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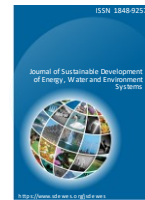
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Economic Viability of the Deposit Refund System for Beverage Packaging Waste – Identification of Economic Drivers and System Modelling

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ABSTRACT

A deposit refund system of management of packaging waste offers a possibility to ensure sufficient quantities of secondary materials for the production of fully recycled packaging. Such market-based systems have proven themselves with large amounts of collected and recovered waste packaging with a small amount of impurities, but they tend to exhibit high costs if the system is not optimized. Ideally, such a system should operate on a non-profit basis. Therefore, economic drivers are identified and economic analysis, as well as modelling of deposit refund system, is conducted to determine overall system costs. Model is used on the case study of Croatia, in which the system is designed from the beginning, not considering previous developments but the most efficient system design elements. Regarding different costs and revenues of the system, it was calculated that the average fee that producers and importers of the beverage packaging pay for the operation of the system, in an efficient deposit refund system in Croatia would be 1.11 cents EUR per packaging unit (with the return rate of 85%).

KEYWORDS

Deposit refund system, Primary waste separation, Packaging waste, Recycling, Waste management system modelling, Economic analysis.

INTRODUCTION

A worldwide steady increase of the waste amounts is a direct consequence of economic growth without taking care for the disposal of the products after their final use, which is particularly evident in terms of putting cheap but not durable products on the market. The consequences are significant, and the problem of municipal waste has been recognised as a priority environmental problem worldwide. The answer to the current situation involves two main groups of activities: remediation of the consequences of previous unacceptable waste management in order to reduce the intensity of further harmful effects on the environment and human health, and the establishment of new waste management systems which include measures for the prevention of waste generation and stipulate mandatory procedures with individual waste categories all in order to separate the individual waste streams and to reduce the amount of the residual mixed municipal waste.

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The European Union (EU) has been importing between 20% and 30% of all resources (raw materials and energy carriers) – around 42% of natural gas, 56% of coal and 88% of oil, 50% of copper, 85% of bauxite, 89% of iron ore and 100% of a wide range of hi-tech metals [1]. However, the European economy simultaneously loses significant amounts of potential secondary raw materials that are a part of waste streams and are currently ending up in landfills. In 2016, total waste production in the EU amounted to 2.3 billion tonne (t), of which 1.1 billion t [2] were not reused or recycled and therefore represent a loss for the European economy. By this, the EU misses the opportunities to significantly improve resource efficiency and create a wider circular economy. It is estimated that an additional 600 million t of waste could have been recycled or reused [3].

The European Union's goals in the field of municipal waste management, as defined in various directives and plans, prescribe an increase of the recovery and recycling rate for municipal waste to 50% by 2020, and 65% for the period up to 2035 [4]. At the same time, the share of packaging waste recycling in the EU (according to modified goal in 2018 in plans of the circular economy [5]) has to rise to 70% by 2030, which will be difficult to achieve without efficient and comprehensive separate collection and material recovery (recycling) of packaging waste. In addition to preserving resources and protecting the environment, such an approach also offers a great potential for development of economic activities through the development of economic branches based on the management and recovery of different types of wastes.

Deposit refund systems

Modern deposit refund systems (DRS), also known as deposit return systems, are recognized today as a very efficient instrument to reduce littering and improve recycling. Although limited to beverage packaging, deposit refund systems exhibit a unique ability that they could ensure very high levels of collection (return that regularly surpasses 90% and sometimes even above 95% [6]), but even more important is that they enable sufficient supply of high-quality feedstock for recyclers, which leads to high levels of recycling (especially in closed loop recycling, like bottle-to-bottle). The EU also gave a special attention to deposit refund systems in a recent EU Plastics Strategy [7], where national and regional authorities are encouraged to put in place well-designed deposit systems, among other measures, for improving the economics and quality of plastics recycling. Consequently, the EU directive from 2019 [8] recommends establishing deposit refund schemes for products listed in Part F of the Annex (beverage bottles with a capacity of up to 3 L, including their caps and lids).

Dating back in 1984 with the start of the first modern deposit refund system in Sweden [9], deposit refund systems are now spread worldwide with about 40 implemented DRSs, of which 10 are in the EU and EEA countries: Denmark, Estonia, Finland, Croatia, Iceland, Lithuania, Norway, Germany, Netherlands and Sweden, while several more countries in Europe are currently considering introducing it. The deposit refund systems are also in place in the United States (10 federal states), Canada (12 provinces), Australia, Israel, and the island states of Micronesia, Kiribati and Palau [10].

In essence, the deposit refund system embodies two main instruments: a tax on the purchase of a product in a packaging, and a subsidy on separate collection of the same packaging after using the product. It is generally accepted that DRS is an efficient scheme for packaging waste collection entailing high environmental benefits [11], but there are some doubts about and critics on economic viability of such systems [12] which effectiveness and their implementation efficiency is directly related to the context they are enforced in [13], as well as to the type of waste/products which are covered by this type of a system [14]. In some countries where DRS were introduced, they sometimes generate excessive costs (for industry, government, or taxpayers) and, in rare cases, it could even lead to complete failure (in 2017 twelve months voluntary trial to introduce DRS (although no household waste was involved) ended unsuccessfully [15]) or near bankruptcy of such systems (usually transient issue, more probable in initial years of implementation).

The legitimate question put here is if the environmental efficiency and benefit should be maintained at any cost, or only if such schemes could operate on sustainable grounds. So, the main research question laid is how to make such systems economically sustainable or even self-sufficient, and if that is even possible taking into account a complexity, interdependency of the subjects, and the costs generated in each phase of the DRS. Additional question is if the cost of packaging waste management in the DRS that mainly burdens the industry (producers, importers) can be minimized but still enabling the system to operate, even on non-profit grounds. The fact is that the deposit refund system will always entail spending for one of the market actors [11], most often for the industry.

Research aims

This research encompasses identification and analysis of cost and income drivers of DRS and economic modelling of DRS system. This way complexity of DRS system is explained, and model is further used for analysis of the case study DRS system. The case study analysis is built upon the case of the youngest member of the EU – Republic of Croatia, and shows how such system can be organized. In that sense, the DRS will be designed as done from scratch, not considering the present organizational layout. Implementation of DRS in Croatia is more challenging because of its geographic characteristics (elongated, long and narrow crescent-shaped, with two more densely populated regions separated by a mountainous area and a very indented coast with many islands) as well as influence of tourism (large difference in population distribution and beverage consumption/waste packaging production between seasons). Thus, the work presented can serve decision-makers in other countries and regions which do not have yet implemented such systems but are discussing that possibility to take into account all drivers that influence economic sustainability of DRS, especially the systems which need to be implemented in countries with similar peculiarities. This way the DRS system, which represents a market-based instrument to address externalities [16], can be better understood, especially from the economic point of view. As a form of extended producer responsibility system [17], it can well realize internalization of external diseconomy [18]. Through stipulation of financial responsibility of the producers, DRS systems can help to the success of environmental policies based on extended producer responsibility [19] and provide support to the implementation of the waste management hierarchy [20]. At the same time, due to the flexibility and economic stimulation of deposit, it can effectively recover the environmental pollution that is difficult to regulate (such as illegal waste disposal [21]).

The deposit refund system setup may vary sufficiently according to legislation, ownership structure, system processes and technical logic [10], but the core of the DRS in different countries is the same, especially from the consumer perspective [18]. The principle is well known: consumer pays product price plus deposit upon purchase of the beverage product and reclaims the deposit, when returns the empty container. In traditional and well-functioning DRSs, retailers' motivation is essential as they are very much involved to provide maximum collection points density and convenience for the consumers, that guarantees high return rates. So, these are two very important factors for DRS which are discussed later: convenience for consumers and high coverage of collection points.

Since the standard deposit refund systems embody the principle of producer responsibility, all the stakeholders in the chain (beverage producers, importers, but also retailers who help to put huge quantities of beverage packages to the market) counted as responsible for the collection of such packaging, are considered as polluters. Therefore, majority of bodies managing the deposit refund systems (the central DRS organizations) are formed and owned jointly by the industry and retailers (in different ownership shares). Although for the central DRS organization being under producer and retailer control, usually means it is very much efficiency orientated in all aspects, from the other hand it could be affected by industry and retailers' different interests. In a government owned and run DRS organization (such as in the case study DRS) there is possibility to make decisions quicker and take into consideration more

the environmental aspects rather than business aspects. But it should not matter, if DRS organization is owned by industry or government, it is clear that environmental and financial aspects both have to be considered and balanced to guarantee DRS sustainability on a long run [22].

The literature review shows that there is a growing number of research papers and studies on DRS mainly of an organizational [23], technical and environmental [18] side, as well as others that are case dependent [24] and can be even more case-oriented by analysing system from a standpoint of only one specific type of packaging [25], at the same time there are quite limited sources dealing with the economic aspects [26] and financial efficiency of DRS [27]. Fundamentals of an efficient DRS were discussed by Numata [26], who minimised negative impacts on suppliers, and Walls [21], who examined DRS in theory and practice.

There are also country-specific works, the most recent for Latvia that is preparing to implement a DRS from 2022, of Dāce et al. [28] in which they assessed sustainability and economy of Latvian DRS, while in [29] it is concluded that care must be taken that economic costs do not outweigh the environmental benefits. More recent analysis of Latvian system is given in [30], where it is found that introduction of deposit refund system requires substantial, not only financial, but also organisational resources which can be alleviated with implementation of deposit system after other separate waste collections systems are already in place, and [31] which emphasised the importance of paying attention on system cost and reduction of payback period. Different authors reviewed DRS in other countries, e.g. the work of Growth [32] in which he analysed the German DRS. Furthermore, in [33] Numata optimized the DRS considering allocation of unredeemed deposits, while in [34] he discussed the policy on DRS in Finland and Norway. There are also other documents on this topic, like the economic analysis of introduction of DRS in Slovakia [35], a social cost-benefit analysis of Danish deposit system [36] and cost-benefit analysis of deposit refund program in Israel [37], but they do not give sufficient emphasis on economic issues. Other researchers focused only to certain packaging materials in DRS, like aluminium [38], PET [25], or glass [39]. Compared to other studied countries, the case study represents a more challenging country for implementation of DRS due to its geographical features and changes in population density due to tourist migration and thus represents a case study of implementation of organizational, transport, and thus economically more complex DRS.

