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Establishment of Deposit Refund System in Greece for PET bottles: Economic Analysis, Benefits and Impacts

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ABSTRACT

The current paper deals with the implementation of the Deposit Refund System (DRS), as new recycling system in Greece for PET packages, in accordance with the European Directive 2019/904. The main purpose of this work was the presentation of a cost-benefit analysis that evaluated the suggestions and the impacts of the aforementioned European Directive for Greece. In addition to the cost-benefit analysis, a comparison between the DRS and the existing recycling model for PET (PolyEthylene Terephthalate) packages was carried out aiming at eliciting the ramifications for Greece. Furthermore, a mathematical model was set up, based on data regarding PET recycling in Greece. This model describes the operation of the corresponding DRS in Greece, and could be useful for understanding, establishing, and improving DRSs for other waste commodities.

1. Introduction

The idea of deposit-refund was generated long time ago to cope with the problem of the increasing purchase power of society and the concomitant increase of recyclable waste littering. Several studies, mostly theoretical, have been carried out on various issues of DRSs and their comparison with other recycling systems (Bohm, 1981; Palmer and Walls, 1997). The application of DRS on the recycling of beverage packages has been proved the most popular (Lavee, 2010; Linderhof et al., 2019; Guangli et al., 2020) but it can be applied on various waste commodities as well, such as lead batteries (Gupt and Sahay, 2015), tires (Walls, 2013), motor oil (Schmitz et al., 2012), electronics (Zhong and Zhao, 2012), etc. (OECD, 2015). The current paper deals with the investigation of the prerequisites, economics, benefits, and impacts from the establishment of a DRS for PET bottles in Greece.

The global production of plastics has risen from 2 million metric tons in 1950 to about 400 million tons nowadays and, according to estimations, it will be doubled by 2035, as shown in Figure 1 that has been generated by the authors from data obtained from World Economic Forum (2016) and World Wide Fund for Nature (2019). In Greece, 730,000 tons are annually produced, which denotes that every Greek citizen discards approximately 68 kg of plastic per year (Dalberg Advisors, 2019).

According to Plastics Europe, association of plastic manufactures (2016), the majority of global production of plastics is lined up for packaging and beverages, which are the main sources of plastic waste because of their limited lifetime. Figure 2, which is based on data from D' Amato et al. (2019), shows the share of plastic consumption in various industrial sectors.

Furthermore, PET (PolyEthylene Terephthalate) is vastly used for the production of food packages and beverages. It is a clear lightweight plastic manufactured from ethylene glycol and terephthalic acid, which are

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combined in order to form the polymer chain. Additionally, PET is extruded, cooled and finally cut into pellets. Afterwards, these pellets are liquefied through heating and then molded in order to provide a product of desired shape (Plastics Europe Association of Plastic Manufactures, 2018).

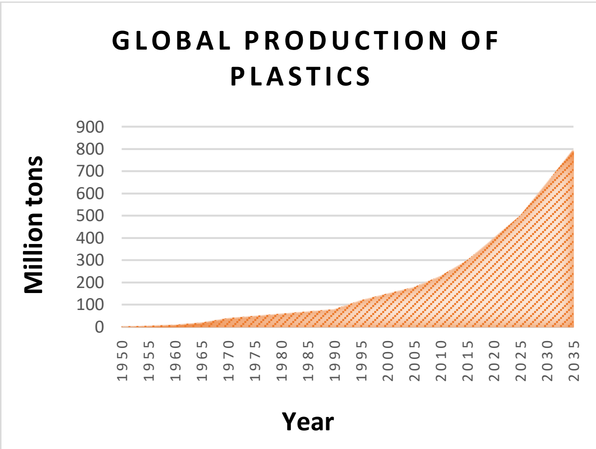

Figure 1. Annual growth rate of global production of plastics since 1950 (World Economic Forum, 2016; World Wide Fund for Nature, 2019)

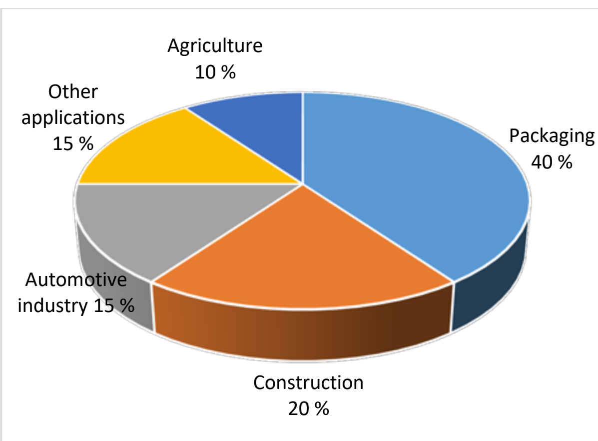

Figure 2. Global application of plastics (D' Amato et al., 2019)

PET is completely recyclable and it is the most recycled plastic worldwide. After washing and collecting the PET containers through the recycling system, PET can be re-melted or chemically broken down into its components in order to make new PET resin, which can be reused for new containers (Plastics Europe, 2016). Although recycling is the most sufficient way to manage the bailed PET packages, some PET bottles can be found in landfills.

Every year, 5-13 million tons of plastic end up in oceans. Consequently, the plastic waste is transported to the shore through the ocean currents, causing many financial and environmental problems (Jambeck et al., 2015). Plastic waste from European States ends up on its coast, especially in the countries around Mediterranean Sea, thus suppressing tourism and fishery activities of the local communities. Additionally, PET packages can be disintegrated into microplastics which are harmful for ecosystems. Microplastics are polymers with size less than 5 mm, which can be easily ingested by marine fauna causing health problems (Razis and Christopoulos, 2021).

In view of the foregoing, the European Union and, by extension, the Greek Government incorporated the European Directive 2019/904 in order to reduce the pollution caused by plastic containers. This Directive sets the target of 77 % for the return rate of plastic beverages by 2025 and the detailed description of plastic beverage items is provided in the Directive as well. Moreover, the target increases to 90 % by 2029. To achieve these high return-rate targets, the Greek Government ought to establish and operate a Deposit Refund System (DRS), which is responsible to collect the plastic beverages and other materials if needed (Razis and Christopoulos 2021). It is expected that the establishment of DRS in most EU States will be a key factor in promoting Circular Economy. Higher recycling rates combined with better design of plastic containers will boost the market of recycled plastics and, simultaneously, reduce the pollution from plastics, especially in the Mediterranean Sea. The operation of DRS in various European States showed that its establishment achieved high return rates, with concomitant reduction of plastic littering (Table 1).

Table 1
Return rates from various European DRSs (created by the authors with data from: Hogg et al., 2015; CM Consulting, 2016; Fullana-i-Palmer et al., 2017; Drab and Sluciakova, 2018)

European Deposit Refund System	Return rate (%)
Croatia	90
Denmark	89
Estonia	90
Finland	92
Germany	98
Iceland	87
Lithuania	74
Netherlands	95
Norway	95.4
Sweden	82.7

Even though the DRS is an effective recycling system to drastically achieve high return rates, recycling should not be displayed as the sole and sufficient solution to approach the circular economy. As it is already shown, the plastic production is drastically growing; as a result, recycling will not be able to handle the quantities of plastic in the future. Considering that the price of virgin PET, produced by oil, is lower than that of recycled PET and the great investment of the petrochemical industry, it is obvious that recycling and Circular Economy will be undermined even if global return rates of recycling systems remain high as shown in Table 1. To recapitulate, achieving high return rates and promoting recycling are not sufficient means to ensure environmental sustainability; on the contrary, promoting recycling without taking control of global plastic production will lead to greater problems because recycling will be degraded to a reason for greater production and, therefore, pollution.

The main purpose of the current paper was to present an integrated technical and financial investigation for the establishment of a DRS in Greece for PET bottles and to compare it with the existing Extended Producer's Responsibility (EPR) model. In addition, a mathematical model was set up, which was useful for understanding and improving the operation of the DRS. The rest of the paper is organized as follows. Section 2 describes the function of a DRS and the relationship between deposit merit and return rate. Section 3 presents in details various economic parameters, which are very important to evaluate the establishment of a DRS in Greece for PET bottles. The effects and benefits of the DRS are presented in section 4 followed by the conclusions in section 5.

