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Production of Packaging from Recycled Materials: Challenges Related to Hazardous Substances

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Packaging waste that is not recycled or reused has a negative environmental effect and presents serious concern. At the same time, various materials, which were used to manufacture packaging, could be used as resources for production of new packaging or other products. For these reasons, legislation is tightening up with waste management objectives becoming more stringent in order to reduce the volume of not recycled, reused or recovered waste and encourage implementation of circular economy concept and use of materials based on the closed-loop principle.

This paper analyses issues related to production of packaging by using materials from recycled packaging waste with the focus on the influence of hazardous substances the waste may contain, and considers potential problems in the context of implementation of circular economy principles according to the latest EU legislation.

Keywords: packaging, recycling, hazardous chemical substances, recycled raw materials in packaging production.

Introduction

A significant part of packaging economy still uses the linear model "take-produce-consume-discard", which assumes that economic growth can be based on the abundance of resources and unlimited packaging waste disposal (Jurgilevich et al., 2016). At the

same time, the concept of circular economy (CE) is getting more and more attention on various levels (Reike et al., 2018), including the legislation. In the circular economy, various materials are highly valued and perceived as a source of resources, unlike in the

traditional, linear economy model (EC, 2018c; Geisendorf and Pietrulla, 2018). Generally speaking, the main purpose of CE for industry is “closing the loop” to promote industrial systems minimising waste, and reducing raw material and energy inputs (Stahel, 2016; Niero and Hauschild, 2017). When turning the linear economy model in to the circular economy model, it is important to understand and separate three existing ways to close the loop (Stahel, 2013). They are “reduce, reuse and recycle” materials and product options (Jurgilevich et al., 2016; Zink and Geyer, 2017). For packaging, the “reduce” loop principle promotes package redesigns and increases material efficiency; it is related to the initial stage of packaging. When a product reaches the end of its life cycle, reuse and recycling provide an opportunity to extend keeping of materials in the economy (Clark et al., 2016). The “reuse” packaging loop’s intended purpose is to reuse packaging as many cycles as possible. Recycling is the third component of the “reduce, reuse, recycle” waste hierarchy. The “recycling” packaging loop’s intended purpose is to return resources as secondary raw materials back to the economy cycle for production of new packages or other products.

Legislation provides increasingly stringent targets for recycling of packaging. However, legislation does not demand the use of minimum levels of recycled materials in new packaging, nor does it require to have a certain share of production (packaging) to be made from recycled materials. In practice, a number of obstacles arise when trying to close the loops of packaging materials. Purity/genuineness of materials constituting the flow of used packaging is one of the major problems. Among the causes which may compromise its purity are substances used in packaging production or added to raw materials in order to make the production processes easier or improve the properties of the packaging.

The purpose of current article was to overview the issue related the use of recycled materials in the production of new packaging, concentrating on the potential presence of hazardous chemical substances in recycled packaging waste flow. As well as, overview the most important legislation that regulates the further usage of recycled materials in the packaging supply chain.

Methods

An overview of recycling and barriers to recycling was based on the analysis of scientific literature, study reports, EU strategic documents and legislation, statistical data, as well as practical experience when working with and assisting companies to develop Declarations of Compliance of the EN 13427.

A survey was conducted in September 2018 with companies that manufacture packaging in Lithuania. In total, 82 such companies were identified, which manufacture packaging from glass, plastic, PET, paper and cardboard, metal, wooden, composite, and other (textile) materials. Questionnaires were sent by e-mail to the identified companies. The response was received from 48 companies out of 82. The questionnaire included questions on the use of recycled materials: does the company use recycled raw materials, why and how much, what share of production is made of recycled materials, what has inspired the production of packaging made from recycled materials, and what are the disadvantages of packaging produced from recycled materials.

