Regional Disparities and Specialization Effects:

Evaluating the Impact of Producer Responsibility Organizations on E-Waste Management in France

Preliminary draft

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Abstract

This study assesses the impact of the geographical distribution of Producer Responsibility Organizations (PROs) on WEEE collection performance in France. It analyzes the institutional organization to determine whether PROs promote uniformity or deepen regional disparities in e-waste management. Furthermore, the study investigates the role of PROs' specialization in specific types of e-waste and the local effects of these specializations on performance. Employing a quantitative approach, we use panel regression analysis across French departments from 2008 to 2022. The aim is to ascertain the effectiveness of focusing on geographical areas, despite the sensitivity of areas in achieving national objectives, and to examine the overall environmental impact. Additionally, the study explores the role of PROs in these outcomes, through their strategic approaches and specializations.

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1 Introduction

The management of electronic waste (e-waste or WEEE) represents a significant challenge in the transition toward a more sustainable economy. Electronic and electrical equipment (EEE) are increasingly prevalent in our daily lives, from households and offices to industrial settings. This surge in consumption translates into a corresponding increase in the generation of e-waste, which contains substances that may pose risks to environmental and human health (Robinson 2009). The complexity of these devices' composition further complicates their management, thereby increasing the associated costs. Electronic equipment consists of a variety of materials, including metals, plastics, glass, and electronic components, among others (Goodship et al. 2019).
Historically, the management of e-waste was primarily entrusted to local authorities, responsible for the collection, sorting, and processing of this waste within their jurisdictions. However, due to the challenges posed by e-waste, it has become increasingly difficult for local authorities to bear the responsibility for managing the end-of-life of these products. To address these challenges, the principle of Extended Producer Responsibility (EPR) was introduced in the mid-1990s, which shifts the responsibility for end-of-life waste management to the producers of the products. Under the polluter-pays principle, EPR mandates that producers financially and operationally handle the collection, treatment, and recovery of their end-of-life equipment. Thus, by transferring the responsibility from the public to private actors, EPR incentivizes these entities to consider externalities in their product design (Lindhqvist 2000).

The EPR was introduced in Europe in 2003 through the Waste Electrical and Electronic Equipment Directive (WEEE Directive 2002/96/EC)[1] for managing e-waste. Due to concerns about practicability and the various challenges posed by the implementation of individual EPR systems (M. Favot 2015), most European countries have developed collective EPR systems. These systems pool the responsibility for e-waste management

[1] An update was implemented in Europe in 2012 with Directive 2012/19/EU, and a public consultation was launched in 2022 for a further update of the WEEE Directive.

by transferring it to a single entity: the Producer Responsibility Organization (PRO). These entities act as intermediaries between producers and waste management operators, tasked with organizing and financing the collection, treatment, and recycling of e-waste. They collaborate with local authorities and specialized operators, utilizing their infrastructures to facilitate waste management, thereby simplifying processes for both producers and consumers. Consequently, consumers can dispose of their used equipment at designated collection points such as retail stores or municipal waste facilities. It is important to note that PROs may specialize in managing specific types of equipment, depending on the producers affiliated with them, thus impacting their performance targets. For instance, the reuse of computer equipment may be more economically viable than that of lamps. Consequently, the targets for reuse or material recovery may vary depending on the types of products managed by the PROs. This specialization directly influences their effectiveness in achieving set objectives, thereby modulating their overall performance.

The performance of PROs is assessed on two levels: they manage local collection and waste processing while aiming to meet national targets. For example, the European Union mandates a collection rate of 65% for electronic waste, calculated based on the weight collected relative to the average of equipment sold over the past three years. For PROs representing numerous producers, this means collecting a volume of waste equivalent to 65% of these equipment sales. Consequently, their collaboration with local authorities is crucial to secure enough waste to achieve these national targets. Additionally, the significant influence of municipalities on the effectiveness of extended producer responsibility systems is well-documented in the literature (Tojo (2008); Cahill et al. (2011); Spasova (2014); Corsini et al. (2017); Rubio et al. (2019); Pazoki and Zaccour (2021)). While the effectiveness of PROs in collaboration with local authorities plays a critical role in achieving national e-waste collection targets, the dynamics within the sector itself, particularly in terms of market dynamics among multiple PROs, present additional complexities.

