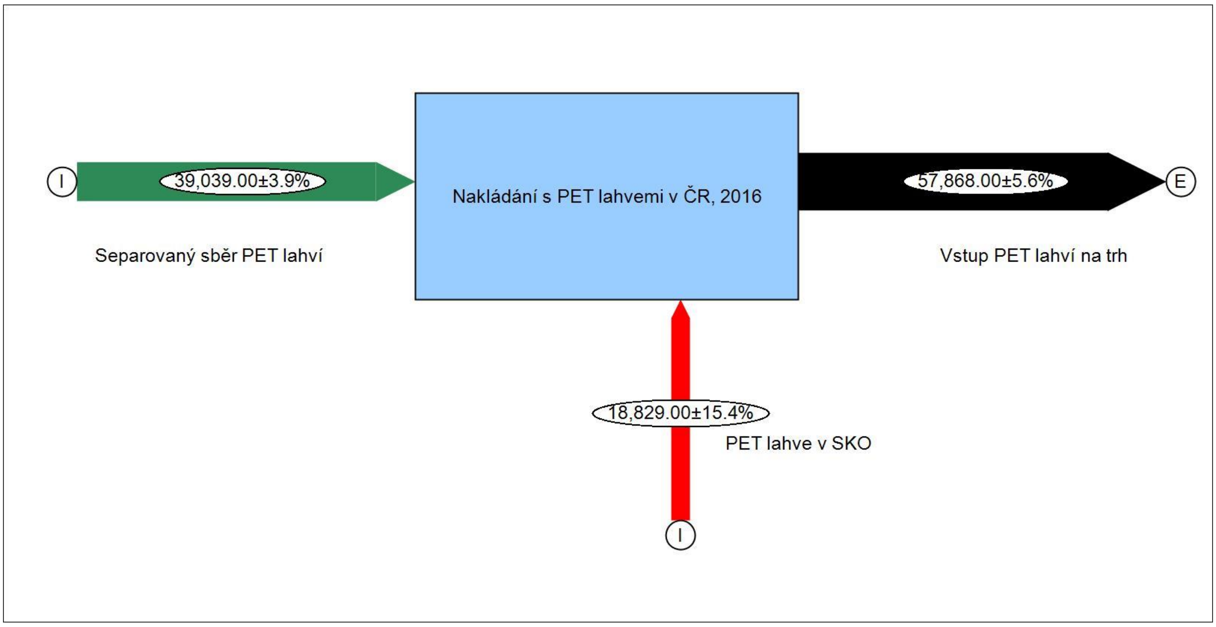

Figure 6: Calculation of a 95% release onto the market using the MFA method

➢ Release onto the market (100%) = separated collection + quantity of PET in MMW + littering = 39,039 (+/- 3.9%) tons + 18,829 (+/- 2,892%) tons + 3,046 (+/- 171) tons = **60,914 tons (+/- 5.4%)** (see Figure 6 and Figure 7).

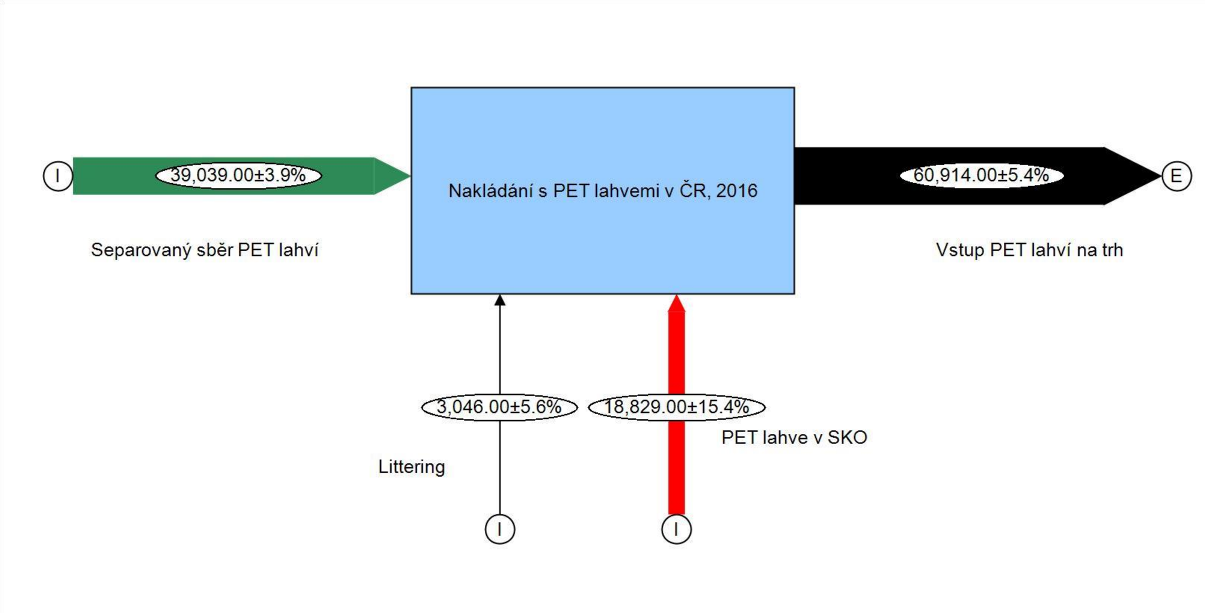

Figure 7: Calculation of a 100% release onto the market, including littering (5% of the quantity released onto the market) using the MFA method

- Thus, the minimum estimated value is 48,200 tons (Balner, 2018), while the maximum value is 64,203 tons (60,914 tons + 5.4%). Final estimated value of the quantity released onto the market: (48,200 + 64,203)/2 = **56,202 tons (+/- 8,002 tons)**.