Packaging recycling: targets, achievements, regulations

Strategic aims for packaging recycling

The European Commission’s ambition to increase recycling and promote a more environmentally friendly economy according to the circular economy concept causes countries to be concerned about the well-functioning packaging waste systems (Dodick and Kauffman, 2015). To improve them, the European Commission allocates much attention to packaging treatment targets in European Union. As a part of the circular economy package, the European Commission presented an action plan as well as a number of legislative proposals in 2015; proposals on Waste Framework Directive and Packaging and Packaging Waste Directive were among them (EC, 2015; European Parliament, 2016). In 2018, amendments to both directives were adopted: 2018/851 made amendments to the Waste Framework Directive (2008/98/EC), and 2018/852 made amendments to Packaging and Packaging Waste Directive (94/62/EC).

Both directives pay attention to prevention, reuse, and collection of waste streams and set a number of new recovery and recycling targets. It is foreseen to increase municipal waste recycling/preparation for reuse to at least 55% by 2025, to 60% by 2030, and to 65% by 2035. Specific targets for packaging recycling by 2025 and 2030 are the following: for all packaging – 65% and 70%, plastic – 50% and 55%, wood – 25% and 30%, ferrous metals – 70% and 80%, aluminum – 50% and 60%, glass – 70% and 75%, and paper and cardboard – 75% and 85%, respectively.

Currently, the EU Member States have to comply with targets set in 2008 for recycling and recovery: a minimum of 60% recovery rate (including waste incineration); between 55% and 80% of packaging waste to be recycled; minimum rates of 60% for glass, paper and cardboard, 50% for metals, 22.5% for plastics, and 15% for wood.

A lot of attention is being paid to plastics as one of the priority areas (Hahladakis et al., 2018; Packaging Europe, 2018). A European Strategy for Plastics in a Circular Economy presents a vision that by 2030 all plastics packaging placed on the EU market is either reusable or can be recycled in a cost-effective manner (EC, 2018a).

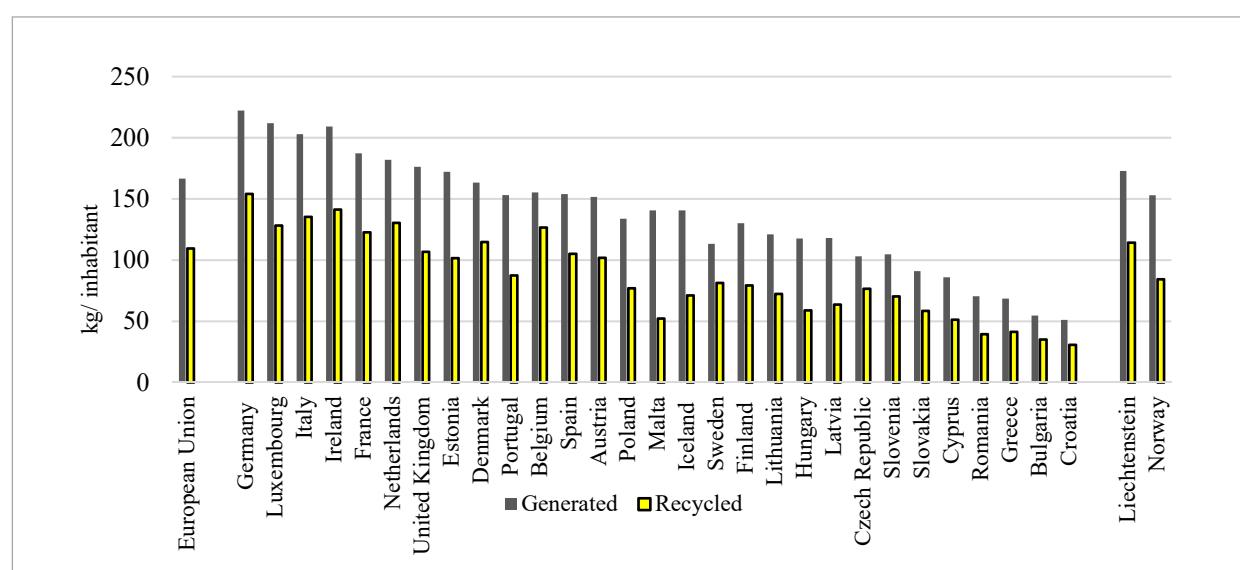
Packaging waste generation and treatment

