

Article

Assessment of the Quantities of Non-Targeted Materials (Impurities) in Recycled Plastic Packaging Waste to Comply with EU Regulations and Sustainable Waste Management

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Abstract: Plastic packaging waste (PPW) can be considered as solid waste with harmful effects on the environment or as a material with recycling potential in terms of sustainable development in a circular economy. Knowing the amount of PPW generated is very important as it is related to the availability of this material for recycling and determines the actual recycling rate (denominator of a fraction). PPW is very heterogeneous and contains a certain number of impurities (e.g., product residues, direct printing, glue, labels, plastic sleeves, cap, etc.). According to EU law, an annual report (for the data in 2021) on the masses of both the PPW actually recycled (PPW_R) (“targeted materials”) and impurities (“non-targeted materials”) must be prepared and submitted to the European Commission. The PPW_R is used for the calculation of the recycling rate (the numerator in a fraction). The impurities should be considered for the calculation of own resources (national contributions to the general EU budget based on the uniform call rate of 0.80/kg of non-recycled PPW). To date, the Council of the EU has not proposed a method for calculating these amounts, so they have only been estimated. The present study (the first of its kind in Poland) aimed to estimate the number of impurities in PPW and the actual amount of PPW_R at the calculation point using a method accepted by the EU. In the installations, PPW (plastic packaging (15 01 02), multi-material packaging (15 01 05) and mixed packaging waste (15 01 06)) is recycled together with other plastic waste (plastic (16 01 19), plastic (17 02 03), plastic and rubber (19 12 04), and plastics (20 01 39)). It was assumed that the proportions of the mass of individual types of PPW in the total mass of plastic waste processed in the installation were proportional to the mass of impurities in these individual types of PPW. It was found that the average percentage of impurities in PPW was 4.40–6.90%, which seems to be relatively low. However, this means that, when calculating the PPW_R, the mass of impurities should be subtracted from the mass of PPW entering the recycling process. As a result, the mass of PPW_R at the calculation point in 2021 in Poland was almost 30,000 tonnes lower than the original mass entering the installation. Thus, applying the uniform call rate to the weight of impurities in the PPW increases Poland’s own resources by approx. 24 million euros.

Keywords: sustainable management of plastic packaging waste; recycling; impurities; calculation point; own resources; uniform call rate



Citation: Waszczyłko-Miłkowska, B.; Bernat, K.; Szczepański, K. Assessment of the Quantities of Non-Targeted Materials (Impurities) in Recycled Plastic Packaging Waste to Comply with EU Regulations and Sustainable Waste Management. *Sustainability* **2024**, *16*, 6226. <https://doi.org/10.3390/su16146226>

Academic Editor: Paolo S. Calabrò

Received: 15 May 2024

Revised: 11 July 2024

Accepted: 13 July 2024

Published: 21 July 2024



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1. Introduction

Plastics have many uses and applications today. However, in addition to the many positive aspects of plastics, they also pose an environmental problem due to their alarming quantities. In 2019, 460 million tons of plastics were used worldwide and it is estimated that this figure will almost triple by 2060 [1]. It should be emphasized that plastic packaging accounts for around 40% of the demand for plastics in Europe [2]. Unfortunately, only part of the plastic packaging waste (PPW) was recycled [3]. In 2021, each EU resident generated

an average of 36.1 kg of PPW, of which 14.7 kg was recycled. To control recycling rates, among other things, the European Commission has identified plastics and packaging as one of the key products in its Circular Economy Plan [4]. This is necessitated by the amendment to Directive 94/62/EC [5], which includes the requirement to achieve the recycling target for plastic packaging of 50%, 55%, and 60% by 2025, 2030, and 2035, respectively [6]. To find the actual recycling rate, the amount of actual plastic packaging waste recycled (PPW_R) (so-called “targeted materials” [7]) and the amount of PPW generated are necessary to be determined. One of the methods to determine the amount of PPW generated annually is based on the amount of plastic packaging placed on the market (PPM) (i.e., with the use of the placed-on-the-market approach) [8]. In our previous study, the annual amount of PPW generated in Poland was estimated with the use of this approach [9]. This methodology and the results of the research meet the EU’s expectations in terms of data reliability as well as the inclusion in the calculations of all sources of products in plastic packaging placed on the market. The difference between the amounts of PPW generated and of PPW_R is the amount of non-recycled PPW, which is used for the determination of a new category of own resources based on national contributions (EUR 0.80 per kilogram of non-recycled PPW). This uniform rate of collection was introduced in 2021 by the decision of the EU Council [10]. The guidelines for the calculation of own resources [8] entered into force on 17 March 2023, for the data of non-recycled PPW from 2021.