4.2.2. Littering

The most detailed data on the quantity of PET bottles that end up littering public places and the natural environment in the Czech Republic are given in the aforesaid study from 2007 (Přibylová & Štejfa, 2007). However, the study does not deal with the total quantity of PET bottles that end up this way after they have been released onto the market; instead, it analyses 20 samples in various parts of the Czech Republic and the share of PET bottles in these samples. Thus no exact figure on the total quantity in the Czech Republic has been calculated to date. The investigation team consequently decided to reference similar studies made in Scotland and Norway where, under the assumption that 70% of PET bottles released onto the market end up in the system for separated waste collection, it is estimated that 5% of the total number is carelessly discarded on the ground in public places or in the natural environment (Hogg et al., 2015; Raadal et al., 2016). 5% of the total quantity released onto the market in the Czech Republic amounts to approx. 3,046 tons, as shown in Figure 7.

For checking purposes, we used a study that refers to a European annual littering average of 4.6 kg per person for all kinds of waste (Cordle et al., 2018). After counting up PET bottles with help from the study on the contents of litter, the resulting quantity then amounts to 2,900 tons, which precisely corresponds to estimated 5% of the total quantity (WRAP, 2018).

Littering is the only process in MFA 1 that contains stocks. This means that a certain proportion of PET bottles gets accumulated in the natural environment and is not cleaned up. Nevertheless, to keep matters simple, we assume that the stocks of waste PET bottles amounted to zero in year *n-1* (i.e. in 2015, which is not certainly true since unspecified quantities of PET bottles were discarded as litter in previous years). Based on interviews with experts, in year *n* (i.e. in 2016), 40% of the waste PET bottles inconsiderately discarded during this year were collected from public places and the natural environment.

4.2.3. PET bottles in MMW

If the consumer decides not to sort a PET bottle or discard it as litter, such a PET bottle will end up in MMW. This, then, is the flow of PET bottles in common black containers for mixed waste.

For example, in Austria, such flow represents 14,884 tons (Van Eygen et al., 2017), which is 32% of the total annual quantity of PET bottles released onto the market in Austria. In Slovakia it is estimated that this flow amounts to 10,307 tons, which is 28.3% of the total quantity. In the context of this analysis, the estimated quantity of PET bottles in MMW in the Czech Republic in 2016 amounts to about 18,829 (+/- 2,892) tons, which represents 30.9% of the total quantity of PET bottles released onto the market.

However, EKOKOM claims that the quantity of PET bottles released onto the market amounts to 48,200 tons and that the separation rate is 39,100 tons; hence, the quantity of PET bottles in MMW amounts to 10,349 tons. When compared to neighboring countries as well as to the preceding paragraphs, this figure (only 21% of the total quantity released onto the market) seems a gross underestimate, for example, also due to the fact that is does not reflect any flow of PET bottles which end up as litter. In addition, this estimate contradicts EKOKOM´s statement that 7.4 out of 10 PET bottles is sorted (Müllerová, 2018).

Nevertheless, even this scenario is described in the MFA and included in the estimated total quantity of PET bottles released onto the market, which amounts to 56,202 +/- 8,002 tons. In other words, the scenario of 48,200 tons of PET bottles introduced into the market in 2016, as provided by EKOKOM, is the lowest possible variant considered by MFA.

If we assume that the quantity of PET bottles released onto the market amounts to 56,202 +/- 8,002 tons, then the estimated quantity of PET bottles in MMW calculated by STAN will change. As a result, we obtain 14,117 +/- 8,146 tons of PET bottles in MMW. This broad estimate includes both the estimate made as part of this study (18,829 [+/- 2,892] tons) and the estimate by EKOKOM (10,349 tons).

Figure 4 also describes the journey of a PET bottle in MMW to each of the final stages. The ratios of MMW sent to landfill, WEP or a waste sorting line are based on ISOH records, in which the process of handling mixed municipal waste is described as follows (without any estimate of standard uncertainty):

- in 2016, 76.3% of MMW was tipped into landfills;
- in 2016, 23% of MMW was subject to energy recovery in WEP;
- 0.7% of MMW was subject to material recovery, or sorted in waste sorting lines.

4.2.4. Rate of separated collection

In order to ascertain what rate of sorting PET beverage packaging is achieved in the Czech Republic, waste sorting lines are used as a major relevant point of measurement. The entire system of handling municipal waste is set up so that once products have been released onto the market and consumed, the sites to deposit all municipal waste produced by the inhabitants of a village or town should be provided for by municipalities, i.e. also for separate gathering of the various components of municipal waste, including packaging waste.

Moreover, the municipality has a duty to hand over the waste produced in its cadastral district to a legal entity or a natural person that is authorized to take over the waste pursuant to section 12(3) of the Act on Waste. In practice, this means that municipalities conclude agreements with waste sorting lines or waste collection companies to transport waste to authorized waste treatment plants for further processing. The operators of waste sorting lines process the collected waste into a secondary raw material and sell it on the market according to the current criteria of processors. As stated in one study devoted to the effectiveness of the Czech waste sorting system, about 95% of separated waste is treated prior to its processing on waste sorting lines (Rod, Rais, & Benko, 2016). According to EKOKOM data, PET beverage packaging was sorted on all waste sorting lines that sort plastics.

Thanks to regular reporting from waste sorting lines, we are able to determine how many PET bottles that have been released onto the market have end up in the infrastructure of waste sorting lines. According to EKOKOM, 39,038.9 tons of PET packaging were handed over for further sorting in 2016 (the figure does not include recycling of repeatedly used packaging, which amounted to 49 tons) (Trylč, 2018). In the opinion of the Ministry of Environment this figure mainly reflects beverage PET, because it is precisely this waste that is primarily sorted and then handed over for further utilization. This estimate is based on sampling the content of separated waste (content of yellow containers).