Currently, about a quarter of EU municipal waste is still landfilled, less than half is recycled or composted, with wide variations between Member States (Eurostat, 2018a). Packaging in the municipal waste stream constitutes some 34% (Eurostat, 2015a). Its generation, somewhat fluctuated during the previous years, might be due to the economic slump in 2009. On average, 84.5 million tonnes, or 166.3 kg/inhabitant, were generated in EU-28 in 2015 (Eurostat, 2018b). According to the report “The Future of Global Packaging to 2022”, the demand for packaging will grow steadily at 2.9% until 2022, which means, respectively, increase in packaging waste (Smithers Pira, 2018). Paper and cardboard (~41%), plastics (~19%), glass (~19%), wood and metals are, in that order, the most common types of packaging waste in the EU Member States. Less than 0.3% are attributed to other materials. It needs to be noted that composite packages are usually declared according to material which is larger by weight.

The recycling and recovery rates of packaging waste evolved in parallel. The recycling rate went up from 56.9% in 2006 to 65.8% in 2015 (for EU-27). The

Fig 1.

Generation and recycling of all packaging waste in EU countries in 2015 (Eurostat, 2018b)



recovery rate rose from 68.9% in 2006 to 79.0% in 2015 (Eurostat, 2018b). Recycling was the main form of recovery in all countries; in addition, recovery also includes incineration at incinerators with energy recovery.

Fig. 1 gives an overview of the situation reported by the EU Member States in 2015 on packaging waste generated and recycled per inhabitant. There were wide variations across the Member States. The generation rate varied between 51.2 kg/inhabitant in Croatia to 222.3 kg/inhabitant in Germany. Germany also reported the highest amount of packaging waste recycled (154.1 kg/inhabitant). However, when expressed in percentage, Belgium had the highest rate for both recycling (81.5%) and recovery (99.3%) (Eurostat, 2018b).

Regarding different packaging materials, the average recycling rate was the following: 85% for paper and cardboard packaging; 78% for metallic packaging; 74% for glass packaging; 40% for wooden packaging, and 42% for plastic packaging (Eurostat, 2016). Obviously, targets set for 2008 by Directive 94/62/EC were reached and exceeded, pointing to the need of more ambitious aims.

Statistics show the amount of recycled materials, but do not indicate whether this was a closed-loop recycling, where the recycled materials were incorporated back into the packages, or whether it was an "open-loop" recycling, where materials were used for other purposes.

Recycling challenges

Packaging recycling as well as the use of recycled materials for packaging production face a variety of challenges related to technical, economic, environmental, social and legal issues. Increasing recycling costs, lack of raw materials, availability of technologies to separate different materials, increasing numbers of legal acts are just a few examples of them. One of the barriers faced by operators who want to use secondary raw materials is uncertainty as to their quality. Many problems occur in packaging recycling when attempts to solve the issue of hazardous substances in packaging are shifted to the end of the process instead of eliminating them at the outset of

the product cycle. Contamination of collected packaging materials with chemicals hinders their further processing and handling. This can happen either due to the use of certain raw materials and additives in the packaging, or because of what was packaged and stored (Hopewell et al., 2009; Peenarun et al., 2004; Pivnenko et al., 2016).

Recycling opportunities and barriers by the type of packaging materials are reviewed below.