The presence of multiple PROs has been the subject of studies in the literature (Spasova (2014); Cahill et al. (2011); Marinella Favot, Grassetti, et al. (2022); Fleckinger and Glachant (2010)), often focused on the impact that competition could have on end-of-life equipment management costs or on the performance of the sector. However, as highlighted by Kunz et al. (2018), competition among PROs can also pose certain problems, particularly concerning rivalry for access to e-waste. This creates situations where some PROs do not have the quantity of waste they are required to collect or treat, thus being obliged to purchase waste on the market to fulfill their obligations. As also noted by Kunz et al. (2018), these problems can be addressed by a central coordination mechanism that allocates waste flows to PROs based on their market share and obligations. A conceivable coordination mechanism involves the strategic distribution of PROs across the territory, particularly by regulating their interactions with municipal collection points. Two major challenges arise: first, ensuring an equitable distribution among the PROs; and second, optimizing the territorial network to enhance e-waste collection throughout the region. Therefore, establishing an appropriate institutional organization is crucial, one that not only provides an effective operational framework for PROs and municipalities but also maintains incentives for these stakeholders.

Our article aims to evaluate the effectiveness of the current institutional organization of PROs in France. We first examine whether the distribution of PROs equalizes collection performance across the territory or whether it exacerbates geographical disparities. Specifically, we seek to determine whether PROs compensate for poor performance in certain areas with better results where collection is more feasible, or if the distribution fosters local development of e-waste collection, thereby improving the sector overall across the territory. Secondly, our analysis also focuses on the territorial impact of the PROs' specialization. We explore whether the nature of the waste collected and the collaborations with collection points, tailored to the specialization objectives of the PROs, vary significantly according to the areas assigned to them.

In this context, France, our case study, is of particular interest for several reasons detailed in Section 2 of this article. Firstly, the e-waste sector in France includes two PROs considered as "generalists," although their specializations may influence local performance of the EPR system. Furthermore, a coordination body has been established to geographically distribute PROs across the entire territory, allowing for the examination of performance disparities. Lastly, the evolution of this distribution over time provides an opportunity to analyze more precisely its effects on local performance.

Section 2 of the paper explains the institutional context in France regarding the distribution of PROs and their relationships with local authorities. The subsequent section provides a literature review. Sections 4 and 5 respectively present the empirical methodology used to address our research questions and our findings. We then conclude in Section 6 with a discussion.

2 Literature review

2.1 The relation between PROs and municipalities

As mentioned in the introduction, PROs have the duty to support municipalities, both financially and operationally, in this mission. This aims to overcome the barriers that hinder the effectiveness of electronic waste collection, by encouraging best practices and developing local collection networks (Spasova 2014).

Although PROs engage in public awareness campaigns, their primary support to municipalities lies in financing waste collection. This relationship can be likened to that of a cost-plus contract, where PROs financially compensate municipalities for a portion of the collection costs. According to Gagnepain and Ivaldi (2002), cost-plus contracts ensure the efficient reimbursement of operational costs. Maskin and Tirole (2008) further argue that such contracts also promote risk-sharing between parties, especially when costs are unpredictable, which is particularly relevant in the context of variability in the volumes and types of waste generated. However, devising performance-based contracts between PROs and municipalities presents a complex challenge. One of the key issues is ensuring that PROs adequately compensate municipalities for the costs associated with waste management. Some municipalities struggle to assess the actual costs of waste management, complicating the determination of reimbursement amounts. Other municipalities may face obstacles in implementing reimbursement terms, thus posing additional challenges to ensure fair and equitable compensation (Ribeiro and Kruglianskas 2020). Securing funding and organizing logistics for e-waste collection, ensuring compliance, and reducing monopolistic practices also represent significant challenges in negotiations between the two parties (Khetriwal et al. 2009).