4.2.5. Sorting

The entire content of yellow containers, i.e. a mixture of packaging plastics, non-packaging plastics and non-plastic admixtures collected within municipal systems, as well as separated plastic waste from HORECA businesses, enters the waste sorting lines. In consultation with the operators of waste sorting lines and EKOKOM, three main flows of PET bottles from waste sorting lines have been identified in the waste sorting process.

- The main flow (31,400 tons) included PET bottles that were baled and sent for processing and being transformed into a new product.

- Another flow included PET bottles in pressed bales of mixed plastics (2,700 tons) intended for energy recovery as a certified good – fuel (SAF) for cement plants.

- Another flow included PET bottles contained in bales of mixed plastics for utilization in goods from mixed plastics. According to EKOKOM data, 800 tons of bales of mixed plastics were sent for manufacturing new products in 2016.

- The last flow consists of discard (4,139 tons), where PET bottles end up because of their properties and design (e.g. color, varying composition between the PVC label and remaining PET materials, or contamination) in the flow that is placed in a landfill or processed in WEP (Balner, 2018).

4.3. MFA 1 – Conclusions and discussion

The MFA 1 objective was to describe and quantify the flows of PET bottles in Czech Republic for 2016. The system of flows of materials and stocks was defined by a system boundary, see Figure 4. Individual processes and flows were selected so as to reduce the complexity of the system of material flow as a whole. One of the key pieces of input data is the estimate of the quantity of PET bottles released onto the market in 2016.

According to their own estimation methods, based on the classification of EKOKOM's clients according to CZ-NACE, EKOKOM then estimated that 48,200 tons of PET bottles were released onto the market in 2016. Nevertheless, this estimate, or the rate of separated waste is very probably underestimated, since the sum of the estimated quantity of PET bottles in MMW and the quantity of PET bottles in separated collection is far greater, which has an influence on the relatively large standard uncertainty (estimated at 14.2%).

Another reason for INCIEN having their own estimate is the fact that the EKOKOM data only take into account MMW from domestic waste, which would mean that MMW coming from companies and institutions does not contain a single PET bottle. The last reason is the fact that the estimate of 48,200 tons does not include the problem of littering; yet, experience from foreign countries shows that the quantity of PET bottles in this flow amounts to about 5% of the total quantity released into the market (approx. 3,000 tons in the Czech Republic).

It is also worth commenting on the great uncertainty in the estimate of the quantity of PET bottles in MMW, which is almost 60%. Hence, MMW contains a quantity of PET bottles that lies somewhere between 6,000 and 22,000 tons. Such great uncertainty arises as a result of taking into consideration the data provided by EKOKOM, which differ greatly from our own estimates. If the estimate of PET bottles released onto the market or the estimate of the quantity of PET bottles in MMW could be made more precise, we would then obtain more precise results for material flows. When interpreting the results of the presented MFA, it is therefore necessary to take into account these aforesaid uncertainties. Thus, interpreting the results without the aforesaid uncertainties is problematic. The essential results of the MFA on PET bottles for 2016 are summarized below:

- The quantity of PET bottles entering the Czech market was estimated at 48,200–64,203 tons.
- The quantity of PET bottles within separated collection of plastics was estimated at 37,516–40,562 tons.
- The quantity of PET bottles within the material recovery of PET was estimated at 29,830–32,970 tons.
- The quantity of PET bottles that end up as unrecovered waste in landfills was estimated at 8,498–20,908 tons.