To determine the amount of actual PPW_R (“targeted materials”), a new methodology (considering the number of impurities in the mass of PPW ((so-called “non-targeted materials”) at the calculation point) was found and used. Targeted or non-targeted materials mean packaging waste materials that are reprocessed or not reprocessed, respectively, in a given recycling operation into products, materials, or substances that are not waste [7].

As defined in the Commission Implementing Regulation [8], recycled PPW is the mass, expressed in kilograms, of PPW at the calculation point for plastics, including the plastic components of the composite and other packaging. The calculation point is defined in the Decision [11] and means “the point where packaging waste materials enter a recycling operation whereby waste is reprocessed into products, materials, or substances that are not waste or the point where the waste materials cease to be waste” as a result of pre-treatment undertaken before reprocessing. The definition of recycling and the attribution of the corresponding types of recovery process (R) is important for the calculation of the mass of PPW recycled.

Recycling means any recovery process by which waste materials are reprocessed into products, materials, or substances to be used for the original purpose or other purposes [12]. Recycling includes the reprocessing of organic materials, but not energy recovery and reprocessing into materials to be used as fuels or for backfilling operations. In light of this definition, the preparation for reuse should also be considered a recycling process, as it concerns recovery processes that include checking, cleaning, or repairing products or components of products that have previously become waste and are processed so that they can be reused without any other preprocessing. Thus, preparations for reuse are recovery processes, which include recycling.

In both cases, the purpose of recycling is the same and leads to waste reuse. These processes are among the highest priorities in EU legislation, and waste prevention and management policy are based on the waste hierarchy. The aforesaid legislation, as well as the targets required by the EU, were the basis for the analysis presented here. In this context, it should be mentioned that the Waste Framework Directive [12] and the Packaging Directive [6] are not consistent in terms of setting values for the main targets, i.e., preparation for reuse and recycling. Article 6(1)(i)(i) of the Packaging Directive indicates minimum recycling targets for plastics contained in packaging waste. On the other hand, the Waste Framework Directive [12] indicates target values for both preparing for reuse and the recycling of municipal waste (Article 11, 2c, 2d, 2e).

To resolve this inconsistency in the Directives, national law [13] about waste recovery outside waste installations and facilities is crucial. Polish legislation specifies the types of

waste and the conditions for their recovery outside installations and facilities in recovery processes R3, R5, R11, and R12. All the types of waste generated from products or parts of products in the recovery process R12 may be subjected to operations that consist of checking, cleaning, or repairing products or parts of products that constitute waste, to prepare them for reuse without any other pre-treatment operations, taking place without the use of stationary facilities. Thus, packaging waste prepared for reuse through the R12 process may be counted as recycled. The types of recovery processes are indicated in Annex II of the Waste Framework Directive [12]. R1 processes—“Mainly the use as a fuel or other means to generate energy”—is not considered recycling according to its definition and the waste hierarchy. Likewise, R13 processes—“Storage of waste before any of the operations indicated in points R1–R12 (excluding temporary storage, before collection, on a site where waste is produced)” —should not be considered recycling.