Plastics packaging. Simple, but true: when plastics are recycled, they are usually "downcycled" (Plastics Europe, 2017). Plastics cannot go through the closed-loop recycling processes like glass or metal, because they cannot be made into the product with same quality, and end up being harmful because of their chemical properties and how they were made in the beginning (Koushal et al., 2014; Ningwei et al., 2009; Plastics Europe, 2016). To attain the desired products, more chemicals and additives are added to the recycled products (McDonough and Braungart, 2002). These additives, used for recycled plastic packaging, mean that plastics often contain a complex blend of chemical substances (DTI, 2014; Li et al., 2009; Satapathy, 2016). Thus, plastics are not always pure products but mixed with resins and waxes, plasticizers, oils, etc. (EC, 2018b; Lahimer et al., 2017). The risk of contamination increases when packaging is made and products are packed outside the EU (Stenmark et al. 2017). Traceability of chemical additives of plastics composition can be a significant barrier to further cyclic use of packaging because they can harm the quality of the recycled material. That is why it is very important for chemical engineers, packaging manufacturers, processors and others to share information about chemicals and processes in packaging. Recycling also becomes complicated when co-extrusion or lamination combines multiple materials.

The broad stream of recycled plastics cannot compete with virgin plastics so far. The plastic packaging chain is currently a dominantly supply-led market: the plastic packaging material is recycled, regardless of the demand for these recycled plastics. And although the demand for recycled plastics for packaging is certainly rising, this is not enough to offset the demand for the primary plastic materials (KIDV, 2017). According to

Villanueva and Eder (2014), the main challenge for the plastics recycling industry is that plastic processors require large quantities of recycled plastics, manufactured to strict specifications, which must remain at a competitive price in comparison with that of virgin plastic. Price is the key determinant in the demand for recycled plastics (European Parliament, 2017).

Paper and cardboard packaging. Paper has always been a significant source of raw material. Paper and carton board packaging are easily recyclable. However, paper packaging cannot be recycled indefinitely because fibres get shorter and weaker each time when they are recycled. Some virgin fibre must be introduced into the process to maintain the strength and the quality of the fibre. Recycled paper and board often contain mineral oils and many other substances which may migrate at levels exceeding safe thresholds. Paper packaging may incorporate a significant number of chemicals, added mainly during the printing and converting processes (i.e., binding, gluing, laminating, labelling), before the product reaches the consumer (Pivnenko, 2016; Smith, 2011).

Glass packaging. Glass packaging is close to 100% recyclability and can be recycled endlessly without significant loss in purity or quality. It is possible to substitute for up to 95% of raw materials. The specific quantity of recycled contents depends on technical performance, consumer acceptance, or colour of glass. Making recycled glass products from cullet consumes by 40% less energy than making new glass from raw materials because of the lower temperature needed for the process. Glass can be safely reused, because chemicals from glass do not migrate. Glass containers have a low rate of chemical interaction with their contents because they are made from natural and stable materials such as sand and limestone. Thus, glass recycling is a closed-loop system, creating no additional waste or products (Padmalatha and Shresta, 2016; West, 2015). Nevertheless, there are some problematic issues, such as increase of heavy metals concentration, even with glass packaging recycling (see section "Regulations on hazardous substances").

Metal packaging. Metal packaging is the perfect example of the circular economy. Metal packages are

infinitely recyclable without loss of quality and there is no "down cycling" of materials; they enter the material-to-material loop (PRAG, 2009). Metal recycling does not necessarily require the addition of primary material or chemical additives to enable the basic material function and properties (Metal Packaging Europe, 2017). Metal food packaging, e.g., aluminium, can continue almost indefinitely. However, untreated aluminium surfaces are prone to oxidation which can cause some loss of material during recycling (Geueke et al., 2018).

Composite packaging. Although individual components that composite packaging is made from may be technically recyclable, the difficulties in sorting and separating the material, for example, of laminates and metalized films, preclude recycling in real practice.