5. MFA 2 – JOURNEY OF A PET BOTTLE FROM THE WASTE SORTING LINE FOR PROCESSING TO BECOME A NEW PRODUCT

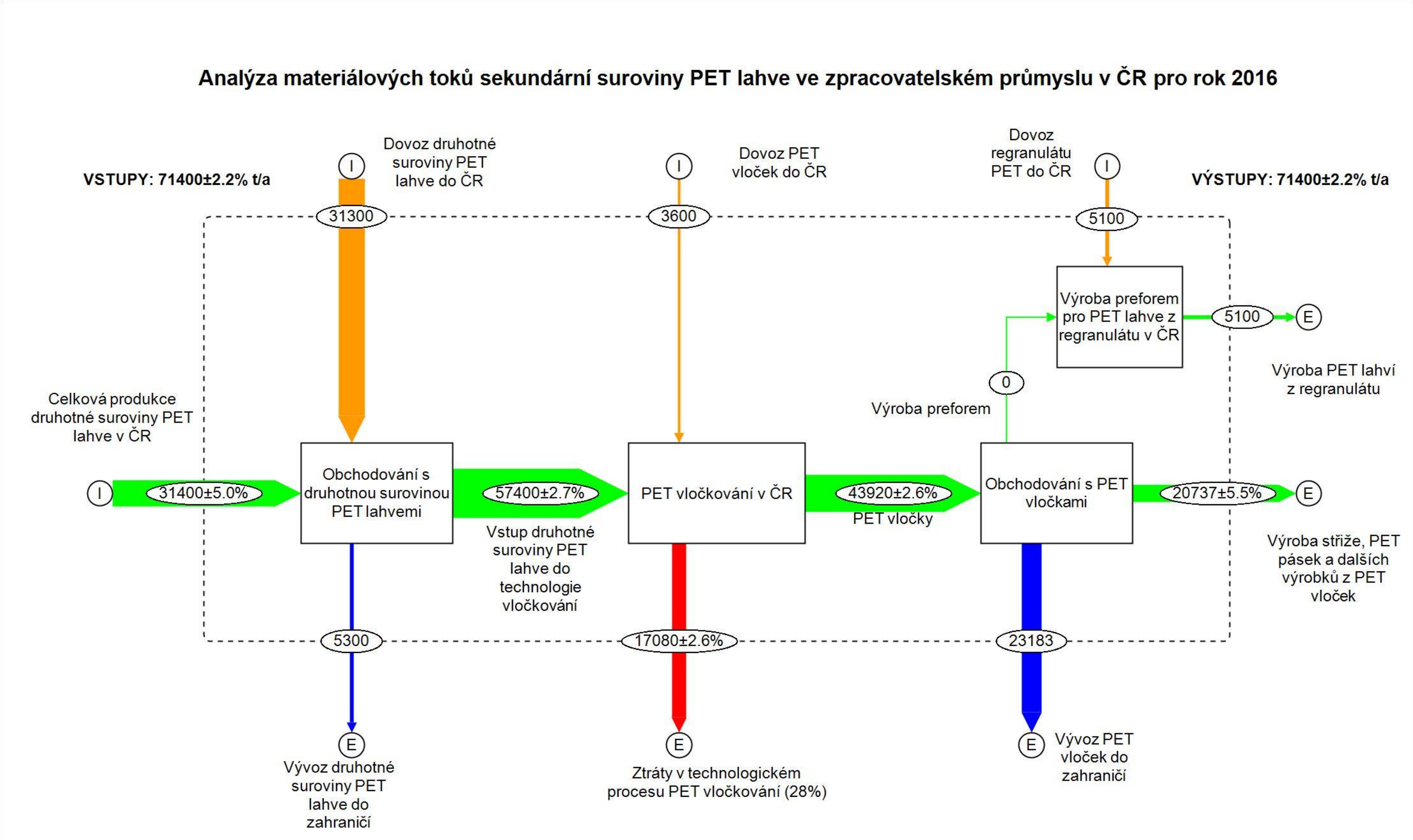

Figure 8: Flow of PET bottles from sorting to processing and transformation into a new product in the Czech Republic during 2016

5.1. MFA 2 – Summary of results

The following data can be regarded as the main results of MFA 2[1]:

- After 31,400 tons of PET bottles (+/- 5%) is picked out from the waste sorting lines in the Czech Republic, about 5,300 tons of PET bottles in bales is exported abroad, which is approx. 16.9% of the total quantity of PET bottles sent for recycling.

- The remaining 26,100 tons, i.e. 83.1% of the total quantity sent for recycling, is handed over to several plants situated in the Czech Republic for transformation into '*PET flakes'.*

- In addition to Czech PET bottles, PET flaking plants in the Czech Republic also process about 31,300 tons of PET bottles imported from abroad. Of the total processed in the Czech Republic, 54.5% of PET bottles were imported from abroad, while 45.5% originated from separated collection in the Czech Republic.

- The total quantity of PET bottles processed in the Czech Republic amounted to 57,400 tons (+/- 2.7%).

- Material losses amounting to 17,080 tons (+/- 2.6%) occur during the process of flaking. This quantity also includes the losses incurred during the processing of the 3,600 tons of PET flakes imported to Czech plants from abroad for further processing. The losses of input materials primarily result from the need to remove materials such as labels, foils or caps from the PET bottle itself, as well as from the need to clean samples.

- In the Czech Republic, around 5,100 tons of '*PET regranulate',* or PET flakes transformed into regranulate, are imported from abroad for the purpose of PET bottle production.

- Of the total quantity of PET flakes produced in the territory of the Czech Republic, approx. 23,183 tons of PET flakes (52.8% of the total quantity of flakes in the country) are exported abroad, while the remaining 20,737 tons (+/- 5.5%) (47.2% of the total quantity of flakes in the country) are sent to production processes or resold in the Czech Republic.

- In the Czech Republic, there is already capacity for processing PET flakes and PET regranulate corresponding to approx. 115,000 tons/year, which is almost twice as much as the highest estimated quantity of PET bottles released onto the market.

[1] All data refer to 2016.

5.1. MFA 2 – Explanation of results

As already mentioned in the introduction, MFA 2 describes in detail the flow of PET bottles from Czech or foreign waste sorting lines, or other sources of material, their processing in Czech flaking plants and the subsequent handling of PET flakes, and maps the material losses, exports, as well as transformation into a new product. As a result, when combined, MFA 1 and 2 provide a complete overview of the flow of PET bottles – from entering the market to their transformation into a new product or some other final operation.

Owing to the fact that no exact database exists of the capacities or plants specifically engaged in PET flaking or processing PET flakes into new products, the research team had to rely on field work. Therefore, the research teams chose the sampling method referred to as "snowball sampling" (Dudovskiy, 2018). At the beginning of research activities, the ISOH database, personal contacts and the Analysis of the Current Network in the Czech Regions (EY, 2015) were consulted, i.e. sources that could provide us with an important database of companies engaged in the field of processing of plastics.

Snowball sampling is a method involving primary data sources that identify other potential primary data sources that should be used in the research. In other words, the collection of data is based on recommendations from initial entities to create other information sources. The exponential, non-discriminating snowball method means that the first entity addressed shall recommend several other entities to address in turn. They are then addressed until the situation occurs when there are no more sources left to contact, or are no longer relevant. Sources and information build up with every new reference and interview – just like a snowball. In this way, we also used our primary sources for recommendations of other important entities.

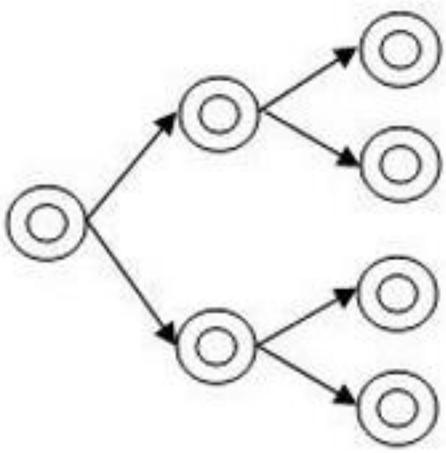

Figure 9: Exponential, non-discriminating data collection using the snowball sampling method (Dudovskiy, 2018)

The following subsections are based on three basic sources of information – organizations that a) process PET bottles to PET flakes, b) use PET flakes to produce new products, or c) use PET regranulate to produce new products.