2. Theoretical Presentation of the Deposit Refund System and Methodology

2.1. Describing the function of the Deposit Refund System

The Deposit Refund System (DRS) is an efficient means through which the Governments could encourage citizens to retrieve the recyclable packages. The system imposes a deposit, which is included in the price of the product and can be returned to the consumer in case of retrieving the package undamaged. This is the main reason that DRS can achieve the highest return rate in comparison with Extended Producer's Responsibility system (EPR), which is widely used in many European States (Fullana-i-Palmer et al., 2017). The route of material and deposit is presented in Figure 3.

The Deposit System Management Operation (DSMO) is responsible for the productive function of the whole deposit refund system. The income of DSMO consists of:

- Deposits
- Producers' Fee that is a capital paid by producers to contribute to the recycling system
- Revenues from selling retrieved packages to recyclers.

As far as the outgoings, the following components are concerned:

- Retail handling fee, a capital paid to indemnify the retailers who take part in the system
- Operating costs of the DRS
- Deposits for the retrieved packages to indemnify the consumers.

2.2. Setting the merit of a deposit

The merit of the deposit is a very important factor to establish a DRS, since it defines the funds to be attributed to DSMO as income, part of which is used afterwards to compensate the consumers. It is easily understandable that the rate of the deposit designates the return rates of the system. A higher rate provides the consumers with a bigger motivation to return their recyclable packages (Biala and Aregbeyen, 2018). However, the level of the deposit should always keep up with the average salary of the Member State, where the DRS will be introduced. Otherwise, the citizens experience a price increase of the product, with concomitant result the fall of their purchasing power. Figure 4 presents the function between the value of the deposit, which is the domain of the function, and the return rates for some established European deposit systems.

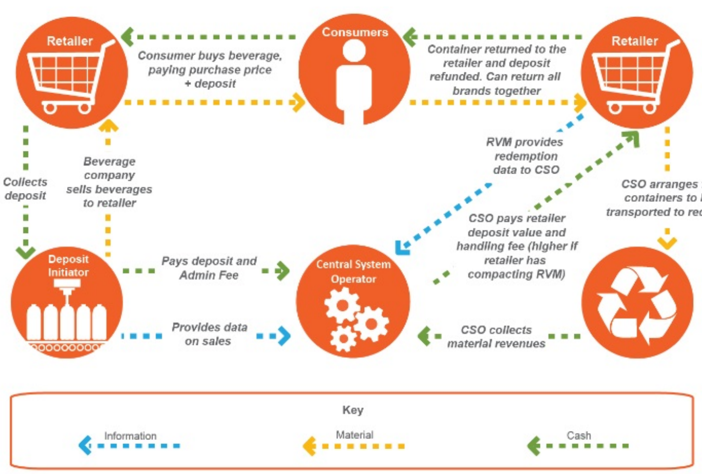

Figure 3. The route of material and deposit through industry, retailer, consumer and final recycler (Cordle et al., 2019; after permission)

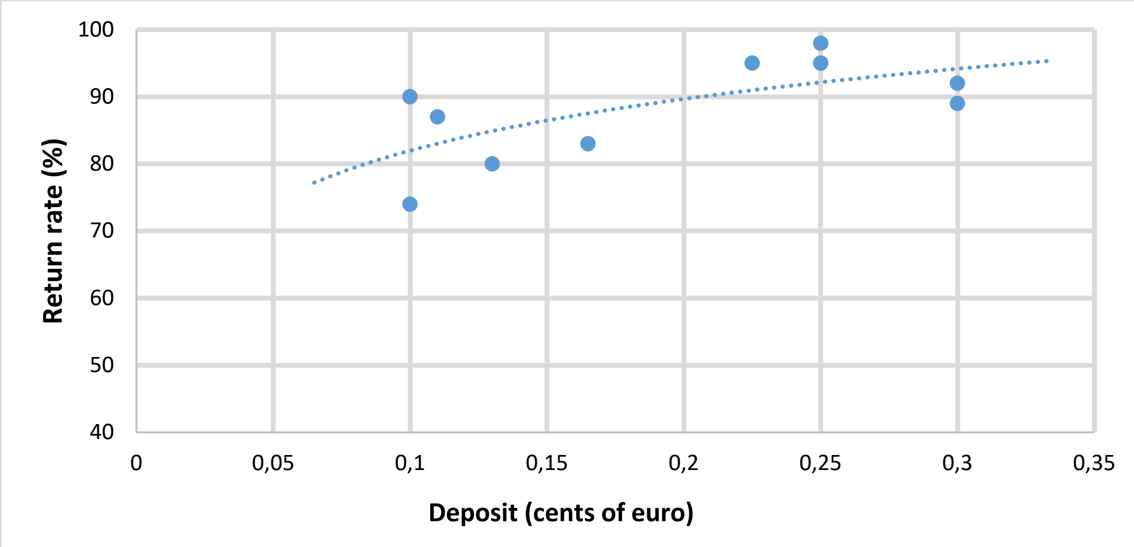

Figure 4. Return rate as a function of deposit value (The data for the creation of this diagramby the authors have been obtained from CM Consulting, 2016)

Obviously, the fluctuation of the return rate for the DRS of a specific-waste is affected by many factors such as the effectiveness of the financial study, on which the DRS was established, and the income of citizens. However, Figure 4 provides considerable information for the valuation of the deposit. In most cases, the choice of value 20 - 40 cents leads to high return rate, over 90 %. On the other hand, a value of 10 - 20 cents results in lower return rates, typically 74 – 87 %. Furthermore, it should always be noted that a DRS, working with high return rate (for example 95 %), demands quite more funding to operate in comparison with lower return rates (such as 90 %). As a result, the difference of 5 cents in the merit of the deposit induces different return rates and, by extension, greater operating costs. The correlation between the return rate and the operating cost will be distinct in the next sections. In view of the aforementioned, the value of 15 cents seems suitable for the needs of the DRS in Greece.

The methodology of the other economic parameters is presented in the corresponding Section.

3. Results and Discussion

3.1. Revenues and working capital

In Greece, 50 thousand tons of PET per year (throughout the study metric tons are considered only, 1 metric ton=1,000 kg) are imported and converted into packages of 0.5 and 1.5 liter. By assuming that the aforementioned packages participate in 1:1 ratio and with corresponding package weight of 20 and 30 g, it derives that approximately 2 billion packages of PET per year are discarded and, consequently, included in the DRS. Can-packages may also be included in the DRS but this is currently under consideration from the side of the Greek State. This work focuses on PET packages only. With 2 billion packages, which represent 50 thousand tons of PET, the annual total deposit capital that is handled among industry, retailers, DSMO and consumers, is estimated to about 300 million euros. It must be pointed out that the Greek DRS presents a distinctiveness in comparison with the other European DRSs regarding the distribution of the working capital throughout the year. In Greece, the consumption of beverages (both in cans and PET packages) is increased drastically in summer compared to winter because of tourism. As a result, the percentage of the annual total deposit capital for summer months is higher in comparison to the working capital for the wintertime.

- The monthly working capital in summertime, namely the percentage of the annual total deposit capital from May until September, is about 2.5 times higher than the corresponding in wintertime because of the increased consumption and, by extension, the increased retrieve of packages. The DSMO should be able to afford the working capital to pay the retailers for the deposits of the committed packages to the system. In case that the deposit refund system in Greece starts operating in summer, the DSMO will need 39 million euros monthly as summer working capital, which corresponds to approximately 13 % of the annual total deposit capital.
- On the other hand, the monthly working capital of the non-tourist season, from October until April, amounts to 15 million euros, which is 5 % of the annual total deposit capital.