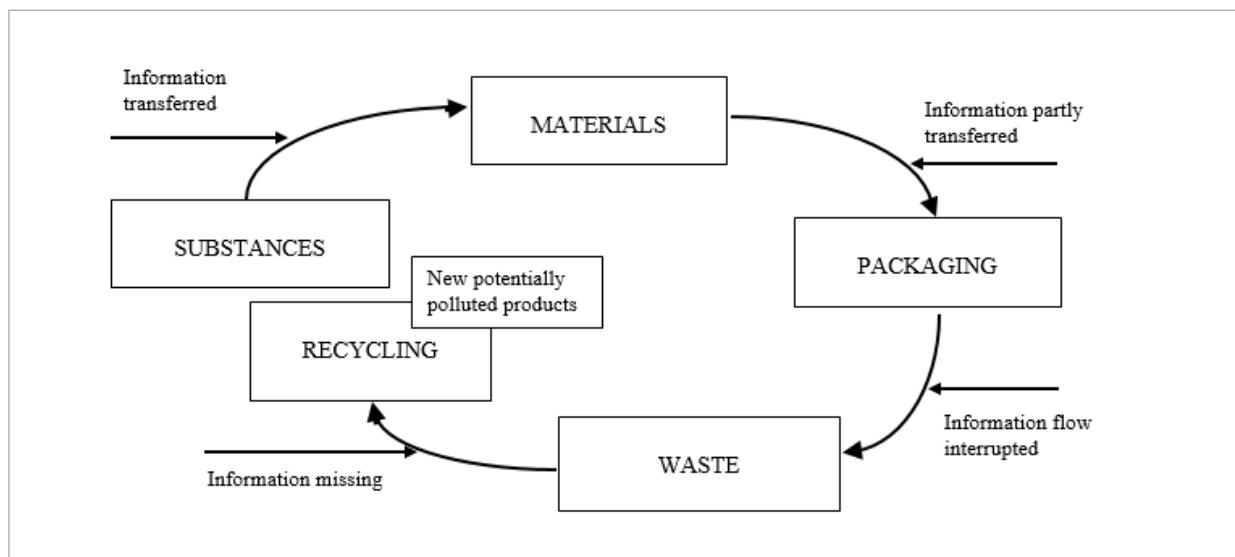
Regulations on hazardous substances

When concentrating on turning waste into resources, increasing resource efficiency, and closing the loop in the circular economy, considerable attention needs to be paid to the implementation of the recycling process for all waste streams with regard to chemicals that they contain. For packaging, there are regulations that require the presence of certain hazardous substances in packaging materials and their components be minimised to protect consumers and workers, and reduce environmental emissions.

REACH Regulation (Regulation (EC) No 1907/2006) is the main EU law on chemicals, which sets ambitious chemicals safety standards. Among other, it sets requirements for communication in the supply chain regarding the environmental and health risks posed by substances. Nevertheless, neither REACH nor other legal acts and existing practices ensure that information on hazardous chemicals is properly passed along the entire material cycle and potential subsequent life cycles (Fig. 2). When the information chain gets broken, this results in technical and financial problems for recyclers, lost trust in secondary raw materials, and in potential for contaminated products, causing health and environmental concerns, entering the market in the new cycle (Bernard and Buonsante, 2017; EC, 2018b; Janssen et al., 2017).

Fig. 2

The packaging supply chain circle with information missing about hazardous substances in packaging material



A special attention is given to substances of very high concern (SVHC). A number of measures encouraging substitution are applied to these substances, such as an authorisation procedure, or a requirement to provide information on SVHC substances in articles. If a waste flow contains SVHCs, it is more difficult to develop the recycling process (Janssen and Broekhuizen, 2016). It is still very hard to separate waste which contains SVHCs from SVHC-free waste streams in an early phase of the waste recycling process (Villanueva and Eder, 2014). These substances may be present in products sold before the restrictions applied. Some of them have a long lifetime, and therefore chemicals of concern can be found in recycling streams. Various measures are currently being developed to help identify SVHCs more easily, such as guidelines (Janssen et al., 2017 and Leeuwen van et al., 2017), or a new database on the presence of SCHCs in articles to be established at the European Chemicals Agency, as foreseen in the revised Dir. 2018/851.