Then, it is important to consider the matching mechanism between Extended PROs and municipalities, as well as the market dynamics of the PROs, to ensure the effectiveness of interactions with municipalities, a cornerstone of e-waste collection. Some literature has focused on the competition among PROs, although there is currently no clear consensus on this issue. On one hand, some researchers, like Marinella Favot, Grassetti, et al. (2022), argue that competition among PROs could enhance the efficiency of the Extended Producer Responsibility system by reducing collection costs and increasing transparency. Corsini et al. (2017) goes further by stating that this could also lead to a more efficient distribution of fees and a reduction in financial contributions for producers, as highlighted by Rubio et al. (2019). On the other hand, Spasova (2014) suggests that an increase in the number of PROs might lead to a decrease in economies of scale and an increase in transaction costs. From this perspective, to effectively pressure prices, competition should target waste operators rather than the PROs themselves. This diversity of opinions illustrates the complexity of the issues and the need for a nuanced approach to optimize the EPR system in the context of e-waste collection.

In practice, in France, PROs are not truly in a competitive situation. Municipal collection points are assigned to them arbitrarily without undergoing an open competition, particularly regarding contracting. This lack of competition raises questions about the incentive mechanisms of this institutional organization. PROs, considered as public utility entities due to their contribution to beneficial environmental goals for the community (Micheaux and Aggeri 2021), are supposed to maximize performance in the areas where they operate, even in the absence of competition, with municipalities.

2.2 Municipalities and geographical disparities in e-waste management

Municipalities are at the forefront of developing strategies to enhance waste management, positioning them as key players in EPR systems (Tojo (2008); Cahill et al. (2011); Spasova (2014); Corsini et al. (2017); Rubio et al. (2019); Pazoki and Zaccour (2021)). As demonstrated in Figure 1 by Marinella Favot and Grassetti (2017), several studies have provided insights on factors that can impact local performance in e-waste collection. In their article, Marinella Favot and Grassetti (2017) present an empirical analysis

	Impact (positive or negative)	Limited or no impact
Socio-demographic factors		
Gender	Barr (2007), Ekere et al. (2009), Hadjimanolis (2013), Saphores et al. (2006*, 2012*), Sidique et al. (2010)	Do Valle et al. (2004), Song et al. (2012)*, Hage et al. (2009)
Age	Song et al. (2012)*, Hage et al. (2009), Sidique et al. (2010), Hadjimanolis (2013), Barr (2007), Nnorom et al. (2009)*, Saphores et al. (2006)*, Arbués and Inmaculada (2016)	Saphores et al. (2012)*, Do Valle et al. (2004), Ferrara and Missios (2005)
House size	Sidique et al. (2010)	Saphores et al. (2012)*, Song et al. (2012)*, Ferrara and Missios (2005)
Education	Arbués and Inmaculada (2016), Barr (2007), Hadjimanolis (2013), Meyer (2015), Song et al. (2012)*, Saphores et al. (2006)*, Yin et al. (2014)*, Zen et al. (2014)	Do Valle et al. (2004), Wang et al. (2011)*, Saphores et al. (2012)*, Ferrara and Missios (2005)
Immigration	Miafodzyeva and Brandt (2013), Hage and Söderholm (2008)	
Income	Darby and Obara (2005)*, Arbués and Inmaculada (2016), Sidique et al. (2010), Zen et al. (2014), Barr (2007), Song et al. (2012)*, Hadjimanolis (2013), Nnorom et al. (2009)*, Ferrara and Missios (2005), Yin et al. (2014)*, Ekere et al. (2009)	Hage et al. (2009), Wang et al. (2011)*, Saphores et al. (2006* and 2012*), Do Valle et al. (2004)
Technical-organisational factors		
Presence of collection points	Saphores et al. (2006)*, González-Torre and Adenso-Díaz (2005), Hage et al. (2009), Zen et al. (2014), Yin et al., 2014*, Sidique et al. (2010)	
Population density	Bouvier and Wagner (2011), Ekere et al. (2009), Passarini et al. (2011), Hage and Söderholm (2008)	Hage and Söderholm (2008)
Metropoles	Arbués and Inmaculada (2016)	
Macro region division	Torgler and García-Valiñas (2007), Crociata et al. (2016), Agovino et al. (2016), CdCRAEE (2015)*	
Characteristic of the territory	Han et al. (2015), Passarini et al. (2011)	
Proportion of household waste separately collected	Darby and Obara (2005)*	