METHODS

Establishing and managing DRS tend to exhibit high operation costs if the system is not optimized and run properly. Ideally, the deposit refund system should operate on non-profit basis, which is in practise not often the case. In this work, system economy is modelled on the presumption of operation of the system on the positive zero yearly cash flow, in a sense that sum of system incomes and expenses gives zero profit at the end of the year. On a basis of this approach, a variety of waste management systems are modelled [40], and their overall cost is tracked [41]. While all other economic flows are modelled as a function of system configuration and integration requirements, a fee that producers and importers of packaging need to pay for system operation is adjusted to achieve defined equality – its minimum required value is tracked to operate the system economically, on a positive zero.

As the system is modelled from beginning, all economic flows are also modelled, thus this calculation can be used for modelling of economy of any given system/country, only with modifying input data and adapting to local conditions. To do that, all the factors influencing investment in and efficient operation of a DRS are identified and explained.

Definition of system boundaries

To model any system, it is important to clarify and understand some key details upfront, which represent key drivers for DRS system modelling as well as tracking of corresponding

economic flows. To enable the use of developed model in different situations, these also need to encompass possible integration particularities that can be expected like population distribution, distribution of stores, as well as time/periodic population migrations that are mostly related to tourism.

Defining the packages in the deposit system. The following factors influence the investment size, and what the refund deposit system for beverage packaging encompasses:

Beverage packaging type, which is encompassed by the deposit system or planned to be added shortly: plastic bottles, aluminium cans, steel cans, glass bottles (both disposable and refillable glass bottles), beverage cartons (not yet recommended until the technology evolves);

Products, which are considered as a part of deposit system: beer, water (carbonated and non-carbonated), soft drinks (carbonated and non-carbonated), juices and juice concentrates, wine, spirits, dairy products (milk, yoghurt, etc.). Dairy products are usually not recommended because the hygiene requirements of the stores are unknown, as well as no satisfactory solution for implementing opaque PET recycling possibilities. At the same time, if opaque PET gets mixed up with another PET then it cannot be quality recycled;

Market share per pieces and different packaging types – it makes the most economic sense and is most efficient if the share of CAN aluminium is the largest, because it can be easily recycled and its residual value is high. On the other hand, collecting and organising recycling of glass is the most expensive, because pressing/crushing glass on site at the stores (some modern Reverse Vending Machines (RVMs) have this capability) is still rather uncommon (mainly due to high noise level, possible glass dust and work safety related problems). Residual value of glass is also the lowest;

Number of inhabitants and population density across the county/country (i.e. what is the level of urbanisation and what is the number of inhabitants per store in low-density areas). Also the number of shops per packaging located on the islands and their service can play an important factor;

Division of stores according to size and their locations across the country by rules of which stores have to provide DRS collection point. As well as the number of shops/packages located on the islands and their service;

The number of tourists and their seasonality, which is very important issue for touristic countries.

Market size and packaging mix. A most important factor in the calculation of the size of the investment in DRS and in planning of handling (recycling) centres is to understand the quantity (number) of packaging, covered by DRS, that is put to the market. This number influences waste generation the most, and needs to be defined/estimated as accurately as possible. Other influencing factors that can influence waste generation are changes in data quality, changes in waste generation due to socio-economic influences, system efficiency or changes in the number of citizens generating waste [42]. To enable modelling of the last factor, as well as changes due to tourism related migrations, it is good to express waste generation per capita. Comparison of amounts of collected packaging waste per capita, as well as number of tourists, for three EU countries is given in **Table 1**.

Table 1. Amount of packaging waste per capita [43]

Country	Mass of packaging waste per capita [kg PC]*	No. of tourists [10 ⁶]
Croatia	48.2	17.0
Lithuania	110.7	1.5
Estonia	173.1	2.1

* kilogram per capita

Packaging collection and collection structure. Another side is represented with a quantity of collected packaging per type of packaging through DRS system. It is different from put to market value by the system efficiency. In the case of DRS, usual system efficiency ranges between 80 and 90% [44].

Also, as some economic flows are connected to the mass of the packaging, and other to a number of collected packaging, it is important to calculate each value. Depending on available data, unknown values can be calculated using average mass of average mass of packages. Average mass of usual packaging that can be found as a part of DRS are measured and amounts to ca 44 gram (g) for PET, ca 13.5 g for CANs and ca 360 g for glass bottles.

In the planning phase of a DRS, it is very important to assess the collection structure, meaning if packages are collected with RVMs and are counted and compacted in the shop or collected manually. To ensure DRS transparency, each collected package has to be identified by EAN code, which means that all manually collected packages or non-compacted packages should be counted by DRS itself or its appointed and controlled third party. As the RVMs decrease DRS operating costs, as they count and compact the packages immediately after acceptance, it is logical that use of RVMs should be motivated through the system because its usage entails bigger investment cost for retailers. The retailers are obliged to invest into the deposit system infrastructure, including package return rooms and the RVMs. DRS should compensate the initial investment according to the accepted packages over time, but the initial investment obligation will remain with the retailers. Many retailers would delegate the package return solution to third parties (service providers). It is important to note that even in such case, the retailer would still remain responsible in front of consumers.

Through the comparison of the statistics in different countries with deposit systems (**Table 2**), a suggested number of inhabitants per one RVM can be defined, and it ranges between 2,500 and 3,000.

Table 2. Number of RVMs per inhabitants [22]

Country	Population [10 ⁶]	No. of RVMs with compaction	Average inhabitant/RVM
Norway	5.20	3,700	1,405
Denmark	5.60	3,000	1,867
Finland	5.44	4,000	1,360
Sweden	9.59	5,000	1,918
Lithuania	2.96	900	3,289
Estonia	1.33	500	2,650
TOTAL	30.12	17,100	1,761
Croatia	4.15	1,100	3,773

When packaging is collected it is transported to handling (counting/processing) centres. These centres receive packaging from surrounding areas and count it, sort and compact. Thus, they need to be positioned and dimensioned taking into account packaging waste generation/collection distribution and quantity, including sessional changes.

All of these steps lead to data transparency which is an important basis for the deposit system and represents the foundation for its controlling. Controlling helps to analyse and monitor possible frauds, including fraud by consumers or workers and cross-border risk. Considering the data volume (basically every sold and returned package is in the database) a DRS must be capable of using the so-called big data analysis.

Economic structure

Economic model of DRS is as complex as is the system itself. In the following subchapters operating costs of each part of the system are separately modelled and discussed, as well as system revenues.

Operating costs. In the countries with deposit refund system, a standard practice is that the system covers direct costs which are in a relation with the collection of packaging. This practice can be different in different EU countries, but a general principle is the “polluter pays” principle in which the polluter is responsible to cover the costs of collection of (beverage) packaging it puts to the market and its recycling. Therefore, the importers and producers have to pay the expenses of operation of the deposit refund system through the so called recycling fee. The contribution of retailers is that they accept the packaging and must not put their usual profit margin to that service [45].

The main costs of the DRS are:

- Retail handling fee,
- Costs of transport and logistics,
- Handling (counting, recycling) centre costs,
- Cost of administration,
- Depreciation on investment.
-

Retail handling fee (RHF). It should cover the direct costs for the stores arising from the collection of packaging (included in the deposit system) returned by the consumers and their delivery to the DRS [22]. In majority of DRS countries, there is agreement that the DRS should cover the direct costs of the packaging with deposit marking (some indirect costs for producers and importers are discussed later), while the retailers will not profit from that activity. The difference can arise if the example store, upon which the calculation of *RHF* is made, is the most effective one or is it a store with an efficiency average over the whole country. Since the retail handling fee is the largest cost in the DRS, it must be agreed with the retailers and other stakeholders of the DRS, and so calculated based on correct basis and at an effective level [22].

Usually, *RHF* is divided in two fees, an automated (RVM) retail handling fee, and a manual reception *RHF*. The RVM *RHF* can vary based on the packaging material since the cost of accepting different materials can be different. Apart from collecting packaging at retail stores, DRS can offer its collection service of packages with deposit markings also to Horeca[†] sector companies. Companies in that sector usually pay only deposit, so there is no need for an additional fee like the one that is paid to the retailers (*RHF*) for collection in stores. The difference is that retailers must enable the collection of the packages marked with the deposit marking from the consumers and invest into it, while companies in Horeca sector collect such packages as a result of their own activity (serving drinks to clients) and they do not need to organize collection of packages from the consumers [46]. So, for the Horeca sector it is useful that the DRS takes over their packaging relieving them from that burden and at the same time paying them value of the deposit.

Based on the review of DRS in different countries [45] the fee for automated acceptance (via RVM) of packaging for the retailers goes in range from 1.7 to over 4.0 cents EUR per package/unit. This is clearly shown in **Figure 1**, where handling fees of DRS systems in five EU countries are presented. Also in **Figure 1**, the difference in the handling fee amounts for the automatic acceptance compared to the manual can be seen. If the relative (percentage) differences in the amount of automatic handling fee (with compaction) is compared to the manual acceptance, it can be seen that most of these countries have a much higher ratio of these

[†] Horeca - hotels, restaurants, catering

fees (ranging between 20–302%). The larger (relative) ratios contribute to investment in the purchase of RVMs and ultimately greater system efficiency.

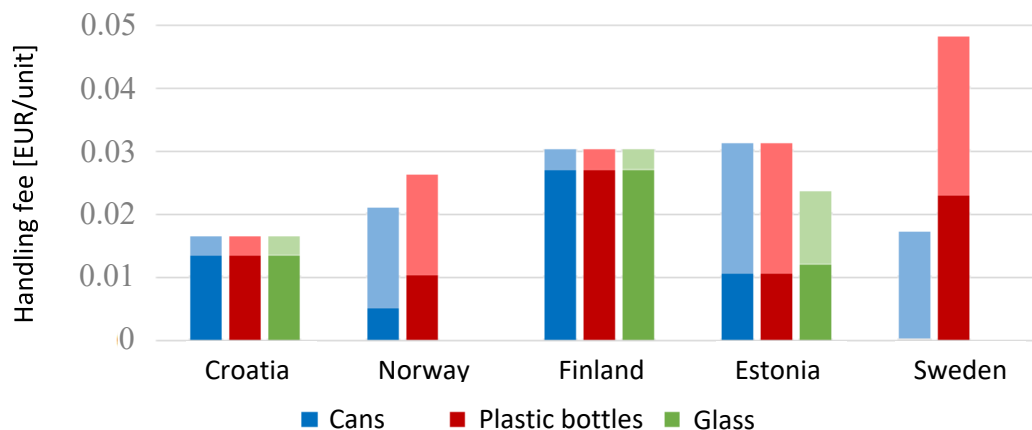


Figure 1. Handling fees in some countries (darker colours indicate the fees for manual acceptance while lighter colours indicate the fees for automatic acceptance)

As it is said, these fees need to cover retailers' costs associated with collection of packaging returned by consumers and its handling, regardless is it manually collected or via RVMs.