In most EU countries, including Poland, the mechanical recycling of plastics is predominant [14]. Recycling installations mainly accept waste separated by type of plastic. Depending on the technology used, the installations can also accept PPW subdivided according to physical properties (color or hardness) or the purpose of the packaging from which the waste originates (e.g., beverage bottle). The properties of PPW have a strong influence on the subsequent processing steps such as sorting and recycling and, consequently, influence the recyclability of PPW and, ultimately, the amount of PPW_R . It is known that PPW is very heterogeneous in terms of polymers (PET, PP, PE, etc.) or packaging types (bottles, trays, films, etc.) [15,16]. PPW contains a certain number of impurities such as foreign materials, for example, used for decoration (direct printing, adhesive, labels, plastic sleeve, cap, etc.) or product residues [17–19]. All of these components are considered “non-targeted materials” and, unfortunately, are mostly not reprocessed in a given recycling operation into products, materials, or substances that are not waste [7]. For example, beverage bottles can contain about 10% of components that are not made of the same polymer as the bottle body and about 10% that are not even made of plastic [20].

In Poland, the primary source of data on the types and weights of treated waste and the treatment processes applied (e.g., recycling), as well as data on the transboundary movement of waste, is the Database on Products, Packaging, and Waste Management (BDO) [21]. The underlying principles for establishing the BDO register in Poland were to:

- increase control over waste management at a national level and ensure the monitoring of waste streams by enabling waste records to be kept in the BDO register;
- optimize the waste management reporting process;
- optimize the processes of registering in the BDO, updating data, and deleting entities from the register by introducing an electronic form;
- reduce irregularities in the waste management sector.

The BDO register constitutes an integrated information and communication technology system that has been in operation since 2018. The register and reporting modules were launched on 1 January 2020. It is administered by the Ministry of Climate and Environment, and the register of entities is maintained on an ongoing basis by the Marshalls of the Voivodships. The terms of registration of certain entities as well as the types of information collected in the Database are regulated by Polish law [21]. Moreover, the BDO register is considered by the EU as a reliable data source. Therefore, the source of the analyzed data in this study was the BDO register. Regarding recycling installations for PPW and OPW, which were the subject of this study, the following data (from 2021) were obtained from the BDO register: the number of materials entering the process (each type of waste labeled with codes (PPW and OPW being a sum of “targeted materials” and “non-targeted materials (impurities)”), and the number of materials at the output of the recycling process, i.e., the number of impurities (sum of “non-targeted materials” from PPW and OPW).

According to EU law, it is necessary to calculate the number of the “targeted materials” (in this case, PPW_R). As mentioned, the definition of PPW_R indicates that the waste mass should be determined at the calculation point. To date, no methodology has been proposed by the Council of the European Union to determine the number of impurities present in

PPW (“non-targeted materials”). Therefore, the present study was carried out to develop a methodology to estimate the number of impurities at the calculation point in PPW generated and recycled at a national level in Poland as well as the actual mass of PPW_R . It should be emphasized that the developed methodology enables the determination of the number of “non-target materials” not only for PPW but also, for example, for other plastic waste (OPW), i.e., non-packaging waste, taking into account the type of waste.

2. Materials and Methods

2.1. Mass of PPW Generated in Poland and Recycled

To determine the mass of PPW prepared for reuse and recycled in Poland in 2021, it was necessary to identify the waste codes assigned to PPW. Waste with the following codes should be considered as PPW: 15 01 02—plastic packaging, 15 01 05—multi-material packaging, and 15 01 06—mixed packaging waste [22]. The following formula (Equation (1)) was used to calculate the mass of PPW generated in Poland and recycled in 2021:

$$PPW = PPW_1 + PPW_2 - PPW_3 \quad (1)$$

where:

PPW_1 —the mass of PPW (kg, Mg) recycled in Poland in 2021;

PPW_2 —the mass of PPW (kg, Mg) generated in Poland and recycled outside Poland in 2021;

PPW_3 —the mass of PPW (kg, Mg) imported from outside Poland and recycled in Poland in 2021.