In the packaging sector, important documents are Packaging and Packaging Waste Directive (94/62/EC) and the Standards (EN 13427:2004; EN 13428:2004; CEN/TR 13695-1:2000). They determine the level of chemicals used in packaging and provide limits for four

heavy metals in packaging material composition applications (Pb, Cd, Hg and $Cr(VI) \leq 100 \text{ ppm}$) (Chem Safety, 2018; Varžinskas et al., 2016). A packaging supplier must ensure that necessary measures have been taken to limit the level of heavy metals and, if possible, to further reduce them in accordance with CEN/TR 13695-1:2000 methodology, as well as the level of all hazardous substances or mixtures as specified in EN 13428:2004 and CEN/TR 13695-2:2004. However, when the Directive was adopted in 1994, practice showed that in many plastic crates, plastic pallets and glass that were on the EU market, heavy metals, due to production or technological reasons, were higher than the permissible 100 ppm limit (Lebedys et al., 2015). Therefore, exemptions have been granted to these types of packages which are in closed packaging systems and the 100 ppm limit is to be concerned by the derogation (2001/171/EC; 2006/340/EC). Studies by Jenseit and Gibbs (2015) showed that the negative environmental impact from extracting heavy metals from the plastic and treating heavy metals exceeded the environmental impact by allowing the heavy metals crates and pallets to be reused and recycled under strict conditions. A similar situation is with glass packaging. Experience has shown that there is a specific problem in the glass

sector, as recycled glass is contaminated by glass material containing high quantities of lead (2001/171/EC). According to the EN 13427, a Declaration of Compliance has to be provided for packages confirming the compliance with requirements related to the presence of heavy metals, and also to substances hazardous for the environment, having in mind the end-of-life treatment, when packaging goes to incineration or landfilling. It needs to be noted that until now, there have been no investigations on how much precise information is provided by manufacturers of packaging and packaging components in this declaration.

An important group of packaging is food packaging (food contact materials, FCM). Recycling of food packaging waste into new food packaging presents particular challenges (Geueke et al., 2018). A strict legal system applies to FCMs because they are intended to be brought into contact with food and are directly related to human health. The key document for this waste group is Regulation on Food Contact Materials (EC) No 1935/2004. It sets up a general safety requirement applicable to all FCMs, and envisages a possibility for the adoption of specific safety requirements for seventeen FCMs. So far, such requirements have been adopted only for four FCMs: plastics (including recycled plastics), ceramics, regenerated cellulose, and so-called active and intelligent materials. Where specific requirements have not been adopted at the EU level, the Member States can adopt such measures at the national level. Some have done so, but the regulations vary in terms of their scope and level of protection. FCMs regulated by national legislation include such widely used FCMs as paper and board, metals and alloys, glass, coatings, silicones, rubbers, printing inks. EU regulations on food packaging require the same level of safety for chemicals migrating into foods for all recycled and virgin materials alike (ChemTrust, 2016; Karamfilova, 2016; Simoneau et al., 2016). Specific measures in case of FCMs are directed not only at materials, but also at hazardous substances directly, restricting or prohibiting their use, such as vinyl chloride monomer, nitrosamines, and BADGE, BFDGE and NOGE.

Assessment by the European Parliament has demonstrated that in spite of a solid legal basis on FCMs,

regulations do not go far enough and contain holes (Chem Trust, 2016; Karamfilova, 2016). Finding hazardous substances in various food packages confirms a need for further actions. Examples were found to contain such hazardous substances as bisphenol A, phthalates, perfluorocarbons, nonylphenol, etc. in various types of packaging (paper and board packages, pizza boxes) during a Danish study, or mineral oils in Germany (Danish Consumer Council, 2015; Food Packaging Forum, 2015).