Considering a deposit of 15 cents, the DRS in Greece is expected to reach a return rate of 85 % according to Figure 4. As a result, the outgoings for the DSMO to indemnify the consumers for the claimed deposits are amounted to 255 million euros. So, the annual earnings from unclaimed deposits are estimated at 45 million euros (or 3.75 million euros per month) as follows:

0.85 · 2 billion PET = 1.7 billion packages of PET returned to DRS

0.15 · 1.7 billion PET = 255 million euros

300 million euros – 255 million euros = 45 million euros annual earnings from unclaimed deposits

Considering an average price for PET of 310 euros per ton, the annual earnings from selling the packages to recyclers are estimated at:

0.85 · 50,000 tons PET = 42,500 tons PET recovered through the DRS or

310 euros/ton · 42,500 tons ≈ 13 million euros

To recapitulate, the annual earnings from unclaimed deposits and packages selling will be 58 million euros.

By comparing the two sources of earnings, it is comprehensible that the DRS is more profitable, if the system degrades its primary target and performs a lower return rate, as the income from unclaimed deposits is 3.5 times higher than the corresponding from returned packages sale. All these occur because the deposit value is higher than the price of bailed PET beverages. This is the main reason that the DSMO should operate as non-profit organization and should always be under close State control. In case that DSMO functioned with profit orientation, the management operation should decrease its return rate and utterly undermine the environmental purpose.

3.2. Investment and operating cost

The main factor that determines the total investment cost of a DRS is the number of reverse vending machines (RVM). Even though the current analysis takes into account only PET packages, the RVMs should be able to collect more materials to efficiently meet the requirements for future needs. Deposit Refund is a system with high investment cost; hence, the Greek State should reap as many benefits as possible from DRS.

The proportion of residents per RVM is an index that can provide an approach of the total RVMs needed for a country. However, this index must be carefully considered because:

- There is not integrated experience, as most European DRSs are still under development
- The proportion of residents per RVM is an index that uses data regarding the general population of the State and the total number of RVMs. Consequently, other significant factors, such as population density, extension of urban centers, etc., are not counted in.

For example, the Danish DRS operates approximately 3,200 RVMs for 5.8 million residents or 1,813 residents per RVM. Nonetheless, the population density of Denmark, with land area of 43 thousands square kilometers, is 135 residents per km^2 contrary to the population density of Greece that is 82.

Another important factor is the transportation cost of retrieved material, which is increased for Greece because of the geographical features. Especially during summer times, the transportation from Greek islands is quite expensive because of the massive consumption caused by tourists. In case of DRS, the transportation of intact, uncompressed material from islands would be unbearable for the DSMO. On account of this, the DSMO should invest more capital to buy even more RVMs to be placed on islands. So, the retrieved material will be cut, compressed, weighted and ready for its transportation. An additional tactic to avoid the rise of transportation cost is the cooperation of the DSMO with local recycling and sorting facilities so that the packages to be cut and compressed, even if they have not been collected through RVM. It is estimated that approximately 6,000 RVMs are required for the operation of the DRS in Greece, which is noticeably higher than in other countries with similar population and consumption. However, this is a strategic decision that every DSMO has to make; for Greece, the higher investment cost for more RVMs will result in the restriction of the annual cost of transportation, which is very significant.

A higher number of RVMs implies that the majority of empty packages will be collected automatically. The correlation between the number of packages collected automatically through RVM and the total number of packages collected through DRS is expressed by the rate of automation R, which is defined in the following way (Drab and Sluciakova, 2018):

R = 100 · (number of packages collected through RVM) / (total number of packages collected through the DRS system)

For Greece, the system is expected to operate at a rate of 90 %. The investment cost in this case is estimated to be around 155 million euros. This amount corresponds to the cost for:

a) investment, installation, and maintenance of RVMs,
b) processing the empty packages, which are not collected automatically, and
c) setting up the DSMO.

In order to reduce the total cost for the establishment of

DRS, the DSMO should take advantage of the existing transportation network and stations of trans-shipment. Similarly, the DSMO should use the existing facilities, which operate under EPR system, to process the empty packages instead of establishing new ones.

Having approached the investment cost, the next factor that should be calculated is the operating cost. The operating cost of a DRS consists of two main sectors:

- The expenses that are related to retailers.
- The outgoings that are related to the different processes and DRS has to perform.

The first sector is referred to the capital, which is paid by DSMO to indemnify the retailers who participate in the project. This capital is called Retail Handling Fee (RHF) and reimburses the retailers for the costs of collecting and storing empty packages. As a result, RHF depends on the way of collection (automatic or manual). For the collection through RVM, the compensation is higher. The main factors that determine the level of compensation are:

- The area of the shop that is reserved for the collection. In the case of automatic collection, this area is reserved by the RVM.
- The bags, which are used for the storage of retrieved packages.
- The consumption of energy (kWh) for the RVMs operation.
- The labor costs. Both automatic and manual collection need workers to operate. In fact, in many European countries, the increase of the working responsibilities does not necessarily imply corresponding rise of the salary; as a consequence, part of the compensation is converted into income for the employer. However, even in this scenario, a DRS analysis should consider the additional labor costs.

Table 2 presents a reimbursement price per empty package for the European Deposit Systems.

Table 2
Reimbursement price per retrieved PET package for the European DRSs (created by the authors with data obtained from: CM Consulting, 2016; Cordle et al., 2019)

Country	Euro per package for RVM and manual collection	
Croatia	0.02 (RVM)	0.01 (manual)
Denmark	0.0115*	
Estonia	0.0310 (RVM)	0.0105 (manual)
Finland	0.03 (RVM)	0.027 (manual)
Lithuania	0.028*	
Sweden	0.045(RVM)	0.023 (manual)

* There is no separate data for RVM and manual collection.

For the manual collection, the average reimbursement price for Europe is:

RHFmanual = (0.01 + 0.0115 + 0.0105 + 0.027 + 0.028 + 0.023) / 6 = 0.019 euro per PET package

As far as the automatic collection is employed, the average price is:

RHFRVM= (0.02 + 0.0115 + 0.0310 + 0.03 + 0.028 + 0.045) / 6 = 0.028 euro per PET package

For Denmark and Lithuania there is no separate data. For this reason, the common reimbursement price is used for the calculation of the average price in both RVM and manual collection. In order to calculate the annual total compensation capital that DSMO has to pay to retailers, the return rate and the rate of automation are required. For return rate 85 % and 2 billion of PET discarded per year (see Section 3.1), the number of packages to be collected through the Greek DRS is 1.7 billion. With an expected rate of automation 90 % approximately, 1.53 billion PET packages will be collected though RVM and 0.17 billion manually. As a consequence, the annual compensation for automatic collection is:

1.53 billion packages · RHFRVM = 1.53 · 109 · 0.028 = 43 million euros

And for the manual collection:

170 million packages · RHFmanual = 3.2 million euros

As expected, the annual reimbursement for manual collection is quite lower than that of the automatic one. The main reason for this significant difference is the number of RVMs. So, the total annual Retail Handling Fee (RHF) for the deposit system in Greece is 46.2 million euros. To calculate the total annual operating cost, the current analysis should approach the outgoings that are related to other processes, such as transportation cost, operating cost for the nonprofit DSMO and, finally, the outgoings for cutting and compressing the PET packages at sorting facilities/collecting centers. The operating cost for the other processes is calculated to 32 million euros (Table 3), while the total to 78.2 million euros or 0.04 euro per PET package; consequently, the average operating cost amounts to 0.04 euros per PET package.

3.3. Calculation of producer fee

Table 4 presents the main financial data used to calculate the producer fee.

The producers and importers will contribute both for the financial deficit and investment cost. The investment cost is an immediate demand for the operation of the DRS. DSMO in collaboration with producers should decide how the required capital will be collected. In the current analysis, it is considered that the producers, through DSMO, will get a loan to be redeemed during the first 10 years of system operation.