If the presumed volume of returned packages with deposit marking per month crosses 10,000 packages, then it would make sense for the store to invest into an RVM instead of accepting packages manually. The market offers RVMs with varied sizes and speeds. The optimum return of a regular, medium size and full compacting (PET/CAN) RVM is between 40,000–60,000 packages per month. There are (market) solutions that could increase that number even further due to the fact that such RVMs do not have to stop operating, continuing to accept the packages, even when being emptied. The characteristics of the country and on which days and at which times the consumers go to the stores must be considered (it can usually be presumed that the packages are returned before shopping). If the number of returned packages exceeds the optimum amount, the store can always add an additional RVM.

When packages are collected with RVM deposit system will cover the costs of:

Investment in and installation of RVM – the retailer should cover the investment into RVM, but the DRS will cover to the retailer that investment cost over time through *RHF*. The usual method for dividing RVM investment into *RHF* is to use the RVM lifespan in years and divide it with the average number of returned packages per year or use the RVM lifespan per accepted packages as the basis. In this case, it does not exactly matter if the RVM accepts 10,000 or 100,000 packages a month (replacing the RVMs with new ones will simply be faster). It is recommended to implement such sort of RVM that can press packaging as much as possible (compaction) immediately after the packaging is identified and accepted. This reduces the possibilities of manipulation and fraud by the RVM personnel (e.g. inserting one package multiple times). The packaging material with the lowest value (and the highest cost of collection) for the DRS is glass. This is because reception and later processing is difficult, while the market value of the glass as the secondary material is very low (the lowest of all packaging materials in DRS). There are RVMs on the market that are capable of crushing the glass packages after the package is identified and accepted, so maybe it is worth to analyse investing in such machines. The benefits of crushing the glass packages on the spot (in store) are that the possibility of multiple return (i.e. fraud) is eliminated and that logistics and processing is simpler and easier which reduces the costs (less volume transported etc.). If applying that, one should pay special attention to the work safety (noise and glass dust during the crushing, hygiene requirements, etc.). Also, it would be most convenient (cost-wisely) if there is a glass

recycling plant in a closer radius. Investment costs in RVMs can be defined as average cost per RVM machine or average cost per installed collection capacity. These costs are estimated at around 39,500 EUR per RVM or around 780 EUR per 1000 accepted units [9] (this and the following monetary amounts are net value, which means that VAT is added according to local regulations).

Cleaning and maintenance of RVM – these operating costs include consumption of electricity and needed materials (receipt paper, other), internet connection cost, cost of cleaning material, and maintenance and spare parts for RVM. Operating costs are on average 9% of investment costs per year [44].

Compactor – the cost of the compactor is separated from the cost of RVM since compactor lifespan is shorter than of RVM. That cost also includes the costs of replacement of the compactor blades as well as the additional electricity consumption of compactor. Compactor unit cost amounts to 2,460 EUR per compactor [44]. Also, it should take into account that in normal operation wear of compactor blades and other parts lead to the need for its replacement every 1.3 million units compressed on average.

Labour – this cost relates only to collection of the packaging with the deposit marking, and it includes: changing and emptying of the collection bags and/or containers at RVM, cleaning of the RVM as well as the package accepting room and client area. Time required to empty a full RVM device and storing the collected packaging waste in the warehouse is estimated on 5 minutes.

Space and utilities – the cost of the space (room) needed for reception of the packages (i.e. rent) along with utility costs (heating, lighting, water, waste, room cleaning). The space required includes the area for placement of the RVM and additional space for servicing the RVM, area for storing of packaging, and client area. If the package accepting room is in the same building with the store, then the rent of the premises is used as the basis. If the package collection is done in a separate building (e.g. in a special container facility located e.g. at the store parking) then the depreciation cost of the building is used as the basis. Usually, a total of 5 m² is required for the retailer to install the RVM device, of which 1 m² is in the retail (store) area [44].

If the volume of accepted packages is less than 10,000 per month, it is usually economically unreasonable to install an RVM, thus manual acceptance is a logical option. In the case of manual collection, cost structure is much simpler. Taking into consideration all previously said and with the assumption that collection is not done inside the store, the retailer only needs to ensure 2 m² of storage space on average [9]. Cost of this can be valued through the local rental cost for business/storage space. Only additional costs are associated with the need for additional man-hours for the packaging acceptance, management and deposit return to customers. The time required for a worker to accept an average of 30 units of packaging waste and temporarily store them is estimated at 90 seconds. The cost of this can be valued through the local average salary for this job type.

Transportation and logistics costs (TLC). They depend on different factors [45] such as:

Dedicated rounds for collection of packages with deposit marking – such special collection rounds have sense in densely populated areas, such as larger cities.

Collection of packaging during goods delivery (back-hauling) – such option is applied in regions which are scarcely populated having fewer stores, so it is possible to collect the packages after goods delivery.

Transfer stations – it depends on the size and characteristics of the territory of a country (e.g. if there are many small islands, mountain ridges or low populated areas) whether to include transfer stations into the DRS or not. If the transfer stations are located more than 100–150 km from the final destination they could be considered justifiable, according to the logistics companies, but if the distance is shorter, it is more reasonable to transport the packaging directly to the processing-counting centre (or recycling plant in the case of glass) after being

collected. The specifics of the companies offering the transport service, or the logistics solutions used by them must also be considered.

Packaging volume – the volume of packaging being transported is one of the key factors for cost efficiency of transport, especially if it includes uncompacted packages. In case of PET packages (bottles), the quantity of pressed packages is twice as large as the number of uncompacted packages, and in case of aluminium cans that difference is up to four times. Therefore, compacting packages in RVMs can decrease the costs of transportation and transportation packaging greatly.

Crushing glass packages on site – similar to previous point, the transportation of glass packaging is also demanding and generates large cost. Considering previously mentioned problems with the noise, dust and hygiene, it should be estimated if the benefits of crushing glass packages on site at the store (in RVMs) surpass the obstacles. If so, that would decrease the costs of logistics and recycling of the glass packaging significantly.

These costs are very case dependent and need to be modelled specifically for each specific case due to local specifics.

Another part of the collection infrastructure are the handling (counting/processing) centres used to further process the empty containers collected at the retailer (stores) and to prepare them for selling and recycling. In a modern counting/processing centre, the already compacted packaging (collected via RVMs having compacting ability) is further compressed in industrial presses into large cubes which are then sold to material recycling plants. When using non-compacting RVMs, or packages that are accepted manually, or collected from Horeca sector companies, empty containers will need to be counted to check the number collected by what is referred to as an industrial RVM (this is because the packages are not crushed, as in compacting RVMs, and so could be re-entered back into the system to claim back the deposit twice). The value of deposit and *RHF* is paid to the respective retailer depending on the amount counted. The packaging is counted based on the EAN code, which ensures that no deposit is paid out for packaging which is not included (registered) in the system, and for which no deposit was initially paid. The payment to the retailers for the deposit packaging that has to be counted by the industrial RVM, is done according to the data generation of such equipment. In the case of compacted packaging, the amount paid to retailers as compensation is based on the data obtained from the RVMs (at collection points, in stores).

Handling (counting/processing) centre costs (HCC). The most relevant are [45]:

The cost of rent of a building – it is also possible to own a building, instead of renting it, in which case the cost of depreciation is used for calculation of total cost, but in the first stage of establishing the DRS it is more convenient to rent the building. The reason for that would be that detailed data of the shares and quantities of different DRS packaging on the market will become better known after first few years. The average required area of the building is calculated to be around 54 m² per 10,000 units capacity [22].

Investment into equipment, the most expensive of which are the industrial counting machines, presses, processing lines, conveyors, and other equipment and machinery. These costs are estimated to 99,580 EUR per 10,000 units capacity on average [22].

Costs of utility and operational costs of handling such as water, sewerage, heating, ventilation, equipment maintenance and spare parts are estimated at 11% of investment cost [22].

Labour – labour represents one of the largest costs for counting/processing. To estimate the handling centre labour costs associated with handling and administration, the Trading Economics data [47] was used. This cost calculation assumes that activities of unloading of transportation packaging, counting of uncompacted packaging, and all handling activities until the packaging is baled and sold to the end-user are responsibility of the workers in the centres. The following aspects have a high impact on costs of labour [45]:

- Type of transportation packaging that is used. E.g., in Sweden, “bulk transport” is used, which means that a reusable container is emptied in a compactor-container truck, which can be easily emptied in the handling centre without the need for workers.
- Depending if the glass bottles are counted at the handling centre or whether some other method is used as a basis for determining appropriate compensation to retailers. For example, in Finland, the basis for payment to the retailers is the average glass container capacity, which was mutually agreed upon (this, however, allows deceiving the DRS). If there is no need to count the glass bottles, cost for labour and counting equipment are reduced significantly.
- Whether glass bottles are crushed at the retailer. In such case, the crushed glass bottles can be transported directly from the store to the recycling plant, which means the material does not need to go through the handling centre at all.

Need for manpower in counting/processing can be estimated to 40 and 55 workers per 10,000 units of capacity, but local specifics should be taken into account for calculation of labour costs.

Central administration costs (CAC) of the DRS system. These costs include labour, IT infrastructure (which is considered among depreciation), promotion and communication, office rent, and general administrative costs. Regarding the core labour costs, it is estimated that an average of 10–12 people is needed in the central DRS operator organisation, which includes management staff, finance staff, security/system accountability staff, customer service representatives, and communication staff [45]. These costs can differ from case to case depending on specific system needs as well as locally dependent requirements (such as legislative dependent requirements regarding employment of workers on specific job functions). To preserve financial sustainability, system accountability and security must be carefully monitored to reduce the risks and effects of possible fraud. Regarding communication costs, it is necessary to inform the public, so that consumers understand the importance of returning their empty packages, know what types of packaging are included in the program, and how the deposit refund can be retrieved. One of the main purposes of communication is to increase recycling rates. Another way to raise recycling rates is to increase the deposit value but this may lead to higher risk of fraud [22]. Regarding IT costs, they include maintenance and support, software licenses, and development costs. In total, from the analysis of different systems, the costs of annual administration can be estimated to amount to around 2% of the system income.

The revenue. The majority of previously defined system costs need to be covered by system revenues. The main sources of revenue for the DRS are incomes from unredeemed deposit, sale of materials and industry/administrative fees.