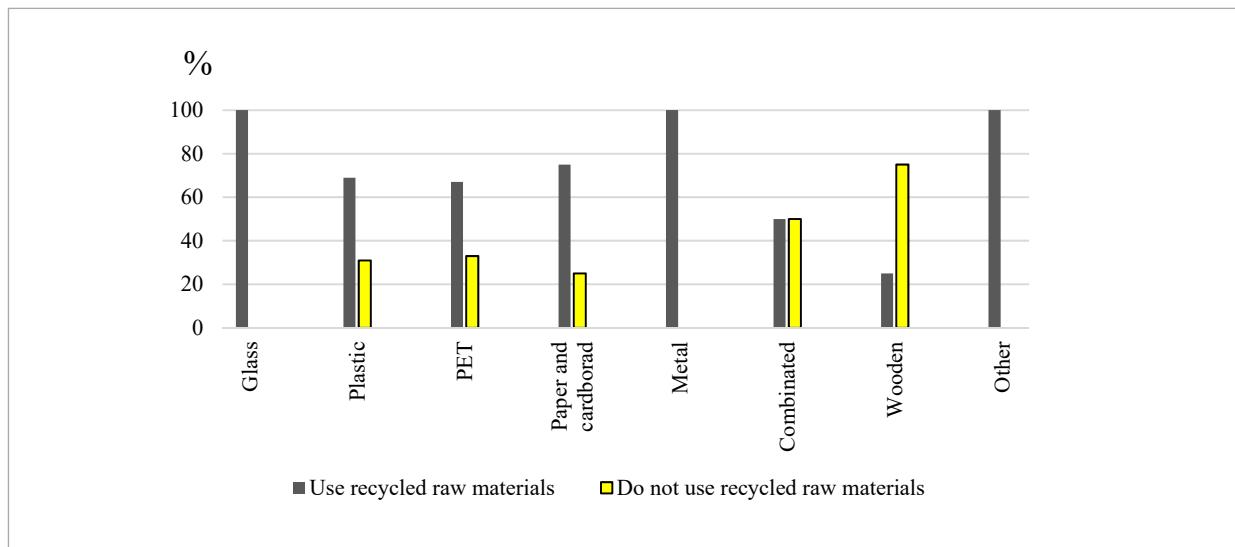
Using recycled raw materials in packaging production

The survey of packaging manufacturers in Lithuania revealed that 60% of those who participated in the survey use recycled raw materials in their production processes. Nevertheless, the percentage varied for various packaging materials. It was 100% for metal and glass packages, as well as for "other" packages. It needs to be noted that the group of "other" packages consisted of one single company, producing "eco-friendly textile bags", as they call them, and therefore it is a specific and not representative case. For paper and cardboard packaging, 75% of manufacturers confirmed the use of recycled raw material. Manufacturers of plastic and PET packaging were divided into two separate groups. However, it appeared that there was no difference between PET and other plastics. The share of those who use recycled raw materials made 68% in both cases. In the case of composite packaging, companies using recycled and only primary materials were equally divided: 50% and 50%. Surprisingly, there were only 25% of wooden packaging manufacturers who made it from the recycled materials. See Fig. 3 for all the results.