5.1.1. MFA 2 – Explanation of results – PET flaking

This section describes the market situation in the field of PET flakes production. In principle, PET flakes are a necessary intermediate stage in the cycle of transforming PET bottles into a new product. In order to realistically recycle a single-use PET bottle and use it as input material for new production processes, then according to an absolute majority of industrial solutions, it has to be crushed, washed, cleaned, and its labels, caps and other components and impurities have to be removed. The material cleaned in this way is called a PET flake. Figure 10 shows the final product after flaking.

Figure 10: PET flakes (Jaktridit.cz, 2018)

Another possible intermediate stage in the transformation of PET flakes into a new product can also include the formation of PET regranulate, which is, for example, used for the production of PET bottles containing recycled PET. As shown in Table 4, at least 5 Czech companies are engaged in PET flaking; nevertheless, it is also estimated that other plants may exist with a processing capacity of <2,000 tons of PET bottles/year which have not been identified by the research team during data collection. Each of the companies engaged in PET flaking was directly addressed; the data contained in the following Table come from email or face-to-face communication with the operators of the aforesaid plants.

The main findings of the results of the data collection and analysis are summarized in Table 4 and section 0. As shown in Table 4, five major entities engaged in PET flaking were identified in the Czech Republic. In terms of their capacities, they can receive approx. 57,400 tons of baled PET bottles a year. The research team also knows the quantities of received PET bottles and the quantities of resulting PET flakes in individual plants, but in order to preserve trade secrets, they are not disclosed below.

As shown in Figure 9, according to EKOKOM records, around 26,100 tons of PET bottles out of the original 31,400 tons handed over for recycling were delivered from the Czech Republic for flaking in 2016 (Balner, 2018). It is estimated that the remaining 5,300 tons were sold by waste sorting lines for processing in foreign countries. However, Czech flaking plants imported approx. another 31,300 tons from abroad, mainly from Germany, to fill their capacities.

In addition, material losses occurring during the process are also one of the characteristics of PET bottle flaking. As indicated in Table 4, the losses incurred by individual plants range between 20–30%. The differences are primarily determined by the quality level of flakes required by the final purchaser, as well as by the technology available in the given plant, or which country the PET bottles are imported from.

Another reason for losses is the PET bottle design itself. Some PET bottles are not exclusively composed of PET. Very often their labels are made of PVC, caps of HDPE or other plastics, or the PET bottles themselves contain a small percentage of impurities. All these components have to be removed, however, and, as a rule, depending on the specific requirements of purchasers, the resulting products have to satisfy the stringent limits for the content of any impurities or heterogeneous materials. That is why representatives of the sector engaged in PET flaking, sorting or final processing agree that PET bottles covered with PVC sleeves, or PET bottles colored orange, red or brown, etc., are difficult to recycle, i.e. they represent less valuable materials with low added value when compared to clear PET. For the aforesaid reasons, losses during flaking account for about 17,080 tons of input material in the Czech Republic.

As indicated in Table 4, customer relations differ a great deal. For example, some entities sell all their material to one purchaser in the Czech Republic or abroad, while the other entities have multiple purchasers. As a result, around 23,181 tons of PET flakes are exported abroad, which implies that around 20,737 tons of PET flakes are sold in the Czech Republic to be transformed into a new product or re-sold. For more details on processing flakes into a new product, please refer to the following section.

Table 4: Overview and the results of enterprises processing PET bottles to PET flakes in the Czech Republic

ENTERPRISE	PET RECEIVED (IN TONS/YEAR)	LOSSES (%)	RESULTING PET FLAKES	FOREIGN SUPPLIER (%)	CZECH SUPPLIER (%)	FOREIGN PURCHASER (%)	CZECH PURCHASER (%)
ENTITY A		28		20	80	100	0
ENTITY B		25		5	95	0	100
ENTITY C		30		90	10	80	20
ENTITY D		25		“PRIMARILY MINORITY”	“PRIMARILY MAJORITY”	15	85
ENTITY E		20		5	95	10	90
TOTAL	57,400		43,920				

5.1.2. MFA 2 EXPLANATION OF RESULTS – TRANSFORMATION INTO A NEW PRODUCT

This section deals with the final stage of the material flow research, i.e. with the transformation of PET flakes into a new product. As shown in Figure 9, of the total quantity of PET flakes produced or processed in the Czech Republic, approx. 23,183 tons of PET flakes (52.8% of the total quantity of flakes in the country) are exported, while the remaining 20,737 tons (47.2% of the total quantity of flakes in the country) are sent to production processes or resold in the Czech Republic.

As further shown in Table 5, five major entities engaged in transforming PET flakes or regranulate into a new product were identified in the Czech Republic. One entity is engaged in the production of PET cuts, which are subsequently used, for example, in the automotive industry or in the production of hygiene articles. Two entities produce PET tapes in similar resulting quantities. All entities use the recycled PET flakes as an input material. The last two entities are engaged in the production of PET preforms and use both virgin PET granulate and PET regranulate for their production processes.

In addition, the table shows that in 2016 the total quantity of received PET flakes amounted to 57,400 tons, and that approx. 5,100 tons of PET regranulate were utilized in two production plants. However, in terms of receiving flakes or regranulate from recycled PET bottles, the total capacities of all enterprises theoretically reach a value of 118,400 tons (provided that the producers of preforms only use PET regranulate as an input raw material).

As shown in Table 5 and Figure 9, despite relatively large production capacity and thus demand for PET flakes, entities F and H, for example, have to import the majority of material from foreign countries, sometimes from countries on the periphery of the European Union. In the case of producers of PET preforms, all of the aforementioned 5,100 tons are imported from abroad because no plant producing PET regranulate of the required quality for producing preforms existed in the Czech Republic at the time of the research.