Unredeemed deposit (UD) represents the value of deposits paid on packages that have not been redeemed and that have likely been discarded as trash or littered in nature. Total revenue from unredeemed deposits is calculated by taking the number of unredeemed packages and multiplying that by the deposit value. This value is inversely proportional with efficiency of the DRS system, the higher efficiency of the system leads to smaller amount of overall unredeemed deposits and vice versa. Deposit value is agreed upon among all DRS stakeholders and differs from country to country. The deposit on beverage packaging in the refund system ranges from very low values – in Croatia it amounts to 0.066 EUR, in Estonia and Lithuania it is 0.10 EUR, very high deposit values of 0.25 EUR are in Germany and the Netherlands, to the highest – 0.32 EUR in Norway for certain types of packaging (plastic and metal bottles > 0.5 L), 0.4 EUR in Denmark (bottles \geq 1 L) and 0.4 EUR in Finland (plastic bottles > 1 L) [45].

Income from materials sale (MS) represents the direct income of the DRS system as DRS organisation in majority of countries is the owner of the material that enters the DRS. The market value of different materials varies depending on the demand and other factors. For instance, in case of aluminium sales price being around 1,000 EUR/t, it means, that it might cover the whole

collection, logistics, counting and sorting related processes. With much lower value of glass, it is good if it covers the logistics costs up to the recycling plant. Sales prices for different materials are in most cases based on secondary material markets and market indexes such as EUWID (Europäischer Wirtschaftsdienst) [48] and Letsrecycle [49]. Recent trends in secondary material market are shown on Figure 2 and Figure 3.

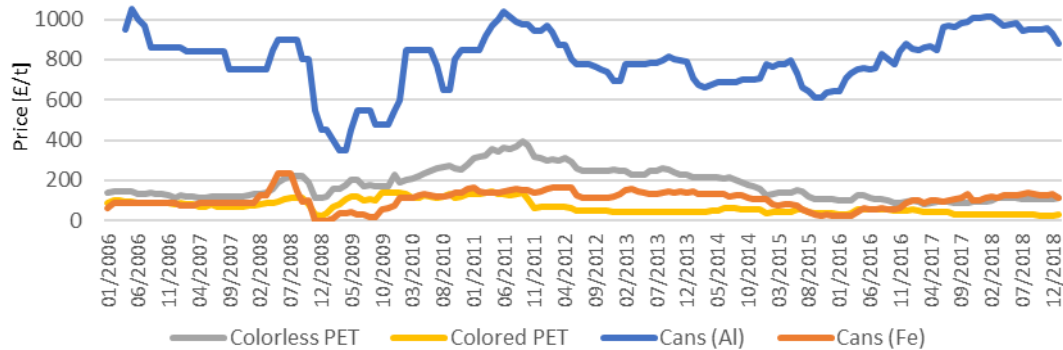


Figure 2. Secondary material market trends for PET and cans [49]

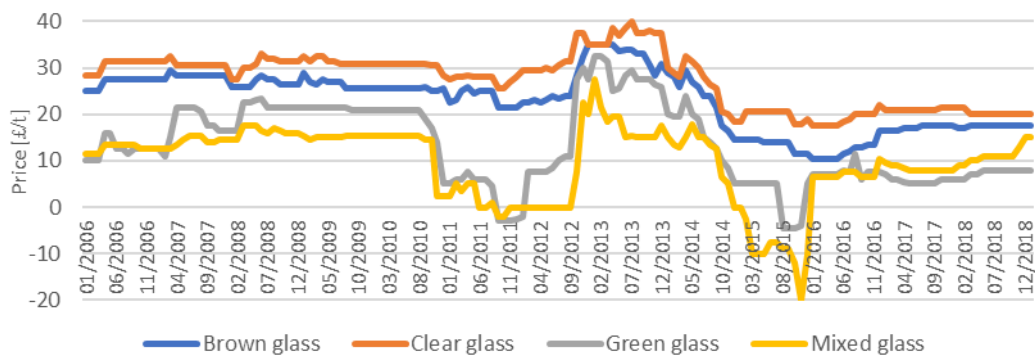


Figure 3. Secondary material market trends for glass [49]

The DRS organisation should operate on the non-profit basis. In other words, the organisation must cover the costs of system operation without a profit motive, i.e. the idea is that DRS system operates at positive zero – Equation 1.

$$RHF + TLC + HCC + CAC + UD + MS + IAF = 0 \quad (1)$$

Industry/administration fees (IAF) are shown as the last factor in the Equation 1. If a small profit is made, this must be re-invested into the system (i.e. for upgrades, etc.) or reserved for future use. As a result, any shortfall in the operation of the system needs to be absorbed by fees paid by industry. *IAF* cannot have negative value, i.e. it can't represent income for industry/administration, as it is previously said. Specific producer fees are usually calculated by taking the deficit (the difference between the total costs and total revenues from deposit which are not redeemed and income from sale of material) and dividing that between all the packaging that is put to the market. Additionally, it is important that there should be no cross-subsidising between materials; producer fees should reflect the actual cost to recycle various materials.

CASE STUDY OF CROATIA

Described model is used on the case of Republic of Croatia. As far as Croatia is concerned, it is far behind the EU average regarding sustainable waste management goals. In Croatia only 25.3% of municipal waste was recycled and composted in 2018, while the European average was 47% [50]. The Republic of Croatia, like other European countries, will have to meet the abovementioned targets for municipal waste recycling (50% by 2020, and 65% by 2035). Data for 2018 showed that the remaining 66% of municipal waste in Croatia was disposed of by landfilling (the remaining 9% are quantities sent to mechanical-biological treatment plants, quantities disposed of by some of the other disposal operations (D8–D11, D13, D15) and estimated quantities for the non-covered part of the population). This is a major loss of potential material resources (including recyclable materials) which ends in landfills, occupying space, which could be used as secondary (recovered) raw materials.

In industrialised countries, discarded waste packaging takes a big share in municipal household waste (especially if volume share is observed). Of the average 492 kg of municipal waste per capita in the EU, 174 kg is packaging waste. Due to the widespread distribution of packaging and a large number of users, it is a major source of environmental contamination, especially through the littering. The EU strategy on the packaging waste management asks for reduction of packaging waste generation, design changes which would reduce packaging, restriction and cessation of landfilling of packaging waste, as well as the introduction of fees for manufacturers and importers which would be used for financing of the organisation of the collection, processing and disposal system for the packaging waste. This path is defined by the Packaging and Packaging Waste Directive (94/62/EC) [3] which prescribes the minimum recycling goal of 55% (and 60% recovery) for packaging waste. The EU has also determined that the member states have to organise a collection and recycling system for the packaging waste, but each state is free to decide on the most acceptable method for the implementation.

As for the packaging waste management, Croatia with 53.3% of a recycled packaging waste in 2017, is also lagging behind of the EU/EEA countries, where the EU average was 67% [40]. If the minimum required recycling rate of 55% is taken into account, this means that Croatia did not meet the target in 2017. In the future, the share of packaging waste recycling in the EU (according to plans of the circular economy) will rise, as said, to 70% by 2030, which will be difficult for Croatia to fulfil without improving the systems of packaging waste collection and recycling.

In 2017, 278,068 t of packaging were placed on the Croatian market. This amount includes the quantity of packaging encompassed by DRS but also the returnable (reusable/refillable) packaging (9,649 t). Of these quantities of disposable (one-way) packaging, 138,502 t were produced in Croatia, 131,461 t were imported, and 1,544 t were exported.

According to the data [51], in 2017, 140,672 t of all waste packaging was collected in Croatia. Of these quantities 140,538 t was recycled (all by material recovery). Furthermore, the individual recycling rate targets were achieved for paper (84%) and plastics (37%), of the set targets 60% and 22.5% respectively, while the achieved recycling rate for glass was 57% of the requested minimum of 60%, for metals 16% of the set minimum of 50%, and for wood 3% of the set minimum of 15% [52].

In all of this, the share of beverage packaging collected through the deposit system (in 2017) was about 34.7% (by mass) of the total amount of collected waste packaging (through all systems), which is significant because it is a high quality and clean material fraction. In relation to the amount of beverage packaging in the deposit system which is placed on the market of the Republic of Croatia, about 85% of these quantities were collected through the deposit system in 2017, which is much more than through other means of waste packaging collection. About 42% of the packaging placed on the market in that year were collected through all other packaging waste collection systems in Croatia.

An additional moment is that Croatia officially reports the least quantities of packaging waste generated per capita (63.8 kg PC) in the EU (Figure 4), which is likely to increase in the future with rising standards and more accurate monitoring of waste streams (at the same time Croatia shows the smallest amount of collected or recycled packaging waste in the EU). This is corroborated by the comparison that also takes into account GDP per capita [50]. When looking at countries with a similar GDP per capita (e.g. Latvia, Lithuania, Estonia), in the case of Croatia, there are large deviations from the amount of packaging produced per capita compared to those countries (Latvia 122.2 kg PC, Lithuania 126.8 kg PC, Estonia 175.5 kg PC). Even countries with lower GDP than Croatia (Bulgaria with 6,310 EUR PC and Romania with 8,320 EUR PC, compared with Croatia, which in 2017 had a GDP of 11,560 EUR PC) have recorded larger amounts of packaging waste generated per capita (Bulgaria 64 kg PC and Romania 72 kg PC) than Croatia.

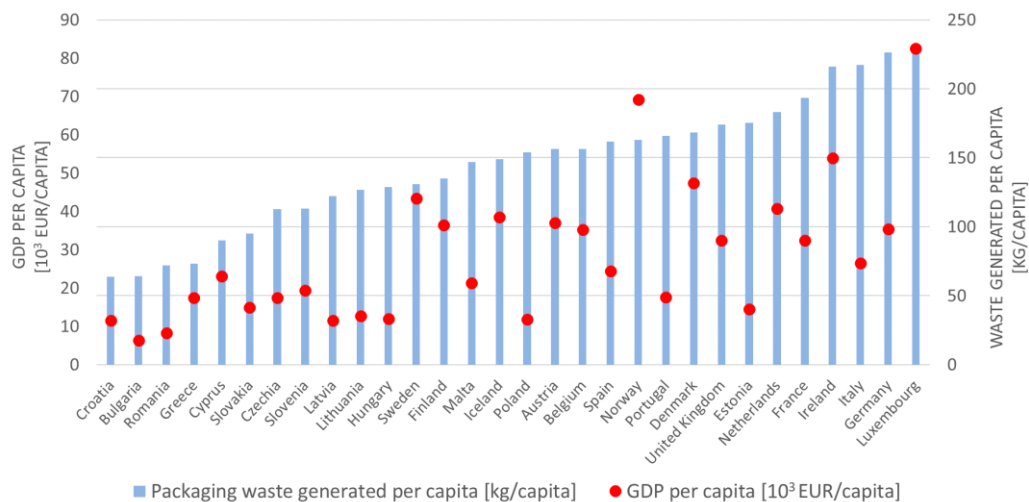


Figure 4. Produced packaging waste and GDP per capita in 2017 (adapted from Eurostat [53])

Regarding the reported deposit refund system results, the Croatian DRS shows relatively high recovery rates (collection) of waste packaging, which in the last years range from 85% (in 2013 and 2017) to 93% (2014), or 89% in average (2013-2016). These return rates are still lower than return rates for the waste packaging in the deposit systems in some EU and EEA countries, such as Germany, Norway, Finland, which often reach 90 percent and more. The five best performing Member States with deposit schemes for PET bottles (Germany, Denmark, Finland, the Netherlands and Estonia) reached an average collection rate for PET of 94% in 2014 [7]. The highest achieved return rates were recorded in Germany, where 97% of waste packaging is returned (data for 2014), while the second was Norway with a return rate of 94%.