Figure 1: Literature identified by Marinella Favot and Grassetti (2017) on e-waste collection performance

of the impact of various socio-economic, demographic, and technical-organizational factors on e-waste collection rates in 20 Italian regions from 2008 to 2015, allowing for an understanding of geographical disparities in the effectiveness of electronic waste collection in Italy. The authors find that local factors impacting e-waste collection include socio-economic and demographic variables such as age, gender, household size, education level, migration, and income, as well as technical and organizational variables such as population density, the presence of metropolitan areas and macro-regions, territorial characteristics, the percentage of household waste collected separately, and the number of e-waste collection points. Specifically, the presence of collection points and the percentage of household waste collected separately are positively correlated with the collection rate. However, population density is negatively correlated with the outcomes of electronic waste collection. Overall, Marinella Favot and Grassetti (2017) confirm the existing literature on e-waste collection, supporting the argument that there is a risk of significant local disparities.

2.3 National objectives *versus* local operations

One of the interest of this research is that, although the objectives of EPR are of national scope, the waste industry is heavily influenced by local characteristics, leading to significant performance disparities at the local level. This raises the question of the institutional organization's ability to locally develop strategies that achieve global objectives.

This issue, a classic concern in public policy, arises in several sectors, such as social protection (Cho et al. 2005), and also extends to environmental policies (Cline 2003). For these authors, the success of implementing national policy goals at the local level heavily depends on the efforts and capabilities of state and local governments or local capacities. According to Cho et al. (2005), empowerment through decentralization plays a crucial role in local disparities in achieving national goals. Importantly, one factor that may explain the challenges is the difficulty in specifying precise objectives (Cline 2003). This is a question that is highly relevant in the context of EPR. In the realm of waste collection, should we favor geographical areas where it is easier to collect in order to achieve national objectives? Or should we lessen the attainment of these goals to locally develop more sensitive areas and thus equalize local performance? According to Cline (2003), this issue involves a compromise between equity and efficiency. Focusing solely on areas where objectives are more easily met could exacerbate existing disparities between regions, even though this strategy may lead to quicker gains and more efficient operationalization in the short term. However, while focusing on easier areas might yield rapid results, prioritizing sensitive areas for development could lead to more sustainable outcomes.

In the context of EPR for e-waste, the study by Bruno et al. (2021) focuses on the organization and efficiency of e-waste collection networks in Italy, emphasizing the spatial accessibility and availability of collection centers for consumers. This research aims to examine variations in collection performance across different regions, assess the impact of spatial accessibility on WEEE collection rates, and suggest strategies to optimize the network to enhance collection efficiency. The study highlights significant regional disparities in terms of distribution and accessibility of facilities, with generally better performance in northern regions in terms of availability and accessibility. It indicates that accessibility, more than availability, is strongly correlated with better collection performance. However, to date, no research, to our knowledge, has explored the role of PROs in these disparities. Moreover, considering the specializations of PROs, it is possible that the nature of the waste varies, an aspect not addressed by Bruno et al. (2021). Such analysis could further reveal the local impact of PROs. Our article makes a contribution to this literature by exploring these dimensions.

3 Empirical strategy

This document is a preliminary draft, and the results are subject to change following more detailed analyses.