Table 5: Overview and the results of enterprises processing PET flakes into new products in the Czech Republic

ENTERPRISE	PET FLAKES TO A NEW PRODUCT:	FLAKES RECEIVED (IN TONS/YEAR)	VIRGIN PET GRANULATE RECEIVED (IN TONS/YEAR)	PET REGRANULATE RECEIVED (IN TONS/YEAR)	FOREIGN SUPPLIER (%)	CZECH SUPPLIER (%)	FOREIGN PURCHASERS (%)	CZECH PURCHASERS (%)
ENTITY F	PET CUTS				84	16	80	20
ENTITY G	PET TAPES				5 – 10	90 – 95	22	78
ENTITY H	PET TAPES				50	50	30	70
ENTITY I	PET PREFORMS				ALL FOREIGN	0	75	25
ENTITY J	PET PREFORMS				ALL FOREIGN	0	70	30
TOTAL		57,400	55,900	5,100				

5.2. MFA 2 – DISCUSSION AND CONCLUSIONS

The MFA 2 objective was to describe and quantify the flows of PET bottles in the Czech Republic for 2016 from the process of sorting, through transformation into PET flakes, and further to becoming a final product. The system of flows of materials and stocks was defined by a system boundary. As in MFA 1, individual processes and flows were selected so as to reduce the complexity of the overall system of material flow.

Owing to insufficient publicly available data, it was necessary to contact entities individually, based on gradually acquired recommendations from key players and industry experts. However, here it is salient to point out the limits of the selected research method, i.e. snowball sampling; despite many recommendations as well as web and database research, the research team may not have identified other entities that use PET flakes or regranulate in production processes in the Czech Republic.

During the research, several entities were identified that had been engaged in such activities in past (for example, one company that manufactured roof covering from PET bottles); however, at the time of the research they could not be contacted or had already ceased doing business, or were subject to an insolvency procedure, for example. Those entities engaged in the resale of PET flakes or regranulate, but who do not produce any products from them, have not been included in the results in Table 5.

Further, companies or plants engaged not only in the production of PET preforms, but also in the production of beverages themselves, have not been included in the research either. It could be supposed that these companies currently use the regranulate in their production processes, or that they might include treated regranulate in their production processes. However, in discussions with the representatives of beverage producers, it became manifestly clear that at the time of research they did not use the PET regranulate for the Czech market in their bottles.

As further shown in Figure 9, in 2016 approx. 54.5% of PET bottles must have been imported from abroad to fill capacities, which for PET flaking came to about 57,400 tons a year. Based on the above data, it can be concluded that the Czech Republic has sufficient capacities to process all PET bottles released onto the Czech market in a given year, and indeed more than half of that total has to be imported from abroad. From the material point of view, there is room for increasing the quantity of separated PET in order to deliver the necessary quantity of material for PET flaking in the Czech Republic.

It should also be noted that the system losses in the process of flaking described in Figure 9 would occur in both the deposit and existing systems; hence the room for making PET bottle recycling more effective after collection is more likely to be found in replacing existing technologies and innovating production processes.

6. CONCLUSION AND DISCUSSION

The main objective of this analysis has been to obtain a precise overview of the flows of PET beverage packaging in the Czech Republic and to give an idea of the research steps undertaken by INCIEN from the beginning of 2017 in this project. Since specific conclusions are described in the individual subsections, here INCIEN only wishes to conclude by giving brief recommendations in the following areas.

INCIEN welcomes initiatives that are ambitiously targeted towards implementing the principles of a circular economy in everyday practice in all areas of our society. This was a contributory factor in the INCIEN team's decision to devote its time to research as part of the project Zálohujme – Let's deposit. After all, the key to a circular economy is not just separating waste, but the perfect return of material, without loss of quality, into as many subsequent cycles of reuse as possible.

The analysis of the material flows of PET bottles in the Czech Republic was conducted on data for 2016 using STAN software and was divided into two parts. The first examined the flow of PET beverage bottles from their release onto the market through to the final operations of waste management. The second part examined the journey of PET beverage packaging from the waste sorting line through to its transformation and processing into new products.

The first part of the analysis showed that of the total quantity of PET beverage packaging released onto the market, which in 2016 amounted to 56,180 tons, 69.5% ended in containers for separated waste. Approximately 25% of PET beverage packaging ended up as MMW and another 5% as litter, a minor proportion of which was cleaned up during the year and the remainder left to accumulate. The quantity of PET beverage packaging sent to sorting lines for recycling as PET secondary raw material was 31,400 tons, or 55.9% of the total released onto the market. In total, approx. 24,000 tons of PET bottles, or 42.7% of the total released onto the market, were lost during the consumption, separation and sorting process.

It should also be stated that record-keeping among individual entities in relation to PET beverage packaging, especially in relation to quantities released onto market, is undermined by non-negligible levels of inaccuracy, and INCIEN consequently recommends that methods of record-keeping and reporting be properly harmonized. Precise measurement, weighing and thorough record keeping, shared transparently among all entities, will in future make proper reporting possible and afford, in particular, an overview of the actual handling of individual types of waste – all of which is currently lacking.

The second part of the MFA highlights the fact that, after 31,400 tons of PET beverage packaging are sent to sorting lines in the Czech Republic, approx. 5,300 tons make their way abroad, while the remaining 26,100 tons are transferred for flaking to Czech facilities. In order to maximize capacities, these plants process an additional 31,000 tons of PET beverage packaging which is imported. So, clearly the Czech Republic enjoys sufficient capacity for flaking all the PET beverage packaging released annually onto the domestic market.