Although at the first glance it seems that these figures of 87% in 2016 (or 85% in 2017) of the collected packaging waste by the deposit system in Croatia do not leave much room for improvement, it can be misleading because the figures include only beverage packaging that is reported to the DRS operator, i.e. for which the corresponding fees have been paid. As previously stated, the Republic of Croatia officially reported the least quantities of packaging waste generation per capita in the EU. A similar situation is also with the officially reported quantities of beverage packaging in the deposit system which are placed on the market. However, it is assumed that the actual quantities of beverage packaging that are placed on the market of Croatia are substantially higher. Since there are no official data on these volumes, it was compared [50] to four well performing DRSs in EU/EEA countries (Norway, Finland, Sweden, Estonia). On the basis of the amounts of reported beverage packaging (covered by the

deposit systems) placed on the market in each of the countries, divided by the total number of inhabitants of a given country, the amount of one-way beverage packaging per capita [units/capita] was obtained, which is shown in **Figure 5**. Glass packaging (even when it is in some countries' DRSS, it is not taken here (in this graph) into account, in order to compare the quantities in different countries with different system scope; e.g. deposit systems in Sweden and Norway do not include glass packaging, while in Croatia, Estonia and Finland it is included in DRS).

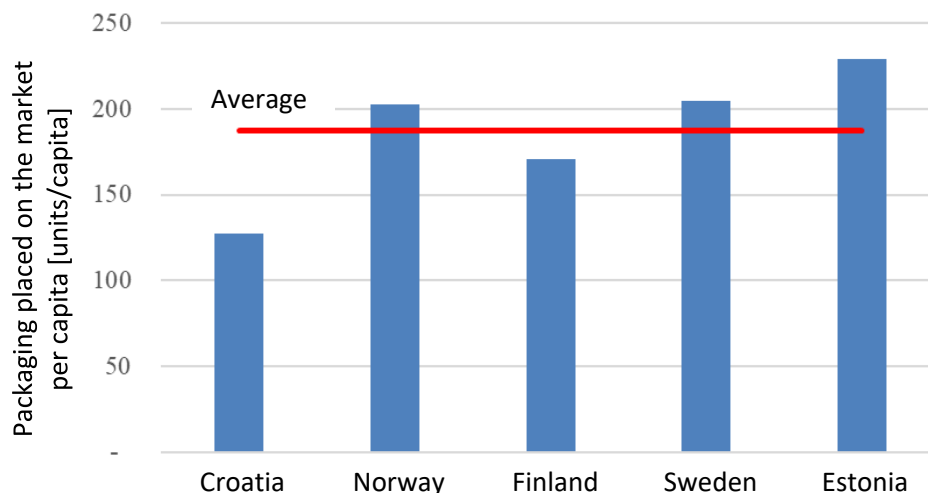


Figure 5. Amounts of packaging (excluding glass) put on the market per capita in 2016 [50]

Compared with other countries, the amount of reported beverage packaging (covered by the deposit system) placed on the market in Croatia is considerably lower than in the other four countries. Even when compared with a country that has a similar GDP as Croatia (Estonia has 20% higher GDP per capita than Croatia), the amount of packaging significantly deviates. In Estonia, the amount of reported packaging (without glass) put on the market was 229 units PC and in Croatia only 128 units PC (also not including glass). When the deviation from the average of all five countries is observed (Croatia is also included in calculation of the average value), which is 187 units PC, it can be seen that the amount of one-way beverage (in the deposit system) per capita in Croatia is well below this average, namely 32% below this average. This assumption can be further substantiated by taking into account a large number of tourists that visit Croatia each season (around 17 million in 2017), which was not included in that previous calculation. From all this, it can be indirectly inferred that in the Republic of Croatia not all quantities of beverage packaging placed on the market are reported and registered in the system and in that respect, it is possible to improve the deposit system in Croatia, i.e. to make it more efficient and cost-effective. Some of the measures recommended in a previous study [50] are directed to identification of all payers in the DRS (introduction of "domestic" (national) EAN code[‡] along with "international" EAN codes), system control and monitoring (on-line clearing), improvement of transparency and system reporting, and other measures for improvement of the efficiency of the system, like increasing the share of automated acceptance via RVM, etc.

And lastly, it should be mentioned that the Croatian deposit refund system is unique in this sense, meaning governmental institution – the Environmental Protection and Energy Efficiency Fund – is at the same time the regulator and the implementing body, also the owner of the central DRS organization, as well as being in charge of its everyday management.

[‡] EAN – European Article Number (also known as International Article Number)

Local system and scenarios definition

In this work, a hypothesis is laid out for zero cost of DRS system, and methodology given in the Methods section is used for case system definition and economic calculation. This is carried out on Croatian DRS, which regularly exhibited substantial costs of operation from its very establishment in 2006 [50]. Therefore, an extensive economic analysis of a deposit refund system in Croatia was conducted, in which the system was designed from beginning, not taking into account previous developments but considering most efficient system design elements. The financial model of Croatian DRS is presented taking into account current available data regards Croatian beverage market but disregarding current system setup. Such presumption allows that similar analysis can be applied at any given system/country, only with modifying input data and adapting to local conditions.

Three scenarios were examined, two evolutive ones in which the system is upgraded in near future, and a current suboptimal one taken as a starting point. But before one starts to analyse economic aspects of any DRS all the factors influencing investment in and efficient operation of a DRS, as they are identified in the Methods chapter, should be defined. All data are given on annual basis.

For modelling location specific economic data for valorisation of used space data from Central Bureau of Statistics [21] on average turnover per square meter of the store is used, as well as market data on price of monthly rent of business storage space [54], while labour costs are modelled based on the Trading Economics data [47].

Defining the packages in the deposit system. As with any investment, it is important to clarify and understand some key details which should be prescribed. It is defined that DRS system encompasses plastic bottles, aluminium cans, steel cans and glass bottles for products like beer, water (carbonated and non-carbonated), soft drinks (carbonated and non-carbonated), juices and juice concentrates, wine, spirits, etc. As it is said, dairy products are usually not recommended, although the dairy products were part of Croatian DRS until 2015, after which they were excluded. They are considered again, and so dairy products are to be reintroduced in the Croatian DRS from 2020 [55]. Geographical particularity of Croatia includes areas of different population densities as well and around 700 islands of which 48 permanently inhabited and this presents a special problem for packaging collection and logistics. Regarding retailers' responsibility, stores with area under 300 m² do not have to accept packages. Also, pronounced seasonality of tourism in Croatia needs to be emphasised as it presents an important issue.

Market size and packaging mix. Number of packages put to the market through the sales represents one of the most important factors for modelling DRS. **Table 3** shows the estimated number of packages that enter the Croatian market. According to data [22], annual sales volume declared to Croatian DRS by producers is 620 million pieces. Free riding[§] share cannot be clearly defined.

[§] Free riding – the packaging entering the market for which the regulated (national) deposit amount and/or administrative fee has not been paid.

Table 3. Size of the market [10^6 pcs] and packaging mix

Sales period	Current (2017) [22]	After the change	3–5 years after the change
PET	403.0	523.9	550.1
CAN*	124.0	161.2	169.3
OWG**	93.0	120.9	126.9
TOTAL	620.0	806.0	846.3

* CAN denotes here both aluminium and steel cans

** OWG denotes one-way glass

If to rely on findings presented in [50], it was estimated that around 30% of the products was not registered at the time (estimation done for 2017). Based on that, it was assumed that producer declared sales will increase by 30% (very soon) after the changes based on recommendations in the previous study [43] are implemented, reaching 806 million units annually. It was also taken that in the next 3–5 years sales will increase additionally by approx. 5%, derived from the estimated economic growth. These two analysed scenarios are named “After the change” (immediate increase of registered packaging volumes for 30%) and “3–5 years after the change” (further increase of packaging volumes put to the market), starting from the present (2017) situation – a suboptimal scenario named “Current”.

The doubts shown in [50], about real market size, were justified with the fact that amount of generated (general) packaging waste per capita in Croatia (which was previously shown in Table 1) is the smallest in the EU and also very small compared to Lithuania and Estonia, which have similar GDP (Figure 4). In addition, the study [50] does not take into account tourists' visits compared to mentioned other countries, with Croatia having the largest number of tourists of the three (especially when compared to population of Croatia of 4.2 million inhabitants), which offers an additional justification to that hypothesis. Considering refillable packaging, DRS countries which have return systems for refillable packaging, have a system in which such packaging and its deposit value circulates directly between producer and retailer. Although refillable packaging is not managed by DRS organization, it still influences the DRS system, because the same infrastructure for their return is often used (RVMs). It was estimated [22] that the annual market in Croatia for refillable packaging is around 500 million packages, but nevertheless refillable packaging is not considered in this work (only one-way DRS packaging).

Packaging collection and collection structure. According to available data for 2017 [22], the collection amounts of Croatia in tons are given in Table 4.

Table 4. Collection of packaging [22]

Material	Collection [t/year]
PET	16,000
CAN	1,500
Glass	30,000

If to use the average mass of packages, like PET ca 44 g, CAN ca 13.5 g, glass bottle ca 360 g, then it can be derived that the annual amount of packages collected in Croatia is 558 million packages (Table 5). In addition, the collection data after system change and 3–5 years after implementation of changes are calculated. The estimation is that after 3–5 years the market would transform into a clear and transparent one, which would motivate consumers to contribute more into environment and packages collection. An efficient DRSs packages return rate is usually between 80–90%, therefore the presumption, that Croatian return rate will be 85%, was taken.