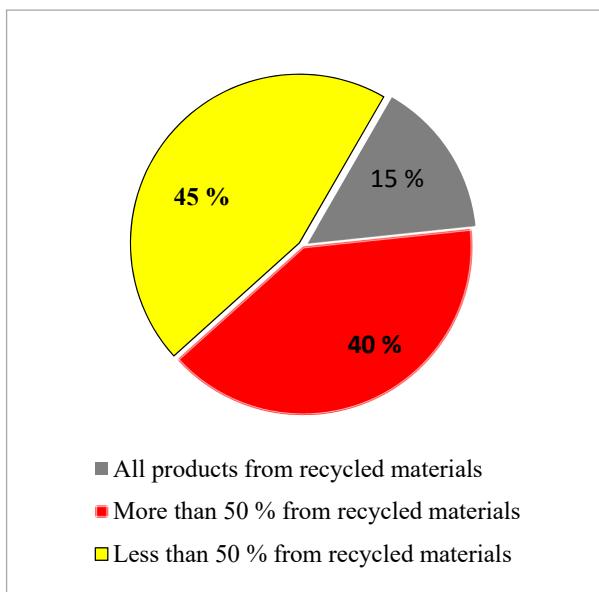
Only a small proportion, 15% of manufacturers, produce their entire production from recycled raw materials. This means that manufacturers of packaging, who replied that they were producing from recycled materials, in fact also had packages produced from primary raw materials only. The proportion of those who produced less than half and those who produced more than half of their production using secondary raw materials was similar, 45% and 40%, respectively (see Fig. 4).

Fig. 3

The share of manufacturers who use recycled raw materials in the production of packaging (by packaging material)

**Fig. 4**

Part of the packaging production that is made from recycled raw materials in companies (%)



The companies listed the following reasons which encouraged them to use secondary raw materials: willingness to be competitive with other companies,

environmental policy in the company, a possibility to use it as a marketing measure, and trends in legislation. Lithuanian companies are facing problems with implementation of the circular economy concept and manufacturing packaging from recycled materials. In the survey, manufacturers of packaging for recycled materials revealed several problems: unclear composition of recycled raw materials, insufficient amount of secondary material, and rising prices for secondary raw materials. We can conclude that the traceability of harmful substances in the supply chain is inadequate and the requirements for safe secondary raw materials are too low to produce a larger quantity of packaging from a secondary raw materials free from hazardous chemical additives to human health and the environment.

Results obtained on Lithuanian companies correlate well with statements of the Netherlands Institute for Sustainable Packaging that despite of rising recycling of household waste of plastic packaging in the Netherlands, at the same time, costs are rising and quality is not yet high enough to compete with virgin raw materials. They come to the conclusion that the objective of a closed loop for plastics, both economically and in terms of raw materials, is not in sight yet (KIDV, 2017).

These examples show that further success with implementation of the circular economy concept in the packaging industry requires thorough general guidance of companies and clarification of numerous questions related to technologies and their advancements, safety issues of recycled material use, economic justification and other.

Conclusions

- 1 Circular economy documents formulate goals and strategic targets, such as recycling of used packaging materials placed to market and closing circular economy loops (reuse, recycle, renew) at 100%, but recommendations and guidelines on how to implement them are still under the preparation. As a result, packagers and processors are facing problems which they cannot solve on their own due to limited knowledge, information and resources they possess.
- 2 The increase in the share of recycled materials in the production of packaging, especially for food products, is directly linked to the information on composition of the material to be used. This information can be found by tracing the entire packaging supply chain before it is recycled and analysing the flow of chemicals. How-
- ever, a complicated traceability process of hazardous substances in packaging materials presents a problem for waste operators seeking to increase the share of recycled materials in the packaging production.
- 3 Analysis of legislation related to packaging with reference to circular economy shows that until now regulations do not go far enough and contain certain holes. Neither REACH nor other legal acts and existing practices ensure that information on hazardous chemicals is properly passed along the entire material cycle and potential subsequent life cycles. The current state of traceability of harmful substances in the supply chain is inadequate for proving which volume of secondary material is still safe to use and stays within limits set by REACH regulation and other documents.
- 4 Special attention at the legislative level is given to recycled materials which are used for food packaging. No specific requirements for some FCMs have been adopted at the EU level; therefore, some EU Member States adopt such measures at the national level, and the laws and regulations may vary from one country to another.
- 5 To stimulate the implementation of circular economy and close the material loops in packaging, the limits should be set for contamination with extraneous materials of the raw material used for recycled packaging production.

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