Once processed, approx. 52.8% of PET flakes are exported and the remaining 47.2% are processed or resold within the Czech Republic. From the information available, we now know that the main products manufactured from PET flakes in the Czech Republic are PET cuts and PET flakes. In the country there also exist several plants manufacturing preforms for PET beverage packaging, which to a lesser extent use PET regranulate. In view of the fact that, at the time of writing this study, there were no domestic facilities capable of producing regranulate of the required quality, all PET regranulate used in manufacturing preforms was imported.

In conclusion, it is important to state that the existing system for the separated collection of plastic waste has achieved very good results throughout its existence. Today, 99% inhabitants have the possibility to sort, and about 73% of them do so (EKOKOM, 2018). Despite this, only 55.9% of PET beverage packaging found its way to PET flaking facilities, and another 1.4% in bales of mixed plastic. Considerable room for raising awareness and optimizing the system therefore exists in involving that part of population that decides not to sort and gets rid of waste by placing it in MMW or discarding it as litter. Room for improvement also lies in the sorting process: approx. 6389 tons are lost at this stage, whether as a result of the design or soiling of bottles, or the technological possibilities of the sorting line itself.

It is obvious that engaging the remainder of the population who do not currently separate their waste will require new approaches and methods of motivation. Unfortunately, failure to involve even a small fraction of the total population can result in strong negative consequences for the environment in the form of landfilling and littering. This situation can also have negative economic impacts, for example, resources spent on cleaning public places, national parks or the verges of roads, railways and highways. Therefore, in terms of the flow of PET beverage packaging, INCIEN recommends analyzing ways of making the existing system more effective so that the quantity of PET beverage packaging being separated and recycled is increased to a maximum, and the quantity of freely discarded PET bottles is simultaneously minimized.

From the viewpoint of the circular economy, it is similarly important to focus on how separated PET beverage packaging is being used, since a fundamental principle of the concept lies in the local termination of material flows, without any loss of material quality during individual recycling cycles, and with as little transport as possible. Today, however, a shortage on the Czech market means that some Czech PET flake processors are importing material from around the EU.

Topic

DRS brings with it several more or less predictable impacts. The economic impacts on the existing system are doubtlessly a subject for further discussion with all stakeholders. This discussion will also be able to draw upon a study of the economic impacts (one of the outputs of our project) which has been compiled by Eunomia Consulting ltd. The specific impacts on the environment have in turn been evaluated by experts at the UCT. These three documents, including this study of material flows, should together offer a comprehensive overview of the current situation and the possibilities of a DRS.

7. ANNEXES

7.1. Explanation of terms

7.1.1. Definition of material

Material within this analysis refers to a '*PET bottle'.* A PET bottle or PET bottles are defined in the concept of a PET beverage bottle in the segment of soft drinks, ciders and both alcoholic and alcohol-free beer, irrespective of the distribution channel. Here, any broader application of PET bottles, such as those for oils, milk or drugstore articles, is not included.

7.1.2. Description and definition of processes, assumptions and transfer coefficients

Processes in the MFA model are shown as differently colored rectangles or squares. These include, for example, the processes of "consumption", "waste generation" or "waste sorting", etc.

Consumption

This is the process of the consumption of PET bottles by customers according to the definition (see above). Consumption refers to both the B2C (households) and B2B (companies, institutions) sectors.

Waste generation

A waste PET bottle is generated once the product contained in the bottle is consumed. When calculating the amount of waste being generated, we work with the simplified assumption that each PET bottle to have entered the market in a given year becomes waste in the same year. Thus, consumption = waste generation.

Natural environment

This is a process that can also be referred as "littering", which can be defined as "the careless discard of refuse (PET bottles) in public places and the natural environment" or as "the inconsiderate discarding of refuse (PET bottles) in the place of its generation without using the containers intended for its collection" (Přibylová & Štejfa, 2007).

Sorting

This is a process in which PET bottles are separated out of the total quantity of collected separated plastics. This PET bottle sorting process is carried out manually on waste sorting lines in the Czech Republic.

MMW handling

The process of handling mixed municipal waste. For convenience, the incineration itself is not taken into account.

Discard

This is the process of generating a waste mixture that is not suitable for material recovery (for economic or technological reasons).

Secondary raw material – mixed plastic

The process in which a waste PET bottle is turned into a secondary raw material suitable for the production of products from mixed plastic. This process is achieved by sorting on waste sorting lines in the Czech Republic.

Secondary raw material – PET
The process in which a waste PET bottle is turned into a secondary raw material suitable for the production of products from PET. This process is achieved by sorting on waste sorting lines in the Czech Republic.

WEP
The process of energy recovery from a waste PET bottle in a waste-to-energy plant.

Cement plant
The process of energy recovery from a waste PET bottle in a cement plant.

Landfill
The process of landfilling PET bottles in controlled landfills.

7.1.3. Description and definition of flows, including input data

Release of PET bottles onto the market
This is the total quantity of PET bottles that physically enter the market in the Czech Republic. Thus it equates to the sale of products (import – export + domestic production) packed in PET bottles within the Czech Republic in 2016.

PET bottles generate waste
The consumption of products packed in PET bottles leads to the generation of waste PET bottles. Thus, release onto the market in year *t* = consumption in year *t* = waste generation in year *t*.

Separated collection
The collection of PET bottles as part of the separated collection of plastic packaging waste. This is the flow of PET bottles in “yellow containers”. For convenience, no other separated waste has been taken into account.

Littering
The flow of PET bottles that is inconsiderately discarded in public places or the natural environment.

Mixed municipal waste
The flow of PET bottles within the flow of mixed municipal waste This is the flow of PET bottles in “black containers”, or containers for mixed waste.

Material recovery
The flow of separated PET bottles to be turned into a secondary PET raw material. This is the highest quality material that goes on to enter the technology for producing new products.

Mixed plastic
The flow of separated PET bottles that are not suitable (economically or technologically) for direct material recovery, but can be turned into a secondary raw material, i.e. mixed plastic. These are, for example, colored PET bottles that are of no interest to the market at a given moment, or PET bottles with PVC foils.