Table 5. Collection of packaging [10^6 pcs/year]

Material	Current (2017) [22]	After the change	3–5 years after the change
PET	362.7	362.7	467.6
CAN	111.6	111.6	143.9
OWG	83.7	83.7	107.9
TOTAL	558.0	558.0	719.4

Currently Croatian DRS has 97% of manual collection and only 3% is collected via RVM**. The most probable reason for such very low RVM share is mainly derived from the relatively low level of retail handling fee, which is paid per each package collected from consumer (Figure 1). Increase in the use of RVMs need to be motivated as the RVMs decrease DRS other operating costs.

Table 6. Collection structure [%]

Material	Current	After the change	3–5 years after the change
	Manual/RVM	Manual/RVM	Manual/RVM
PET	97/3	30/70	20/80
CAN	97/3	30/70	20/80
OWG	97/3	30/70	20/80

Table 6 shows current RVM share and the scenario after changes implementation. In addition, it was presumed that after 3–5 years RVM share will rise to 80%. RVM share in collection in some efficient and long experience DRSs is even 90–95%.

Handling (recycling) centres. According to current distribution of collection of packaging in the Croatian deposit refund system (Figure 6) and considering the size, shape and distribution of population in Croatia, it was assessed that at least two handling centres are needed, one should be located around the city of Zagreb and another near the city of Split – two biggest agglomeration areas (Figure 7).

** Only RVMs with compactors are counted here as automatic acceptance-RVM.

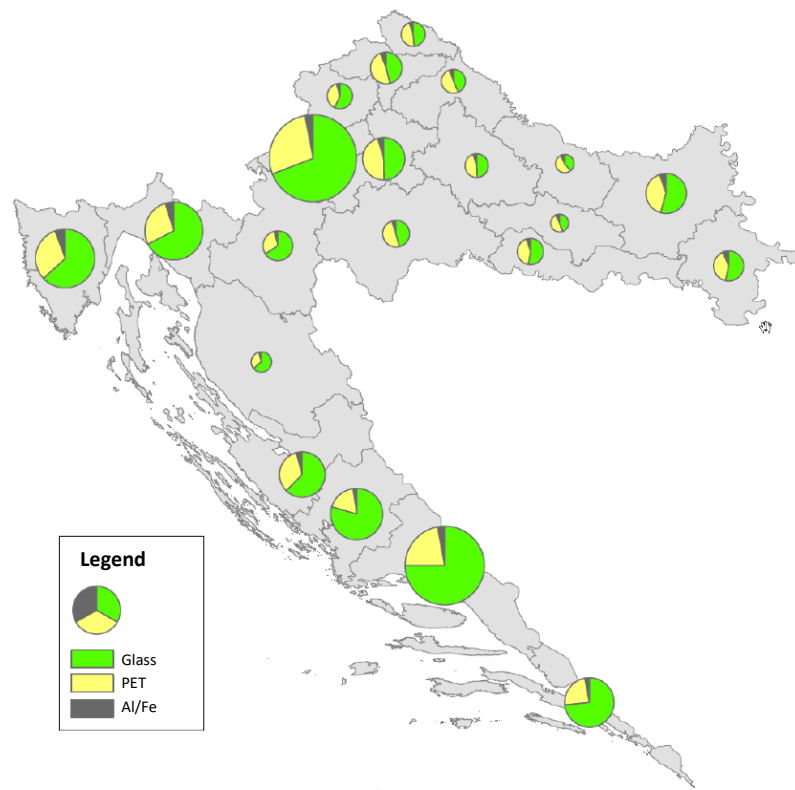


Figure 6. Collection in Croatian deposit refund system, by counties [51]

Figure 7 depicts two influence areas of handling (counting/processing) centres covering accordingly 80% (Zagreb) and 20% (Split) of the population. But one must take into consideration tourism, that results in ca 65% of the packages being consumed and collected in the Zagreb area and ca 35% in the Split area.

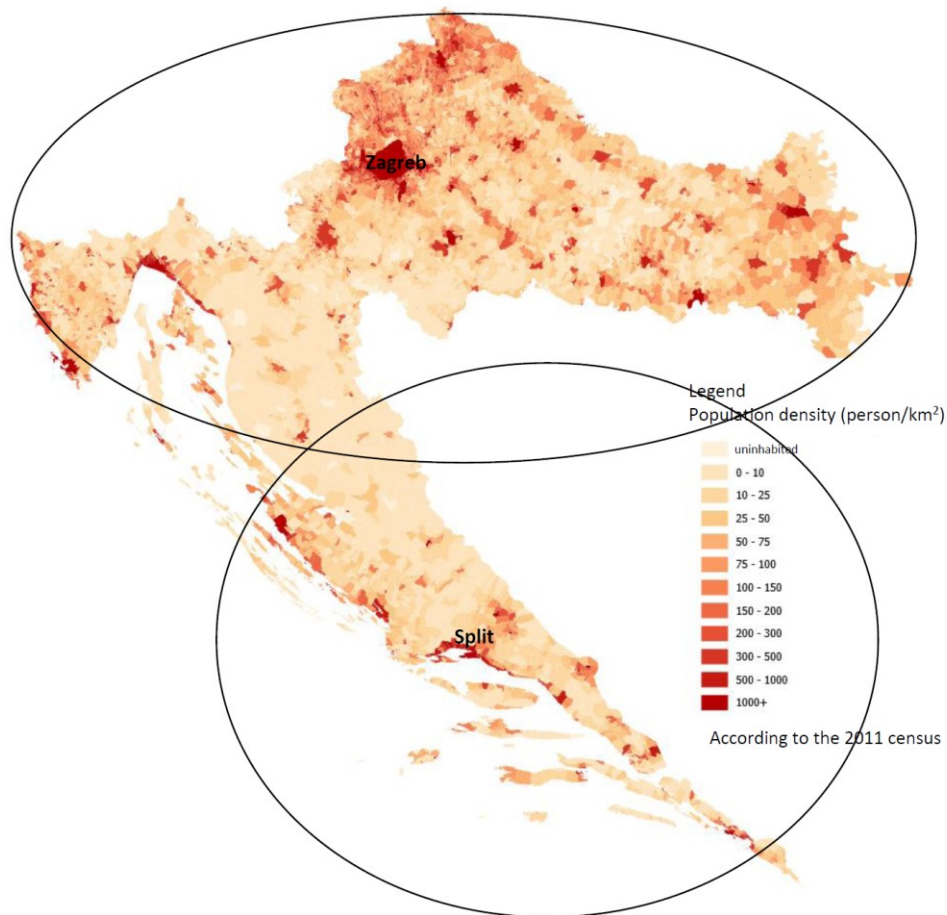


Figure 7. Areas serviced by the proposed handling centres (adapted from [22])

Detailed overview of the packaging volumes processed by the handling centres is described in Table 7.

Table 7. Annual quantity of packaging processed in the handling centres

Material	Zagreb		65%		Split		35%	
	After the change		3–5 years after the change		After the change		3–5 years after the change	
	[10 ⁶ units]	[t]	[10 ⁶ units]	[t]	[10 ⁶ units]	[t]	[10 ⁶ units]	[t]
PET	235.8	10,400	303.9	13,407	126.9	5,600	163.6	7,219
CAN	72.5	975	93.5	1,257	39.1	525	50.4	677
Glass	54.4	19,500	70.2	25,139	29.3	10,500	37.8	13,536
TOTAL	362.7	30,875	467.6	39,803	195.3	16,625	251.8	21,432

This analysis assumes that both centres will receive packaging from surrounding areas on equal basis, i.e. the amount of manually accepted packages and volume of glass bottles is similar in both centres. Thus, the investments into both centres include industrial counting machines that count manually accepted packages and glass bottles, compactors, sorting and baling lines and other necessary machinery and equipment. Additionally, it is taken into account that the DRS central office is in Zagreb handling (counting/processing) centre, meaning an administrative unit with IT system. Pursuant to this, the planned investment into the two handling centres would be around 7.17 million EUR (net value). It is important to point out, that according to this projection, the handling centre facilities will be rented. It is also

important to note, that beverage products consumption and collection is very seasonal, and sales volumes differences between low season (winter) and high season (summer) may be double. The biggest investments in both handling (recycling) centres are industrial counting machines in amount of ~2.3 million EUR, sorting lines ~1.9 million EUR, balers ~1.8 million EUR, IT system (including software and hardware) ~0.4 million EUR, other equipment (including office and other handling centres equipment) and setup cost ~0.77 million EUR.

Initial investment of the retailers. The retailers are obliged to invest into the deposit system infrastructure, including package return rooms and the RVMs, which then should be compensated over time through DRS operation. Taking into account previously defined average number of RVMs per inhabitants it was calculated that ca 1100 RVMs are needed to install in Croatia to reach situation where 80% of packages are collected with RVMs. Overall initial investment by the retailers into the package recycling system is calculated on the basis of previously defined costs and ranges between 30–40 million EUR (without VAT).

RESULTS AND DISCUSSION

In this chapter an operating costs structure and system overview are given. The system is optimized to run on a non-profit basis where the difference in costs and revenues of DRS is covered according to Producer Responsibility Principle by producers/importers of the beverage packaging.

Retail handling fee

As it is defined, retail handling fee (*RHF*) should cover previously estimated investment costs of the retailers as well as operating costs of the stores arising from the collection of packaging (included in the deposit system) returned by the consumers and their delivery to the DRS [22]. As there are two different approaches to packaging collections, they are separately analysed.

As it is previously said, investment in RVM makes sense if volume of returned packages with deposit marking per month crosses 10,000 packages, and optimum return of a regular, medium size and full compacting (PET/CAN) RVM is on average ca 50,000 packages per month. Previously defined range of fees associated with automated acceptance of packaging (via RVM) for the retailers goes between 1.7–4.0 cents EUR per package. Since the compensation paid to the retailers is the largest cost for DRS, it should be carefully agreed with retailers according to concrete and fair terms. This calculation takes the average RVM (automated) *RHF* of 2.13 cents EUR per package (the same for all types of packaging materials).

Manual collection is a logical choice for retailers if the volume of accepted packages is less than 10,000 per month, since is economically unreasonable to install an RVM. It is up to the store to decide, but in such case the *RHF* paid by the DRS will not completely cover the costs related to accepting the packages. Depending on the legislation to be provided, small stores near each other can cooperate and install a common RVM together, which would have an optimum packaging volume per month and the deposit receipts issued by the RVM could be used in the stores that have joined the agreement.

When the packages are collected manually, there are following costs that should be included: labour costs, cost of the space (rooms) and utilities. The calculation for Croatian DRS considers the average fee for manual reception of packages to be 0.53 cents EUR per package.

More detailed overview is provided in Table 8 (considering that the RVM ratio is 70% after the change and 80% 3–5 years after that).