2.2. Determination of the Contribution of Impurities (I) (“Non-Targeted Materials”) at the Calculation Point

A schematic diagram of the recycling process at the installation can be useful in the determination of the contribution of impurities (I) in PPW at the calculation point ($I_{15\ 01\ 02}$, $I_{15\ 01\ 05}$, and $I_{15\ 01\ 06}$) (Figure 1). At the installations, PPW with the codes 15 01 02, 15 01 05, and 15 01 06 is recycled with other plastic waste (OPW) from waste categories 16, 17, 19, and 20 (16 01 19—plastic, 17 02 03—plastic, 19 12 04—plastic and rubber, and 20 01 39—plastics) [22].

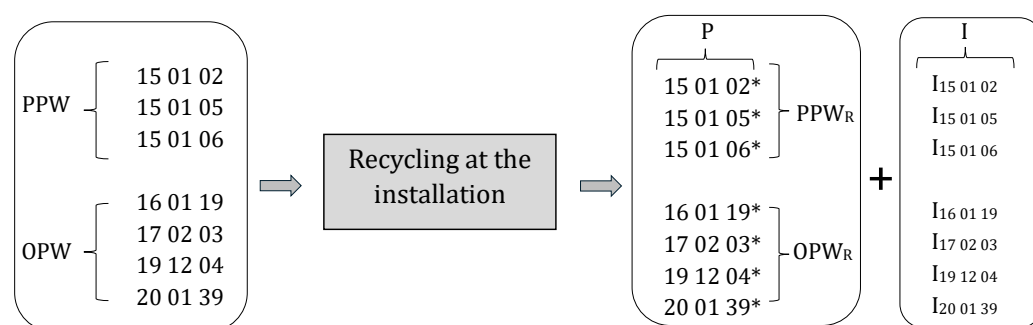


Figure 1. Schematic diagram of the recycling process at the installation; PPW processed (recycled) at the installation (15 01 02—plastic packaging, 15 01 05—multi-material packaging, and 15 01 06—mixed packaging waste), OPW waste processed at the installation (16 01 19—plastic, 17 02 03—plastic, 19 12 04—plastic and rubber, and 20 01 39—plastics), P—product, which is the actual mass of PPW and OPW free from impurities (waste codes with *), I—impurities.

The recycling process of both PPW and OPW separates the impurities (I) from the product (P), which is the actual mass of PPW_R and OPW_R free of impurities. At this stage, there is no possibility of directly distinguishing the number of impurities that come from PPW. To determine the number of impurities present in PPW at the calculation point and then the actual mass of packaging waste recycled (PPW_R), the following methodology was developed. Firstly, the percent share of PPW processed at the installation (S_{PPW}) in the total

mass of plastic waste (PPW+OPW) that was processed at the installation was determined (Equation (2)):

$$S_{PPW} = \frac{PPW}{PPW + OPW} \cdot 100\% \quad (2)$$

where:

PPW—the mass of PPW (kg, Mg (15 01 02, 15 01 05, and 15 01 06)) processed at the installation;

OPW—the mass of other plastic waste (kg, Mg, (16 01 19, 17 02 03, 19 12 04, and 20 01 39)) processed at the installation.

Taking into consideration the individual types of PPW, i.e., corresponding to codes 15 01 02, 15 01 05, or 15 01 06 (kg, Mg), the shares of the individual types of PPW processed at the installation ($S_{15\ 01\ 02}$, $S_{15\ 01\ 05}$, and $S_{15\ 01\ 06}$) in the total mass of plastic waste processed (PPW+OPW) at the installation was determined (Equation (3), shown in three versions, one for each code):

$$\begin{aligned} S_{15\ 01\ 01} &= \frac{15\ 01\ 01}{PPW + OPW} \cdot 100\% \\ S_{15\ 01\ 05} &= \frac{15\ 01\ 05}{PPW + OPW} \cdot 100\% \\ S_{15\ 01\ 06} &= \frac{15\ 01\ 06}{PPW + OPW} \cdot 100\% \end{aligned} \quad (3)$$