Discard
The flow of PET bottles that end up in the process of discard. These are PET bottles that are not suitable (economically or technologically) for direct material recovery or for use within mixed plastics. These are, for example, color PET bottles that are of no interest to the market at a given moment, or PET bottles with PVC foils, or PET bottles contaminated in some other way or extremely fouled. This flow also includes PET bottles that are not picked out in manual separation (thus it represents individual failures or the general technological deficiency of manual separation).

WEP
The flow of PET bottles heading towards a waste-to-energy plant. Both MMW and discard that contain PET bottles can go to a WEP.

Landfill
The flow of PET bottles intended for landfilling within the flow of MMW, discard, or as part of "clean-ups" in the natural environment.

SAF
The flow of PET bottles as 'solid alternative fuel' from the processing of mixed plastic and discard to a cement plant for waste-to-energy recovery. Pursuant to the applicable legislation and according to records on waste disposal in the Czech Republic, it is considered as material recovery because prior to entering the cement plant a good has been generated, i.e. SAF.

Secondary raw material – PET
The flow of PET bottles as a secondary raw material that is subject to further trade. Baled PET bottles are then exported for processing abroad, or enter the process of PET flaking in the Czech Republic (in our case, the system of PET flaking lies outside the specified system boundaries).

Secondary raw material – mixed plastic
The flow of PET bottles in a fraction of mixed plastics as a secondary raw material that is subject to further trade and that further enters the process of mixed plastic processing (outside the system boundaries).

Energy, waste
This is the material flow that arises due to energy recovery from PET bottles within WEP or cement plants. This flows lies outside the system boundaries.

Material loss
This is the material flow produced by landfilling PET bottles. This flows lies outside the system boundaries. For convenience, we assume that landfills will not be exploited in future, for example for SAF production technology. Thus, it is a definitive material loss (Bocken, de Pauw, Bakker, & van der Grinten, 2016).

7.2. Overview of input data and estimates of standard uncertainties in MFA 1 and 2

7.2.1. Overview of input data and estimates of standard uncertainties in MFA 1

Table 6: MFA 1 – Overview of input data and estimates of standard uncertainties

Flow	Name of flow	Input data (t/year)	+/- uncertainty (t/year)	Calculated data (t/year)	+/- uncertainty (t/year)
T1.2	Release of PET bottles onto the market	56,202	8,002	56,202	8,002
T2.1	PET bottles generate waste			56,202	8,002
T3.1	Separated collection	39,039	1,522.521	39,039	1,522.521
T3.2	Littering	3,046	170.6	3,046	170.6
T3.3	Mixed municipal waste			14,117	8,147.3
T4.1	Material recovery	31,400	1,570	31,400	1,570
T4.2	Mixed plastic	3,500	350	3,500	350
T4.3	Discard			4,139	2,214.8
T4.4	WEP			3,246.9	1,873.9
T4.5	Landfill			10,768.5	6,214.8
T4.6	WEP			1,378.3	737.5
T4.7	SAF			2,760.7	1,477.3
T4.8	Landfill			2,760.7	1,477.3
T4.9	Landfill	1,173.6	234.7	1,173.6	234.7
T4.10	Material recovery			101.6	58.6
T4.11	SAF			2,700	359
T4.12	Material recovery	800	80	800	80
T5.1	Secondary raw material – PET			31,400	1,570
T5.2	Energy, waste			4,625.2	1,923.6
T5.3	Energy, waste			2,700	359
T5.4	Material loss			14,702.8	6,205
T5.5	Secondary raw material – mixed plastic.			901.6	99.2

Table 7: MFA 1 – Overview of applied transfer coefficients

Process	Name of process	In -> Out	Transfer coefficient (TC)	+/- TC	TC (calculated)	+/- TC (calculated)
P7	MMW handling	T3.3 ->T4.1O	0.0072	n/a	0.0072	n/a
P7	MMW handling	T3.3 ->T4.4	0.23	n/a	0.23	n/a
P7	MMW handling	T3.3 ->T4.5	0.7628	n/a	0.7628	n/a
P9	Discard	T4.3-> T4.6	0.333	n/a	0.333	n/a
P9	Discard	T4.3-> T4.8	0.667	n/a	0.667	n/a

7.2.2. Overview of input data and estimates of standard uncertainties in MFA 1

Table 8: Overview of input data and estimates of standard uncertainties in MFA 2

Flow	Name of flow	Input data (t/year)	+/- uncertainty (t/year)	Calculated data (t/year)	+/- uncertainty (t/year)
T1	Total production of secondary raw material – PET bottles in the Czech Republic	31,400	1,570	31,400	1,570
T2	Import of secondary raw material – PET bottles into the Czech Republic	31,300		31,300	
T3	Export of secondary raw material – PET bottles abroad	5,300		5,300	
T4	Secondary raw material – PET bottles entered the flaking technology			57,400	1,570
T5	Import of PET flakes to the Czech Republic	3,600		3,600	
T6	Losses in the technological process of PET flaking (28%)			17,080	439.6
T7	PET flakes			43,920	1,130.4
T8	Export of PET flakes abroad	23,183		23,183	
T9	Production of cuts, PET tapes and other products from PET flakes			20,737	1,130.4
T10	Production of preforms	0		0	
T11	Production of PET bottles from regranulate			5,100	0

Table 9: MFA 2 – Overview of applied transfer coefficients

Process	Name of process	In -> Out	Transfer coefficient (TC)	+/- TC	TC (calculated)	+/- TC (calculated)
P2	PET flaking in the Czech Republic	∑ -> T6	0.28	n/a	0.28	n/a
P2	PET flaking in the Czech Republic	∑ -> T7	0.72	n/a	0.72	n/a

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