Table 8. Retail handling fee costs [10⁶ EUR/year]

Material	After the change		3–5 years after the change	
	Manual	RVM	Manual	RVM
PET	0.58	5.42	0.50	7.98
CAN (Al, Fe)	0.18	1.67	0.15	2.46
Glass (OWG)	0.13	1.25	0.12	1.84
TOTAL	0.89	8.34	0.77	12.28
Grand TOTAL	9.23		13.05	

Transportation and logistics costs

Cost of transportation and logistics incorporates costs of accepting the packages (from the packaging storage in stores), costs of loading the transport packaging, costs related to transfer stations (if these are used), all up to the point the transported packaging reaches the handling centre/recycling plant (for glass). That cost is calculated with the assumption that in (immediate) “after the change” scenario, the share of automated (RVM) acceptance is 70%, while that share increases to 80% in “3–5 years after the change” scenario. Another assumption is introduced that all RVM-accepted packages are compacted (apart from glass packaging). Unloading of the packaging in the handling/counting centre/recycling plant is not incorporated into transportation/logistics cost but into the handling centre/recycling plant costs. The calculated transportation and logistics costs, along with the cost of transport packaging, totals to 8.3 million EUR. Although the collection of packaging is expected to grow 29% in 3–5 years, logistics costs will remain practically on the same level, because RVM and therefore compacted packages share will increase by 10% point, from 70% to 80% (Table 9).

Table 9. Total logistics costs including transport packaging [10⁶ EUR/year]

Material	After the change	3–5 years after the change
PET	2.54	2.89
CAN	0.22	0.24
OWG	5.43	5.15
TOTAL	8.19	8.28

As presented, it is possible to reduce costs of transportation and logistics by introducing different solutions, like crushing glass packages in RVMs (on site at the store), as well as implementing advanced IT solutions. The logistics can be optimized using IT solution that helps to track and process information on the number of packages being accepted on different reception points (stores), so that the logistics company and the carriers could know when to go the stores to pick up the packages and how many transport packages will be waiting to be collected at the different stores. That would be necessary information both for collection rounds and for optimum use of storage space [45].

Handling centre costs

Already compacted packaging (collected via RVMs having compacting ability) is further compressed by industrial presses into large cubes, and then sold to material recycling plants. When using non-compacting RVMs, from Horeca sector of manual collection, empty containers need to be once again counted by using industrial RVM. All of this is done in handling centres. Based on counting/processing data from handling centre, and data obtained from RVMs, the value of deposit and *RHF* paid to the respective retailer is defined.

The central DRS operator often has a decision to make, that is, whether to manage the handling centre operations itself or to outsource these services to a private sector operator. In many countries, such as Estonia, Lithuania, Norway and Sweden, some components of counting/processing operations are operated by the DRS operator, while others are outsourced (e.g. compaction centres, where only compacted material collected via RVM is directed). Other countries such as Finland have outsourced 100% of handling centre services. Nevertheless, it is convenient to manage one’s own handling centre from the beginning in order to minimize costs. While the DRS organisation is a non-profit company, a third-party service provider would probably add a profit margin to its service.

Another important issue is to estimate the number of needed counting/processing centres. Apart from the number of inhabitants, significant factors include population density, level of tourism, and geography (e.g. number of small islands and their inhabitants). In order to keep the logistics costs acceptable, a counting/processing centre should have a range of around 150–250 km radius [22]. Considering such range and the size of Croatia and its population density, it has been estimated that it is optimal to have two such centres, as mentioned earlier, one in the Zagreb region and the other near Split

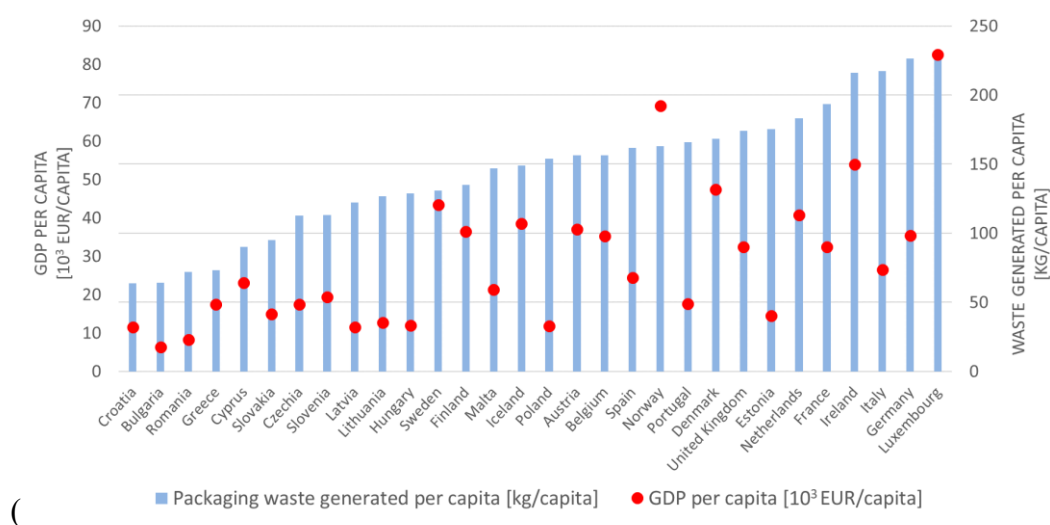


Figure 4).

Considering previously defined most relevant costs of handling centres, more detailed estimation of overall costs is shown in Table 10.

Table 10. Estimated annual costs of two handling (counting/processing) centres [10^6 EUR/year]

Cost item	After the change	3–5 years after the change
Total*	4.65	5.52
Rental	0.58	0.58
Operating cost	0.62	0.80
Production labour cost	2.39	3.08

*Excluding costs related to administration. Without VAT.

Administration costs

Administration costs encompass all main central administration and include labour, IT infrastructure, promotion and communication, office rent, and general administrative costs.

Considering the sheer quantity of packaging that is put to the market (0.81 billion units and 0.85 billion pcs in 3–5 years) and the value of deposits paid (0.50 HRK or 6.7 cents EUR), the annual income of the company is calculated to be between 53–56 million EUR. Therefore, as previously said in the methodology chapter, the security and system accountability are of the utmost importance for the efficient functioning of DRS.

Taking that in count, as well as previously defined costs dependencies, the costs of annual administration are calculated to be 1.06 million EUR (including office rent and office related costs, labour cost, IT operating and marketing costs).

Revenue

Overall system revenues are defined as a sum of main income streams of the DRS:

Unredeemed deposit – annual deposit system income from deposits which are not redeemed is calculated to vary between 16.5 million EUR (after the change, when the average (real) return rate is ~69%) and 8.5 million EUR (3–5 years after the change, when the average return rate is 85%) per year. Calculated revenues per packaging type from deposits which are not redeemed is given in [Table 11](#).

Table 11. Revenue from unredeemed deposit [10^6 EUR/year]

Unredeemed deposit	After the change	3–5 years after the change
PET	10.75	5.50
CAN	3.31	1.69
OWG	2.48	1.27
TOTAL	16.54	8.46

Sale of materials – it was calculated that in Croatia 47,500 to 61,000 t of material, respectively, will be collected through the DRS annually – [Table 12](#).

Table 12. Amount of collected material [t/year]

Material	After the change	3–5 years after the change
PET	16,000	20,627
CAN	1,500	1,934
OWG	30,000	38,675
TOTAL	47,500	61,236

The market value of different materials varies depending on demand and a number of other factors which are mainly accounted in market indicators. Not all materials sale generate net income, for instance, it can be seen that, aluminium and clear polymer sales usually cover the overall processing costs while on the other end, glass do not. By using market data for secondary materials and quantity of collected materials, total sales revenue is estimated to range between 7.8 and 10.1 million EUR. The estimated revenues by material type are presented in [Table 13](#).

Table 13. Revenue from sale of materials [10^6 EUR/year]

Material	After the change	3–5 years
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		after the change
PET	5.82	7.51
CAN	1.67	2.19
Glass	0.30	0.39
TOTAL	7.79	10.09

Industry/administrative fee – it is calculated using Equation 1 and represents the difference between system income and expenses that need to be covered by industry which puts packaging on the market. Because it represents a fee that is paid to the system, it also represents system income. This fee expressed as specific cost per unit of packaging, represents the overall system cost which will be calculated further in the article via calculating all other system costs and incomes.

Total costs of deposit refund system

Operating costs and incomes of DRS are presented in **Table 14**. The overall goal in this work was to optimize the DRS to reach a zero (net) profit, considering a non-profit principle of DRS organizations and as lowest possible cost for the industry (producers). This is done by calculating minimal needed industry/administrative fee to satisfy equality defined by Equation 1.

Table 14. Calculated annual total costs of DRS and cost per package put to the market

Cost item*	After the change		3–5 years after the change		
	Total cost [10 ⁶ EUR]	Cost per sold piece [EUR]	Total cost [10 ⁶ EUR]	Cost per sold piece [EUR]	
Retail handling fee (<i>RHF</i>)	-9.2	-0.0114	-13.0	-0.0154	Expenditures
Transport and logistics costs (<i>TLC</i>)	-8.2	-0.0102	-8.3	-0.0098	
Handling centres costs (<i>HCC</i>)	-4.7	-0.0058	-5.5	-0.0065	
Central administration costs (<i>CAC</i>)	-1.1	-0.0013	-1.1	-0.0013	
Unredeemed deposit (<i>UD</i>)	16.5	0.0205	8.5	0.0100	Incomes
Material sales (<i>MS</i>)	7.8	0.0097	10.1	0.0119	
Industry/administrative fee (<i>IAF</i>)	-1.2	-0.0015	9.4	0.0111	
Net result	0.0	0.0000	0.0	0.0000	

*Negative value means that producers/industry do not have to pay any administrative fee because of unredeemed deposit and income from material sales will cover all expenditures.

As it can be seen from **Table 14**, the largest cost is the cost of compensating the retailers (through retail handling fee). The second largest is cost of transportation and logistics. Therefore, it is of utter importance to make such an agreement with the retailers, that the compensation in a form of *RHF* for the collection of packaging with deposit markings is determined on the basis of direct costs of most effective sample stores. Furthermore, additional savings in increasing the efficiency of transport and logistics can be accomplish, which would reduce the total cost of the handling (counting/processing) centres and the initial investment.

In terms of the system revenues, the value of deposits which are not redeemed represents the largest source of income (at least in the first phase of the system change). That revenue will

depend on the return rate, because, if the return rate is growing, the revenue from unredeemed deposits is decreasing.