Table 3
Annual operating cost for the Deposit Refund System (DRS) in Greece

Retail Handling Fee per package for manual collection	0.019 euro
Retail Handling Fee per package for automatic collection	0.028 euro
Annual Compensation for manual collection	3.2 million euros
Annual Compensation for automatic collection	43 million euros
Annual Retail handling fee	46.2 million euros
Operating costs for DSMO + treatment of material (PET)	9 million euros
Annual transportation cost	23 million euros
Total annual operating cost of DRS	78.2 million euros

Table 4
The main financial data of the Deposit Refund System in Greece

Investment cost	155 million euros
Operating cost	78.2 million euros
Revenues	58 million euros
Deficit	– 20.2 million euros

Consequently, the producer fee should cover both the financial deficit of 20.2 million euros and the payoff of the loan, amounted to 35.7 million euros in total. This denotes that the producer fee is:

35.7 million euros / 50,000 tons = 714 euro per ton of PET or

35.7 million euros / 2 billion packages = 0.01785 euro per PET package

All the data that describe the operation of the DRS in Greece are summarized and presented in Table 5.

3.4. Statistical data and mathematical model for the DRS in Greece

Based on Table 5, statistical data derive in respect the share of producers' fee, selling material and unclaimed deposits in the revenues of the DRS in Greece (Figure 5). Similarly, data may be used to estimate the share of various components in the operating cost (Figure 6). Correspondingly, Figure 7 shows the effect of automation rate on investment cost.

Figure 5 indicates that the greatest share of the income for the DRS derives from the unclaimed deposits, especially when compared to the revenues from selling materials, which are quite lower. Regarding to the operating cost, the annual transportation cost remains at low level, contrary to the annual retail handling fee that is the most important factor.

Table 5
Features of the DRS in Greece

Total PET packages	2 billion packages, 50,000 tons
Return rate	85 %
Deposit	0.15 euro
Rate of Automation	90 %
Summer monthly working capital	39 million euros
Winter monthly working capital	15 million euros
Annual working capital	300 million euros
Total number of RVMs.	6,000
Annual earnings from unclaimed deposits	45 million euros
Annual earnings from selling bailed PET bottles	13 million euros
Producer Fee	714 euro/ton of PET or 0.01785 euro/package
Annual total revenues	93.7 million euros
Retail Handling Fee for manual collection	0.019 euro/package
Retail Handling Fee for automatic collection	0.028 euro/package
Operating cost	78.2 million euros
Investment cost	155 million euros

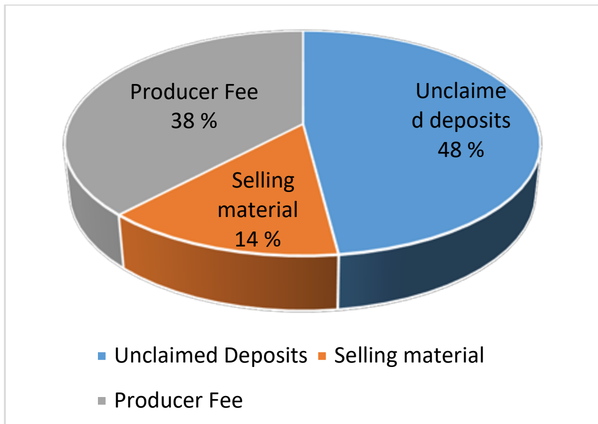

Figure 5. Revenues of the DRS in Greece

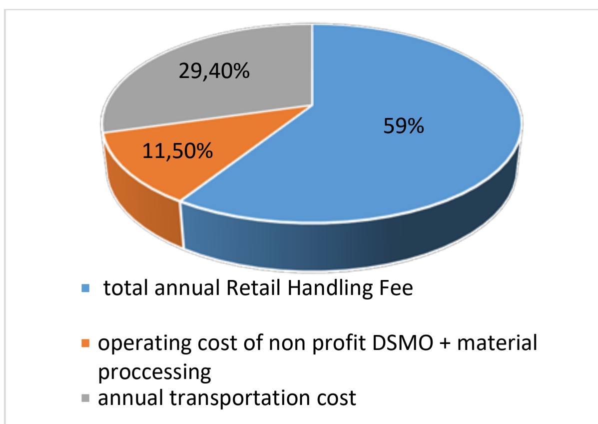

Figure 6. Allocation of the operating cost components of the DRS in Greece

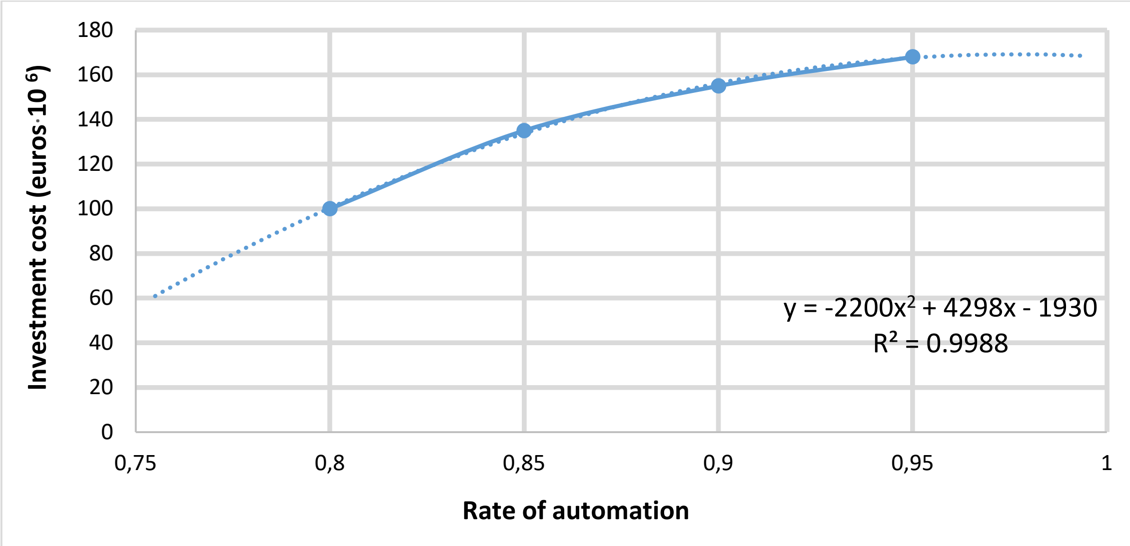

Figure 7. Investment cost as a function of the automation rate for the DRS in Greece

From Figure 7, it is obvious that higher rate of automation implies higher investment cost. However, a DRS operating at extremely high rate is not always efficient. An extremely high rate of automation, for example higher than 95 %, means that even the small retail shops will collect the bailed PET packages automatically. In most cases, the number of packages that are collected in small retailers is not enough to justify a RVM. In this case, the investment cost rises up and the efficiency of the system drops. In contrast, a low rate of automation, 80 % or lower, might affect the return rate negatively, which is the main target of the whole system; in addition, it will surely increase the cost of material processing, because the bailed bottles will not be shredded and compressed for transportation. In conclusion, the rate of automation, combined with other significant factors, such as deposit and return rate, greatly affect the operation of a DRS. Figures 8 and 9 show the correlation between the cost of manual and automatic collection, correspondingly, with automation rate, based on the data for the DRS in Greece.