$S_{15\ 01\ 02}$, $S_{15\ 01\ 05}$, and $S_{15\ 01\ 06}$ were assumed to be proportional to the mass of impurities in 15 01 02 ($I_{15\ 01\ 02}$), 15 01 05 ($I_{15\ 01\ 05}$), and 15 01 06 ($I_{15\ 01\ 06}$), respectively, processed at the installation (Equation (4), with three versions, one for each code)

$$\begin{aligned} I_{15\ 01\ 02} &= S_{15\ 01\ 02} \cdot I \\ I_{15\ 01\ 05} &= S_{15\ 01\ 05} \cdot I \\ I_{15\ 01\ 06} &= S_{15\ 01\ 06} \cdot I \end{aligned} \quad (4)$$

where:

I—the mass (kg, Mg) of impurities in both PPW and OPW.

The actual mass of PPW_R at the calculation point, i.e., the sum of 15 01 02*, 15 01 05*, and 15 01 06*, was determined by taking the differences between the masses of PPW (kg, Mg (15 01 02, 15 01 05, and 15 01 06)) processed at the installation and the masses of impurities in 15 01 02 ($I_{15\ 01\ 02}$), 15 01 05 ($I_{15\ 01\ 05}$), and 15 01 06 ($I_{15\ 01\ 06}$).

3. Results and Discussion

The analysis included entrepreneurs who submitted reports to BDO on PPW for 2021:

- 464 entrepreneurs who reported waste with codes 15 01 02, 15 01 05, and 15 01 06 that was recycled in installations and facilities in Poland (PPW₁);
- 31 entrepreneurs who reported waste with codes 15 01 02, 15 01 05, and 15 01 06 that was prepared for reuse (PPW₁);
- 167 entrepreneurs who reported waste with codes 15 01 02, 15 01 05, and 15 01 06 that was exported from Poland (PPW₂);
- 147 entrepreneurs who reported waste with codes 15 01 02, 15 01 05, and 15 01 06 that was imported to Poland (PPW₃).

3.1. Determination of the Mass of PPW Generated in Poland and Recycled in 2021 (PPW₁)

Waste with codes 15 01 02, 15 01 05, and 15 01 06 that was treated in recycling processes was analyzed. Regarding waste with codes 15 01 05 and 15 01 06, only the masses that were managed in facilities treating only plastic waste were included. The masses of other types of PPW and the recovery process applied are shown in Table 1. In total 621,463,790 kg of PPW₁ was recycled.

Table 1. PPW recycled in Poland in 2021 (PPW₁) (data from the BDO register).

Waste Code (Unit)	15 01 02 (kg)	15 01 05 (kg)	15 01 06 (kg)
Total	567,515,561	19,486,586	34,461,643
Sum		621,463,790	

3.2. Determination of the Mass of PPW Generated in Poland and Recycled Outside Poland (PPW₂)

This analysis used information submitted to the BDO in 2021 by entrepreneurs who reported exporting from Poland waste with codes 15 01 02, 15 01 05, and 15 01 06 for recycling outside the country.

The share of PPW₂ in the total mass of waste with codes 15 01 05 and 15 01 06 was determined based on the share of the mass of multi-material packaging with a predominance of plastics in the total mass of all multi-material packaging placed on the market. In 2021, 1,298,539,900 Mg of multi-material packaging was placed on the market, and the share of packaging with a predominance of plastics accounted for 29.02% of this. On this basis, 29.02% was assumed to be PPW₂ in waste with code 15 01 05 (multi-material packaging). The share of plastic packaging in waste with code 15 01 06 (mixed plastic waste) was assumed to be 33.33% according to the results of the study by Waszczyłko-Miłkowska et al. [23]. It was determined that 110,767,503 kg of PPW₂ was exported for recycling outside the country in 2021 (Table 2).

Table 2. PPW generated in Poland and recycled outside Poland in 2021 (PPW₂) (data from the BDO register).