Summarizing all the costs and revenues of deposit refund system, in the scenario “after the change” (with implemented recommendations and changes of the DRS, when the return rate is ~69%) the system generates profit in amount of 1.2 million EUR and will have a shortfall of 9.4 million EUR in the scenario “3–5 years after the change” (when the average return rate increases to 85%), which means that the average producer/administrative fee can be 0 cents EUR and 1.11 cents EUR per package respectively.

Sensitivity analysis

This short sensitivity analysis considers situation when some of the main parameters which affect costs of DRS or revenues change. In all cases, the “3–5 years after the change” has been taken as a basis and if the referred factor should change, then all other indicators remain the same. The main purpose of the sensitivity analysis is to observe, what will happen with the industry (producer/administrative) fee if one relevant cost or income should change. Most observed instances deal with some cost type increasing, but similar positive effect to industry fee is achieved if some cost type should reduce. Following is the influence of key factors in terms of DRS functioning:

Sales – since currently there is uncertainty regarding the real market volume (because of free-riders), if the amount of packaging entering the market is 10% larger and other indicators remain the same (at the same time, resulting from the change in the returning rate, the number of returned packages increases), then the total sum paid to the DRS by the industry will increase by 0.7 million EUR. At the same time, in case of both scenarios the industry fee per package sold will reduce by 0.02 cents EUR.

Return rate – if the return rate increases by 1% that will negatively influence the administrative (industry) fee, since the amount of deposits which are not redeemed will decrease and because more packages are collected, more compensation should be paid in form of *RHF* and for other operational costs. The cost for producers and importers will grow by 0.7 million EUR annually (administrative fee will increase consequently by 0.09 cents EUR per package).

Collection structure/share of RVM – one of the most influential indicators. If collection structure (share of automated acceptance or share of compacted packages) increases from 80% to 90%, then the cost for producer will decrease by 1.2 million EUR per year (administrative fee will decrease by 0.14 cents EUR per package). At the same time, if collection structure (share of compacted material) is not 80% within 3–5 years after the change, then the impact is opposite, which means that deposit system is more expensive for producers.

Transport and logistics – as discussed earlier, transport and logistics costs can be reduced by applying different solutions. At the same time, if logistics costs (incl. cost of transport packaging) increase by 10% then cost for producer/importer will grow by 0.8 million EUR annually. An increase of the administrative fee is then 0.1 cents EUR per package.

Counting centre(s) – relatively low risk. Pressure on labour cost (which is approximately 55% out of total counting centres cost) increase may have the strongest effect on this cost type. If the counting centres cost increases by 10% then cost for producer/importer will grow by 0.7 million EUR annually. Consequently, the administrative fee will increase for 0.08 cents EUR per package.

Material market price – the prices of secondary materials have changed in large extent in past decade on the market, e.g. price of aluminium has changed 40% and prices of PET have doubled. So, if the price of material (taking as a total material sale) increases by 10% then the total cost for producer/importer will decrease by 1.0 million EUR annually. % then cost for producer/importer will grow by 0.7 million EUR annually. Consequently, the administrative fee will decrease by 0.12 cents EUR per package. This factor is actually very difficult to predict due to enormous variations in market price of different secondary materials over the last decade.

Deposit value – one of the major dilemmas in case of all DRSs has always been selecting the proper and optimum deposit value. If the deposit is too low, it will not motivate the consumers to return the packaging and thus a low returning rate will become an issue. If the deposit amount is too large, it will lure people into deceiving the system. This study uses deposit value of 0.50 HRK (correspondingly 0.0667 EUR). If the deposit value of 0.10 cents EUR is used as a basis and return rate remains 85%, then producers' cost will reduce by 4.2 million EUR and industry fee will reduce by 0.5 cents EUR per package.

Indirect costs of deposit system

In addition to the industry/administrative fees, producers may have additional indirect costs, the most relevant of which are described below. These costs will vary depending on the size and types of products they put on the market:

Labelling – if neighbouring countries do not apply the deposit system, it may result in DRS requirement that separate product labels must be made for Croatia with the Croatian DRS marking and with the product EAN code that is only sold in Croatia (a national EAN code, as opposite to an international EAN code). This, however, means a separate label supply. The producers will have to start planning sales specifically per country. Also, the production process will become slower because the assembly lines must be stopped to change the labels which in turn reduces the bottling efficiency. This would mainly affect those Croatian producers who supply beverages to several countries. This possible DRS decision would also complicate things for importers, who must: a) agree with the international producers to make a product for Croatia with a separate EAN code, b) glue a local market EAN code over the existing EAN code and add the Croatian DRS deposit marking (local rules for re-labelling must be followed), or c) end product importing. One viable alternative would be to use the two-coding logic, as it is explained in [43].

Warehouse – as stated in the previous clause, the producers may have to bottle the same product with two different EAN codes. This may increase the need for warehouse space or more detailed planning of sales and production. This solution would definitely not be as flexible as producing products with the same EAN code also for export. This cost is different for all producers because some producers use different division centres in different countries and in this case the warehouse cost would not increase at all.

Fraud and cross-border risk – if the DRS enables to use the so-called international EAN code, then there is a risk either that products are brought from neighbouring countries, which are consumed and returned to the Croatian DRS, or there will be “illegal” collection points for empty packages with the Croatian DRS marking in neighbouring countries, which are then returned to the Croatian DRS. This means that the DRS must pay the deposit and cover the package handling related costs, for which the producers have not paid the deposit or industry/administrative fee to the DRS. As is known, the producers pay deposit and industry fee to the DRS only for the packages which are offered on the Croatian market.

CONCLUSION

A deposit refund system is generally accepted as an efficient scheme for packaging waste collection and recycling entailing high environmental benefits, but if not organized and managed properly it could exhibit high costs that could jeopardize its economic viability. Therefore, the main research question put in this work was how to make such systems economically sustainable or even self-sufficient, and if that is even possible taking into account a complexity, interdependency of the subjects, and the costs generated in each stage of the DRS. Additional question was if the cost of packaging waste management in the DRS that mainly burdens the industry (producers, importers) can be minimized, but still enabling the system to operate, even on non-profit grounds. What is also known, is that the deposit refund system will

always entail spending for one of the market actors, most often the industry, or in other cases government and indirectly taxpayers.

In this research, an extensive overview of economic drivers, driving both system costs and incomes, is given. This overview shows the complexity of DRS and what needs to be looked upon by the decision makers when considering the implementation of such a system. On the basis of this overview, system modelling, based on the premise of positive zero cash flow operation of the system, is conducted and its implementation on the case study country is shown. A deposit refund system of the case study country – the case study of Croatia, is modelled with a goal of showing how such a system can be organized. In doing so, the DRS was designed from the beginning, not taking into account previous developments but considering most efficient system design elements. The financial model of Croatian DRS was presented considering current available data regards Croatian beverage market but disregarding current system setup. Such presumption allowed that similar analyses can be applied at any given system/country, only with modifying input data and adapting to local conditions. Three scenarios were examined, two evolutive ones in which the system is upgraded in near future, and a current suboptimal one taken as a starting point.

Implementation of DRS in Croatia is more challenging because of its geographic characteristics (elongated, long and narrow crescent-shaped, with two more densely populated regions separated by a mountainous area and a very indented coast with many islands) as well as influence of tourism (large difference in population distribution and beverage consumption/waste packaging production between seasons). Thus, the work presented can serve decision-makers in other countries and regions which do not have yet implemented such systems but are discussing that possibility, especially the systems with similar peculiarities.

Taking into account the current situation in Croatia, where one-way packaging made of plastic, metal and glass is included in the DRS, and regarding the new scenario in which “free riding” packages is included in the DRS (packages, which deposit is currently not paid and their share is about 30% (estimation in 2017)), then it can be concluded that market share is 806 million packages, which will again grow within the next 3–5 years by 5% due to economic growth (reaching in total 846 million packages).

With the current value of deposit of 0.50 HRK per package, which is 0.066 EUR, and a market volume of 806 million packages that will be declared after the system change, the number of returned packages will be the same, but derived from the increase of market volume, return rate will decrease to 69%. Also, a market volume will increase up to 846 million packages in 3–5 years and return rate will increase up to 85%, similar to other countries with efficient DRS.

Comparing all the system costs, the biggest cost is the cost of compensating the retailers, and the second largest is the cost of transportation and logistics. Therefore, it is very important to make such an agreement with the retailers, that the compensation (retail handling fee) for the collection of packaging with deposit markings is calculated on the basis of direct costs of most effective sample stores. Besides that, additional savings can be achieved in increasing the efficiency of transportation and logistics, which would reduce the total cost of the handling (counting/processing) centres and the initial investment.

In terms of the system revenues, the value of deposits which are not redeemed represents the largest source of income (at least in the first phase of the system change). This revenue depends on the return rate, and so, if the return rate is growing, the revenue from unredeemed deposits is decreasing. The second source of revenue is sale of collected packaging material, but that income can vary a lot depending on the current market price of material.

Summarizing all the costs and revenues of the deposit refund system, and retaining a non-profit principle of DRS, it was calculated that the average administrative (producer) fee should be 1.11 cents EUR per package (with the return rate of 85%) for the DRS to be able to operate on the zero net result. This administrative fee could be even lower if all the different

possibilities and measures described in this paper and earlier studies of the authors [43] and [50] are to be implemented.

To conclude, it can be said that the deposit refund system, as a form of extended producer responsibility principle, is a well thought market-based instrument to address externalities. At the same time, due to the flexibility and economic stimulation of deposit, it can effectively recover the environmental pollution that is difficult to regulate, such as illegal waste disposal, which was heavily present in Croatia prior to introduction of DRS in 2006. Also, it can be said that it is the deposit, not the value of the material from which the packaging is made, the reason why packaging in the deposit system is separately so successfully collected.

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NOMENCLATURE

<i>CAC</i>	central administration costs	[EUR]
<i>HCC</i>	handling centres costs	[EUR]
<i>IAF</i>	industry/administrative fee	[EUR]
<i>MS</i>	material sales	[EUR]
<i>RHF</i>	retail handling fee	[EUR]
<i>TLC</i>	transport and logistics costs	[EUR]
<i>UD</i>	unredeemed deposit	[EUR]

Abbreviations

g	gram
kg	kilogram
pcs	pieces
t	tonne
CAN	Steel and Aluminium Cans
DRS	Deposit Refund System
EAN	European Article Number
EEA	European Economic Area
EU	European Union
EUR	Euro
GDP	Gross Domestic Product
HRK	Croatian Kuna
IT	Information Technology
OWG	One-Way-Glass
PC	Per Capita
PET	Polyethylene Terephthalate
RVM	Reverse Vending Machine

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