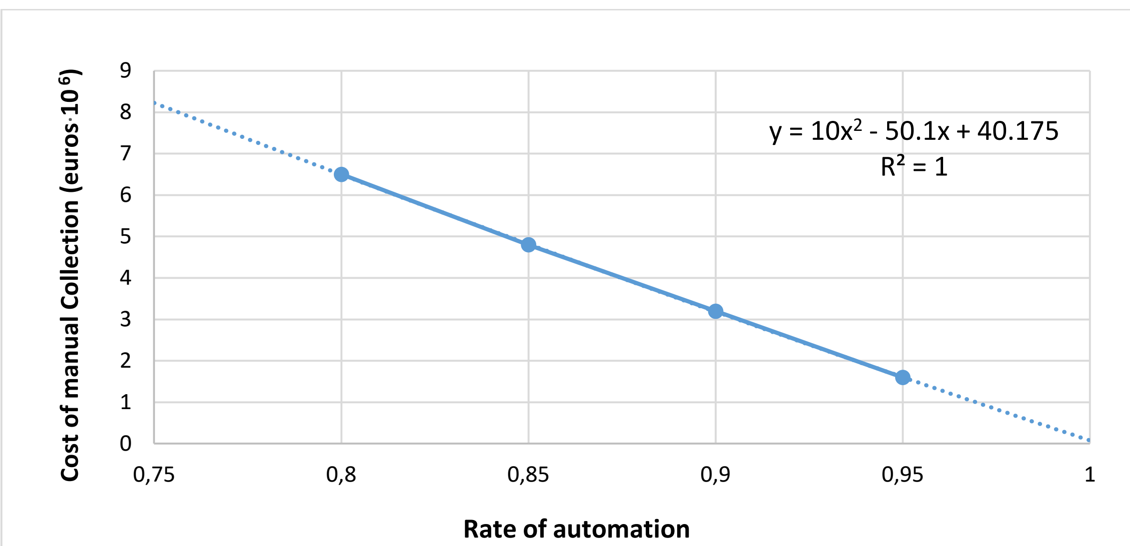

Figure 8. The cost of manual collection as a function of automation rate

The initial choice of automation rate for a new DRS is experiential. However, in the following years, DSMO is responsible to collect all the required data in order to calculate the real rate, under which the system operates, and, by extension, to change it if required.

The following functions can be used to review and modulate the operation of the Greek DRS:

Investment cost:

$(x) = -2200 \cdot x^2 + 4298 \cdot x - 1930 \qquad R^2 = 0.998 \qquad (1)$

Manual collection cost:
(x) = $10 \cdot x^2 - 50.1 \cdot x + 40.175$ $R^2 = 1$ (2)

Automatic collection cost:
(x) = $-28.571 \cdot x^2 + 98.229 \cdot x - 22.16$ $R^2 = 0.997$ (3)

The symbol R^2 is the coefficient of determination; its high values do not necessary divulge the appropriateness of the fitted statistical models. The operation of DRS is complicated; as a result the presented statistical model is being described by many factors compared to the amount of information of the existed literature.

The domain X of each function is the rate of automation. Theoretically, the values, which are assigned to the domain, are defined between [0, 1]. The value "0" represents the case that the DRS operates through manual collection of all packages; as a result, there is no investment cost. Similarly, the value "1" is assigned to the domain X when all packages are collected through RVMs. It is obvious that there is a theoretical explanation for both values, but, in reality, they represent extreme values of no practical usage.

Based on the previous analysis regarding the efficient values of automation rate, in the current case the domain X has been defined in the space [0.75, 1). As a result, the functions can be used for automation rate values from 75 % up to approaching 100 %.

The values of investment cost, manual and automatic collection cost can be easily either calculated from Equations 1-3 or determined from Figures 7-9. From these Figures, it can be concluded that:

- For the function of investment cost, the domain of values is [56, 168). The investment cost will get the value of 56 million euros when the rate of automation is 75 %. Similarly, the maximum investment cost is 168 million euros, when the rate of automation approaches 100 %.
- For the function of manual collection cost, the domain of values is [8.3, 0). The manual collection cost rises up to 8.3 million euros and tends to become zero as the rate of automation approaches 100 %.
- As for the function of automatic collection cost, the domain of values is [35, 48). The automatic collection cost starts with 35 million euros, when the rate of automation is 75 %, and rises up to 48 million euros when automation rate approaches 100 %.

Summing up the aforementioned costs, regarding automatic, manual collection and investment cost, a new function derives:

Cost (x) = Investment cost (x) + manual collection cost (x) + automatic collection cost (x)

Cost (x) = -2218.571 x2 + 4346.129 x -1911.985

The domain X of the function is the rate of automation with values from 0.75 to 1 or 75 % to 100 %, as it has already been pointed out.

With the aid of Geogebra, an interactive statistics application, it is feasible to present the graph of the Cost function (x).

The domain of the function is restricted in order to present the graph for the rate of automation from 75 % to 100 %. As shown in Figure 10, as the rate of automation rises, the cost also increases. This increase is expected and can be mathematically explained by comparing the monotonicity of the functions that were inserted into Equation (4). To conclude, the increase of automation rate of an operating DRS results into severely higher cost.

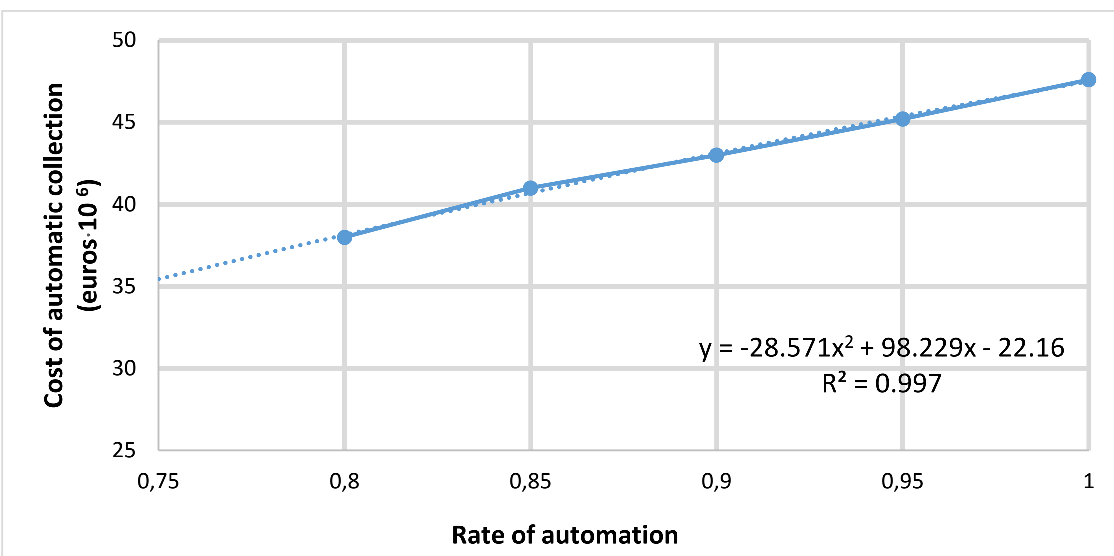

Figure 9. The cost of automatic collection as function of automation rate

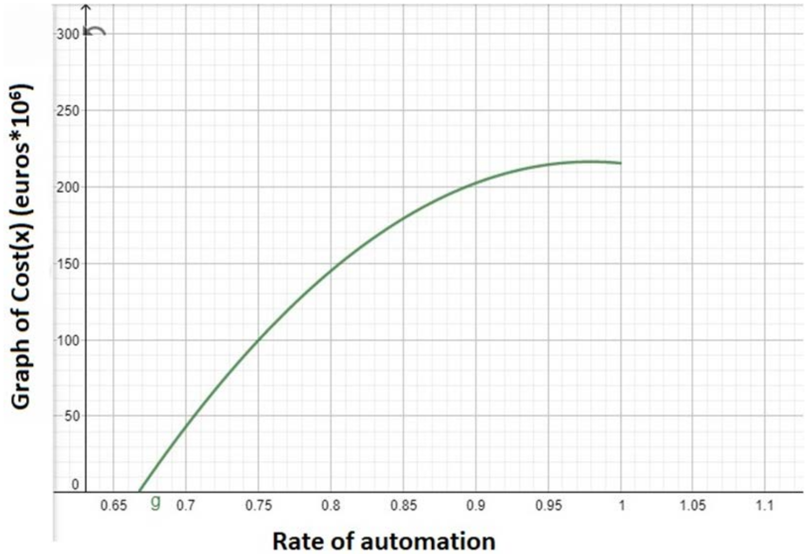

Figure 10. Graph of cost vs. automation rate restricted approximately in the range [0.75, 1)

However, it is already mentioned that a rate of automation lower than 75-80 % negatively affects the environmental goal. As a result, the increase of the automation rate in order to improve the existing return rate of an operating DRS should be the least preferable action considered by DSMO. In case of missing the target, the first action to be taken by DSMO is to re-examine the positions of RVMs in order to make sure that they are distributed properly.