Waste Code (Unit)	15 01 02 (kg)	15 01 05 (kg)	15 01 06 (kg)
Total	109,190,062	1,573,594	3847
Sum		110,767,503	

3.3. Determination of the Mass of PPW Imported to Poland and Recycled in 2021 (PPW₃)

This analysis was based on information submitted to the BDO in 2021 by entrepreneurs who reported importing waste with codes 15 01 02, 15 01 05, and 15 01 06 with the purpose of recycling. To determine the mass of PPW₃, an analysis was carried out that compared the reports of entities that indicated importing PPW and those of entities that indicated recycling processes for this type of waste. The waste masses that were managed at facilities treating only plastic waste were included in this study (Table 3). The calculated mass of PPW₃ was 76,942,825 kg.

Table 3. PPW imported for recycling in Poland in 2021 (PPW₃) (data from the BDO register).

Waste Code (Unit)	15 01 02 (kg)	15 01 05 (kg)	15 01 06 (kg)
Total	76,741,165	70,620	131,040
Sum		76,942,825	

3.4. The Share of Impurities in PPW and the Actual Mass of PPW after the Recycling Process (PPW_R) at the Installation Where the Calculation Point Is Located

The calculation point was where waste entered the recycling processes, i.e., the beginning of the recycling process at the installation authorized to process PPW. Installations that treated only plastic waste in the recycling process were included in this study. To assess the average share of impurities in PPW recycled by installations in Poland, an analysis was made of the pertinent reports from 100 out of 384 installations treating waste with code 15 01 02 in the recycling process, and all installations treating plastic waste with codes 15 01 05 and 15 01 06 in the recycling process.

The reports submitted by entrepreneurs to the BDO include data on waste recycled and prepared for reuse, and waste exported from/imported to Poland. The entrepreneurs report the quantities of each type of waste managed at the installation as well as the types and quantities of waste (impurities) generated in processing. In the present study, we used data on the amounts of waste treated in recycling and the impurities generated after the recycling process. The analyzed information included the type and mass of waste treated, the recovery process applied (R), and the mass and type of waste generated from waste processing at the installation.

Based on the annual reports related to each of the above installations and submitted to the BDO register for 2021, the masses of impurities in the 15 01 02 ($I_{15\ 01\ 02}$), 15 01 05 ($I_{15\ 01\ 05}$), and 15 01 06 ($I_{15\ 01\ 06}$) processed at each installation were determined. Then, the average masses of contaminants in the 15 01 02 ($I^*_{15\ 01\ 02}$), 15 01 05 ($I^*_{15\ 01\ 05}$), and 15 01 06 ($I^*_{15\ 01\ 06}$) for Poland were determined (expressed also as the average percent share of impurities in PPW (I^*)) (Table 4). The obtained average percentages of contaminants in PPW were proportional to the masses of PPW.

Table 4. Actual mass of PPW recycled (at the calculation point) (PPW_R).

PPW		I^*		PPW_R		
Code	(kg)	I^*	(%)	(kg)	Actual *	(%)
15 01 02	599,964,459	($I^*_{15\ 01\ 02}$)	4.40	26,398,436	15 01 02 *	573,566,023
15 01 05	20,989,560	($I^*_{15\ 01\ 05}$)	5.81	1,219,493	15 01 05 *	19,770,067
15 01 06	34,334,450	($I^*_{15\ 01\ 06}$)	6.90	2,369,077	15 01 06 *	31,965,373
Total	655,288,469			29,987,007		625,301,462

* The actual mass of waste.

The actual masses of waste with codes 15 01 02*, 10 01 05*, and 15 01 06* recycled at the calculation points were over 26,398, 1219, and 2369 tonnes lower, respectively, than the waste mass entering the recycling process. This adds up to a decrease of almost 30,000 tonnes, which should be taken into account in the national reports.