In conclusion, the rate of automation is a key factor for the operation of the Deposit Refund System (DRS). One more vital component is the return rate. The importance of the return rate can be seen in Figure 11, which presents 5 scenarios for the Greek DRS with different return rates while all the other factors remain constant.

Figure 11 shows that for return rate 85 % there is annual financial deficit of 20.2 million euros, which will be covered by producer fee. On the other hand, return rate of 75 % implies financial surplus of 16.95 million euros annually. Although operating costs would be decreased because of the less retrieved packages, this surplus corresponds to the case of almost unclaimed deposits, which the DSMO get as revenues due to lower return rate. At higher return rates, the financial deficit increases, as expected, and finally reaches to 53.6 million euros for return rate of 95 %. From Figure 11, it is obvious that the DRS requires extremely big financial support to achieve high return rates; in contrast, DSMO would have enough profit to repay the loan at low return rates scenarios. The relation between the financial balance of DSMO and the return rates is clearly seen in Figure 12.

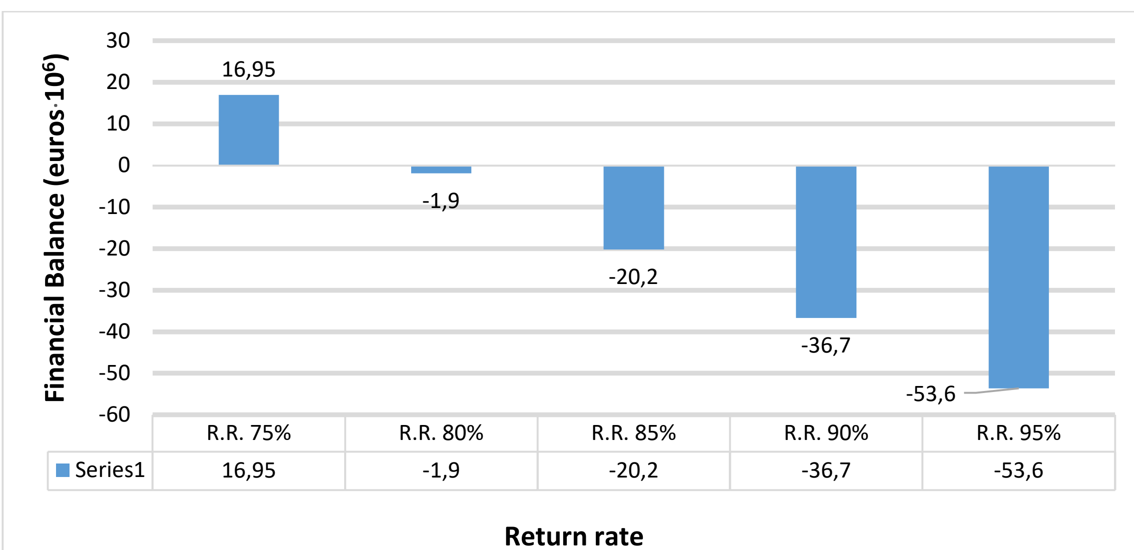

Figure 11. The financial balance of the Greek DRS for various return rates

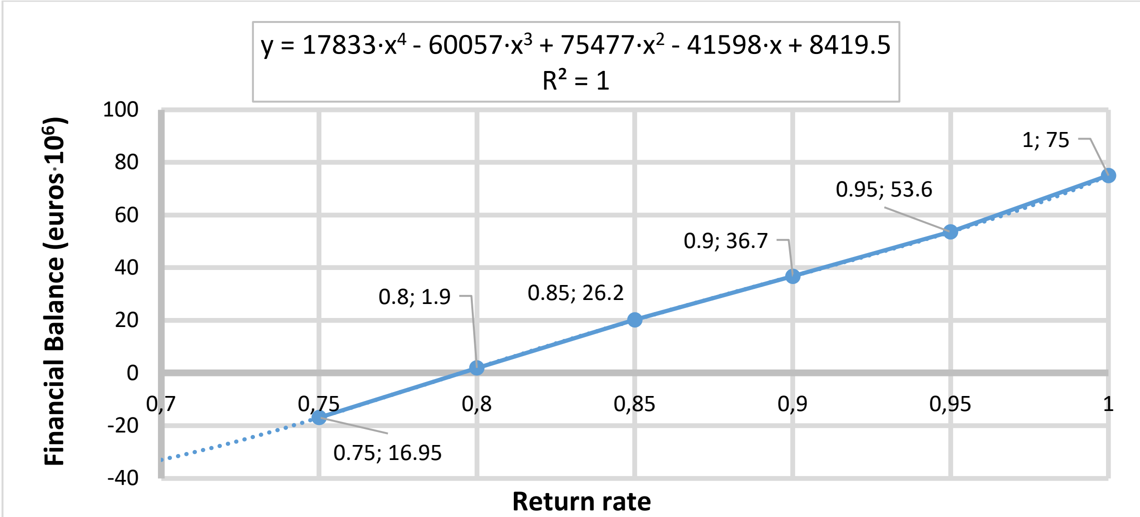

Figure 12. The financial balance of the Greek DSMO as function of the return rate

In Figure 12, the negative values of vertical axis represent a financial surplus for DSMO, while the positive ones depict a financial deficit.

The function that describes the relation between the financial balance (F.B.) and the return rate (x) is:

$$F.B.(x) = 17833 \cdot x^4 - 60057 \cdot x^3 + 75477 \cdot x^2 - 41598 \cdot x + 8419.5 \quad R^2 = 1 \quad (4)$$

The F.B. function such as (1), (2), (3) is derived from the model-based approach of the present paper. The approach started with two major estimations based on the data of existing European deposit systems:

1. A deposit of 15 cents will entrain roughly a return rate of 85% (section 2.2 “Setting the merit of a deposit”).
2. The Greek DRS requires approximately 6,000 RVMs in order to operate at 90 % rate of automation. The high return rate utterly configures the investment cost and portion of the operating cost, such as transportation cost (section 3.2 “Investment and operating cost”).

Entrenched on these two estimations, the paper sets scenarios where the Greek DRS operates on different return rates and rates of automation. However, in these scenarios, a major assumption is made. While rate of automation changes (see Figures 7, 8, 9), all the other factors (for instance return rate and transportation cost) remain constant. The same observation is in force in Figures 11 and 12, where the independent variable is the return rate. Under real conditions, an increase of the rate of automation could lead to raise of return rate. The domain X of the function is the return rate and, as previously mentioned, it can get values in the space [0.7, 1), namely from 70 % up to the theoretical value of 100 %.

The domain of the function F.B.(x) can get values from -33.21 million euros, which corresponds to profit for the DSMO, up to 75 million euros as deficit, that is to say [-34, 75). The equation F.B.(x) = 0 is realized for the value of the domain x=0.7957, which means return rate 79.57 %. Practically, the DSMO demands no financial support from the producers at the point (0.7957, 0) of the Cartesian coordinate system. As a result, the revenues of the system would be able to cover the operating costs with no need of producer fee.

The relation between the producer fee and the return rate can be seen in Figures 13 and 14. The difference between the Figures 13 and 14 is the process of calculating the Producer Fee. Regarding Figure 13, producer fee is calculated to cover the financial deficit for different return rates, while as for Figure 14 the producer fee is calculated to repay both financial deficit and annual capital required to pay off a 10-year loan for the investment cost.

3.4. Effects and impacts

The biggest advantage of the DRS establishment in Greece is the return rate, which is expected to be very high. Practically, it is expected to collect approximately 42,000 tons of PET per year; in turn, this means that 25,000 tons of PET will be added up to the recycling system, which otherwise would end up in the sea or in landfills. The production of one PET bottle generates approximately 82.8 grams of CO_2 emissions (Razis and Christopoulos, 2021). Taking into account that the ratio of packages 0.5 liter to1.5 liter is 1:1 and the corresponding weight of each package (also see Section 3.1), it can be concluded that the 25,000 tons of PET correspond to 1 million PET packages. Consequently, if not recycled, approx. 82,800 tons of CO_2 emissions should had been released to replace the lost PET packages and cover the consumption needs.

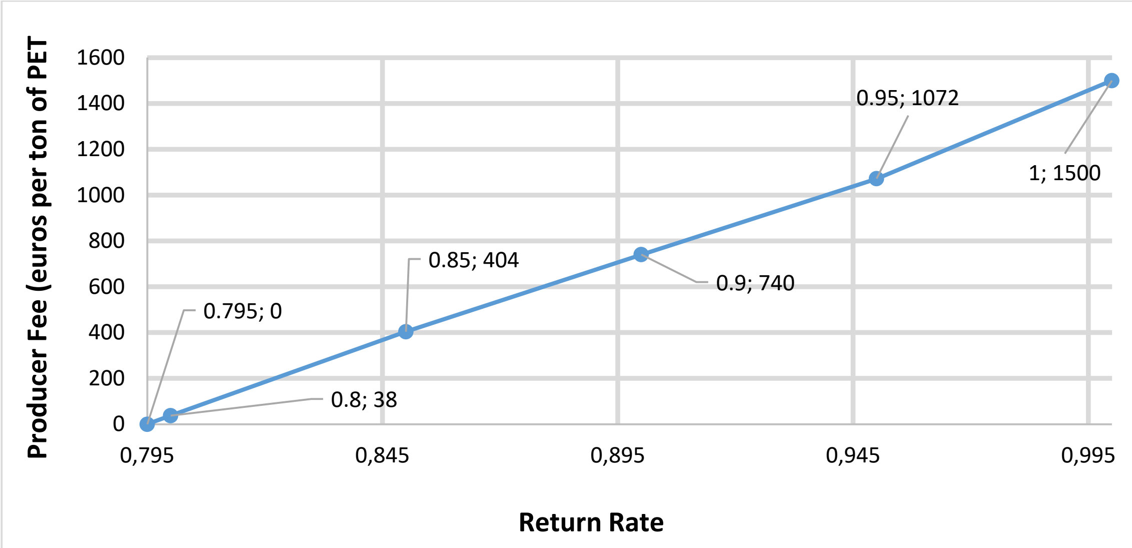

Figure 13. Producer Fee as function of Return Rate

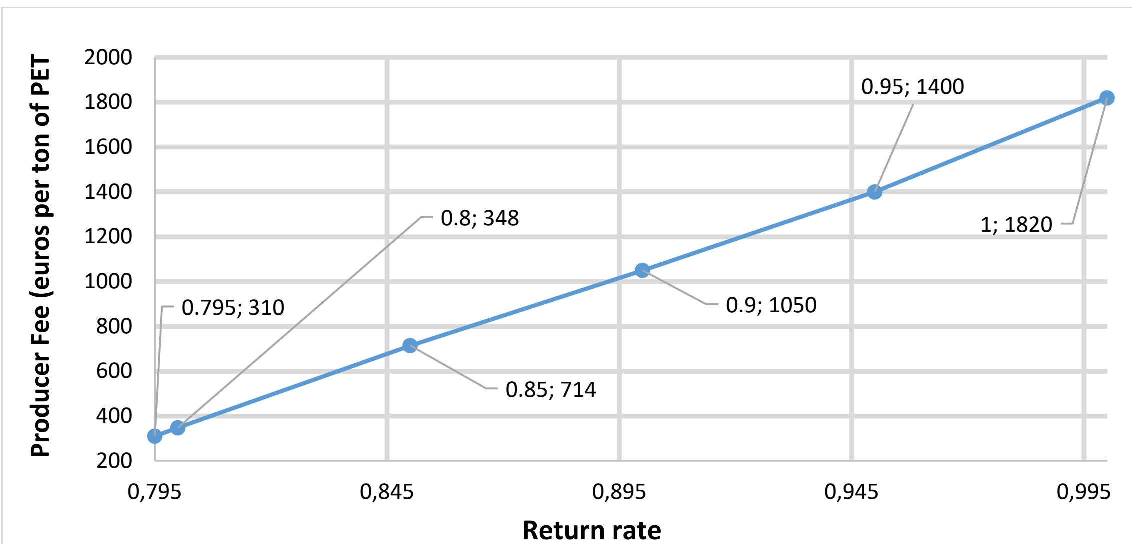

Figure 14. Producer Fee, calculated to cover both the financial deficit and the investment cost, as function of return rate

The recycling of packages can reduce the CO_2 emissions by 30-70 %, with the exact rate depending on many factors, such as the selected recycling system and the adaptation of the system to the needs of the country. Therefore, the DRS in Greece could annually reduce the CO_2 emissions by 24,000 - 58,000 tons.

Furthermore, the establishment of the DRS in Greece will provide a better control of the material and, by extension, of the whole system, in comparison with the existing EPR model, whose most data are based on estimations. Finally, it will result in the reduction of cleaning costs for the local authorities.

On the other hand, the main drawback is the financial burden of the DRS. Both investment cost and operating cost of the system are quite high, especially in comparison with the existing EPR model. The investment cost is estimated from 90 to 155 million euros (Razis and Christopoulos, 2021), depending on the strategic decisions that DSMO has to make. This cost will lead to a financial transaction between Greek State and a foreign company, since there is no Greek manufacturer to provide the RVMs. As a result, there will be no other sector of the Greek economy to be involved and take benefit of this capital.

The establishment of the DRS in Greece will negatively affect the operation of the existing recycling model EPR. For the EPR model, PET is a material with financial surplus; basically, the PET packages support the collection of the other materials such as glass and paper. As a result, the operation of the DRS in Greece will decrease the revenues of the existing model. In case of including aluminum packages to DRS, the EPR revenues will be reduced drastically.

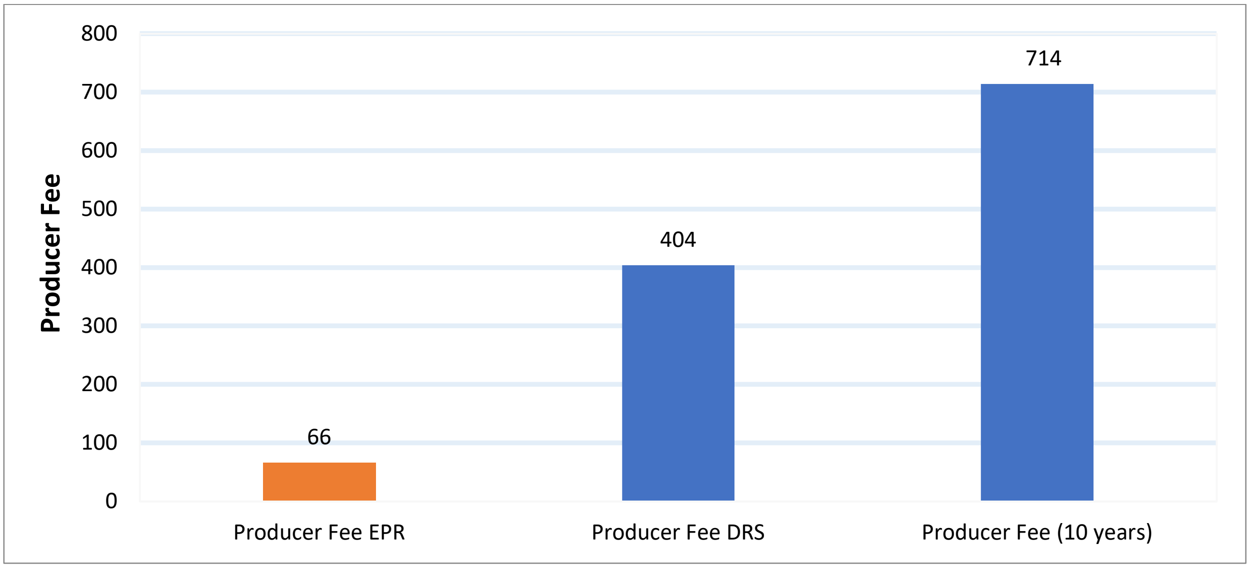

Figure 15. The producer Fee for the Greek DRS and the existing EPR model

The Producer Fee of PET material for the EPR model is 66 euro per ton of material (Razis and Christopoulos, 2021), contrary to DRS model where the Producer Fee is 404 and 714 euro per ton of PET (also see Section 3.3), including investment cost. In conclusion, the financial support necessary for the operation of the Greek DRS is 6 to 10 times higher than that of the EPR (Figure 15).