According to Article 5(5) of the relevant Regulation [24], the EU Member States should provide statistical data to the European Commission on the mass of recycled PPW expressed in kilograms. The required data are indispensable for the calculation of the own resources based on non-recycled PPW [10]. To determine this waste mass, calculations should be performed in a manner consistent with Article 6a of Directive 94/62/EC [5] using the method laid down in Decision 2005/270/EC [11], and, more specifically, in Article 6c. The mass of recycled PPW should be calculated as the mass of packaging that becomes waste and then enters the recycling process after all the necessary controls, sorting, and other preprocessing steps are performed to remove waste materials that are not subsequently recycled and to ensure high-quality recycling. In the recycling process, the waste materials are reprocessed into products, materials, and substances. The mass of recycled PPW is measured when it enters the recycling process. The mass of recycled PPW is the mass of waste at the calculation point. The mass of waste entering the recycling operation includes the target materials. It may include waste materials only to the extent that their presence is acceptable for a specific recycling operation.

The uniform call rate applied to the mass of PPW generated in each Member State and not recycled is EUR 0.80/kg. The mass of PPW that is not recycled is calculated as the difference between the weight of PPW generated in a Member State in a given year and the mass of PPW that is recycled in this year. Applying the uniform call rate (0.80 euro/kg) to the weight of impurities in recycled PPW (ca. 30,000 tonnes (the results of the present study)) indicates that the own resources of Poland should increase by approx. 24 million euro.

The calculation of the actual mass of packaging waste recycled in a given Member State is also important in the context of achieving targeted recycling levels for both packaging waste and municipal waste.

4. Conclusions

EU Member States are required to submit an annual report for 2021 on the masses of PPW that were generated and recycled, as well as the amounts of own resources based on non-recycled PPW. The guidelines for the calculation of own resources [8] entered into force on 17 March 2023, for data of non-recycled PPW from 2021 (starting from this year). In order to prepare the report correctly, it was necessary to take into account the number of impurities in the mass of PPW generated in Poland and recycled at the calculation point. Until 2023, the own resources of each Member State, due to the lack of a calculation methodology, were only estimated and the estimations did not take into account the guidelines contained in the newest regulation. It was, therefore, necessary to undertake research (this study is the first of its kind in Poland) aimed at estimating the number of impurities in PPW recycled at the calculation point. The developed methodology enables the determination of the number of “non-target materials” not only for PPW but also, for example, for other plastic waste (OPW), i.e., non-packaging waste, taking into account the type of waste. It was found that the average percentage of impurities in PPW ranged from 4.40% to 6.90%. This means that the actual mass of recycled PPW at the calculation point in the year 2021 in Poland was almost 30,000 tonnes lower than the initial mass entering the installation, which increases the own resources of Poland in the EU budget.

Ensuring high amounts of the actual mass of recycled PPW and the lowest possible number of impurities means not only the availability of high-quality materials for recycling, but also achieving a high level of recycling. This is in line with the concept of sustainable waste management in a circular economy.

Author Contributions: Conceptualization, B.W.-M. and K.B.; methodology, B.W.-M. and K.B.; formal analysis, B.W.-M. and K.B.; investigation, B.W.-M.; resources, B.W.-M.; data curation, B.W.-M.; writing—original draft preparation, B.W.-M., K.B. and K.S.; writing—review and editing, B.W.-M., K.B. and K.S.; visualization, K.B.; supervision, B.W.-M.; project administration, B.W.-M.; funding acquisition, B.W.-M. All authors have read and agreed to the published version of the manuscript.

Funding: The above study was funded as the National Fund for Environmental Protection and Water Management project “Estimation of annual amounts of non-recycled plastic packaging waste in Poland” (No 38/2023). The funding was obtained by the Institute of Environmental Protection—National Research Institute. This is a departmental institute under the supervision of the Ministry of Climate and Environment (Poland). The project involves the development of expert opinions commissioned by the Ministry of Climate and Environment as part of a subsidy from the National Fund for Environmental Protection and Water Management for the implementation of the activities indicated therein under priority program No. 8.1.1. “Support to the Minister of Climate and Environment in the implementation of environmental protection policy. Part 1. Expert opinions, studies, implementation of international obligations”.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data are not publicly available due to privacy restrictions.

Conflicts of Interest: The authors declare no conflicts of interest.

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