As Figure 16 indicates, PET is a profitable material under the current EPR system while the outcome under DRS is financial deficit for high return rates.

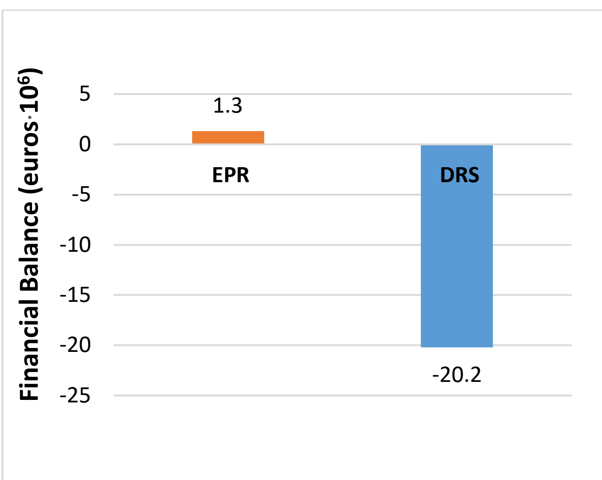

Figure 16. The annual financial balance of PET material for EPR and DRS

EPR model is estimated to collect annually 17,000 tons of PET approximately. As a result, the total amount of capital required to support the collection of the material is:

17,000 tons · 66 euro per ton of PET = 1.12 million euros

Taking into account that the population of Greece is 10 million, the financial burden per capita for the EPR model, regarding PET material, is 0.112 euro per capita.

As for the DRS, with expected return rate 85 % there is a financial deficit of 20.2 million euros or 36.7 million in case of including the investment cost (also see Section 3.4), which denote a financial burden 2.02 or 3.67 euros per capita correspondingly; the producer fee is estimated to be 404 or 714 euros per ton of material (also see Section 3.3).

To compare, the financial burden per capita for the DRS in Greece is 20 to 32 times higher than the corresponding of the EPR system that is currently applied (Figure 17).

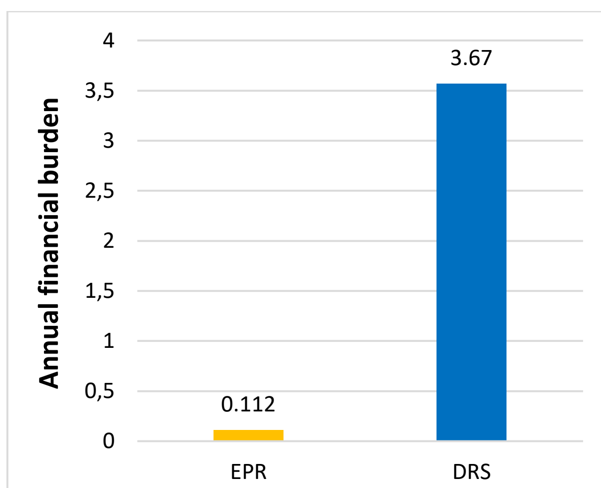

Figure 17. The annual financial burden per capita for DRS and EPR system in Greece

In Table 6 the advantages and the drawbacks of the establishment of the Greek DRS are briefly presented.

Table 6
Benefits and disadvantages of the establishment of DRS in Greece

Benefits	Disadvantages
High return rate	High investment and operating cost
Annual reduction of CO_2 emissions	Unfavorable ratio of cost and environmental outcome
Endorsement of circular economy	Binding decision for the future of national recycling system
Better control of the material and, generally, of the whole collection system	Indirect financial burden of EPR system
Discharge of the local governments from collecting PET material	High financial burden for the Greek society in comparison with the existing system
	Interaction of DRS with a great number of retailers
	Disputable environmental outcome

4. Conclusions

This study clearly shows that the establishment of a DRS (Deposit Refund System) in Greece will increase the return rates for plastic containers which is quite important for Greece, considering the great pollution of Mediterranean Sea from plastic leakage. Furthermore, DRS will especially benefit the Greek islands, which attract thousands of tourists every year. However, the operation of the system will burden the Greek citizens. The investment cost of DRS is quite high compared to the annual funding of other important sectors such as public health-care system, public education, or the existing funding of recycling. The Greek State, society and science community should examine in length the application of this system. Finally, it has to be noted that aluminum packages should be incorporated into the DRS, in order to take maximum advantage of the high investment cost. In case of adding more materials to the DRS, there should be financial support for the existing EPR model, so there will not be any undesired results on the environmental targets of the other materials.

To globally approach an ideal circular economy, there must be a combined effort towards three main directions (Figure 18):

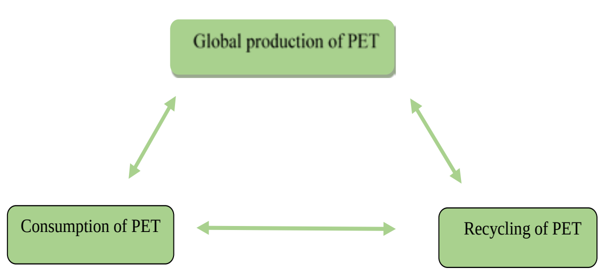

Figure 18. The three main factors for approaching Circular Economy (Mavropoulos and Nilsen, 2020)

- Promoting the recycling of materials though collecting the bailed packages and processing them to re-enter the production.
- Changing the global production of all goods such as energy and products by designing new products with bigger life cycle based on recycled raw materials.
- Reducing the consumption of products in general.

These three factors are important and should be equally promoted in order to entirely achieve the environmental goals. Advancing the recycling without reducing the global consumption of all goods will turn the recycling into a reason for even more consumption, which means even more pollution of the planet regardless of the effectiveness of the established recycling systems. Similarly, promoting the recycling without changing the global production of goods will lead to partial limitation of the waste without providing the environmental issues with actual solutions. Establishing new systems for plastic recycling or designing new alternative products for single-use plastic products, such as plastic straws, is not sufficient means to cope with the growing plastic production in the following years.

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Uspostavljanje sistema povraćaja depozita za PET ambalažu u Grčkoj: ekonomska analiza, prednosti i posledice

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Evaluacija Sistema povraćaja depozita u Grčkoj
Reciklaža PET amabalaže

I Z V O D

Ovaj rad se bavi uvođenjem Sistema povraćaja depozita kao novog sistema reciklaže u Grčkoj za PET ambalažu, a u skladu sa Evropskom direktivom 2019/904. Osnovna svrha ovog rada je predstavljanje analize troškova i prednosti, koja se bavila procenjivanjem sugestija i uticaja koje bi pomenuta direktiva imala u Grčkoj. Pored analize troškova i prednosti koje bi sistem imao, izvršeno je i poređenje između ovog modela i postojećeg modela reciklaže za PET ambalažu kako bi se otkrio njihov uticaj u Grčkoj. Pored toga, uspostavljen je i matematički model zasnovan na podacima o reciklaži PET ambalaže u Grčkoj. Ovaj model opisuje rad odgovarajućeg Sistema povraćaja depozita u Grčkoj, a mogao bi biti koristan za razumevanje, uspostavljanje i poboljšanje ovakvog sistema za druge otpadne proizvode.