3.1 Institutional context

The French e-waste management market is currently managed by two generalist PROs, *Ecosystem* and *Ecologic*, largely due to stringent approval requirements which restrict new entrants. However, this configuration has not always characterized the sector. Historically, it included three generalist PROs organizations and one specializing in lamps. Mergers and non-renewals of approvals have transformed market dynamics, as demonstrated by Figures 4 and 5 in the appendix. This absorption is primarily due to the institutional organization of the sector, the details of which will be explained in more detail later in this article. It is also relevant to highlight the distinct specializations among these PROs. Furthermore, although defined as generalists in their specifications, these organizations nevertheless exhibit specializations according to equipment categories, as illustrated by Figure 6. Thesee specializations can influence the environmental objectives of PROs, depending on the relevance of their specialized equipment. However, as generalists, PROs are required to collect all types of equipment in the areas assigned to them.

This duopoly is framed by the government, which has established an institutional organization to address two major challenges. The first goal is to ensure continuous separate collection from municipalities, including in the event of a PRO's accreditation being terminated and to maintain uninterrupted service. The second goal is to prevent the concentration of collection services in "premium" municipalities, that is, areas that are more advantageous for PROs, ensuring a fair and equitable distribution of e-waste management services across various regions. In this context, the french law impose the creation of a coordinating body, the *OCAD3E*, which manages liaison between the PROs and local municipalities, thereby helping to achieve two major objectives. On one hand, contracts with municipalities are signed directly with *OCAD3E* rather than with the PROs, which ensures continuity of collection services even if a PRO's accreditation is withdrawn. Furthermore, *OCAD3E* decides the allocation of PROs to various municipalities. This structure thus ensures an equitable distribution of PROs across the entire French territory, independent of the specific advantages or disadvantages of each municipality.

PROs are allocated taking into account geographical factors and waste volume estimates to ensure they can meet their collection targets. A PRO is designated responsible for each municipality wishing to contract with such an organization, with possible rebalancing. In practice, the vast majority of local authorities have chosen to contract with a PRO, as this represents a non-tax funding source for waste management, which is particularly incentivizing for municipalities.

3.2 Data sources

To conduct our study, we combined several data sources, some of which, to our knowledge, have rarely been used in the literature. Our data comes from three main sources. The first and most significant is the SINOE database provided by ADEME. It primarily gave us information on collection infrastructures and territorial collection data. The second source, also from ADEME, involves annual reports from the WEEE sector. These documents were crucial for gathering data on PROs and national per capita objectives. Finally, we enriched our study with socio-demographic data provided by INSEE. Table 3 provides a summary of all the variables used in our study, specifying the corresponding sources.

Although access to municipal-level data is not available, we still manage to maintain a geographical dimension in the information we possess, with data at the departmental level in France. Our study covers the period from 2009 to 2021, with data collected biennially. Thus, we have seven study periods at regular intervals, allowing us to maintain continuity and track dynamics throughout the entire period studied.

3.3 Panel regression on local disparities

For our first level of analysis, which focuses on performance and local disparities, and considering the data available to us, we will address this issue using panel regression. This statistical method will allow us to analyze data collected over several periods and different departments, thus providing a detailed view of dynamic effects and intra- and inter-departmental variations.

To evaluate the impact of PROs on local disparities in collection performance, it is crucial to first define what constitutes performance. Studies commonly use the collection rate per capita because this measure helps eliminate the effects of the size of the areas studied, thus providing a less biased approach(Marinella Favot and Grassetti (2017);Bruno et al. (2021)). However, while estimates of tons collected per inhabitant inform about the effects of various variables on a gross volume, they do not necessarily reveal the quality of the performance.

We adopt a different strategy to more accurately capture "performance" and "local disparity." Annual reports from ADEME, which provide the national collection target per capita each year, allow us to develop a new indicator: *Target Distance*. This indicator is defined as the difference between the actual weight of electronic waste collected per capita and the governmental collection target, as outlined in Equation 1. A positive indicator signals over-performance, while a negative indicator indicates under-performance.

$$Target\ Distance = Kilos\ collected\ per\ capita - Kilos\ targeted\ per\ capita \quad (1)$$

This indicator reflects the level of performance of a department relative to national objectives but does not measure relative performance between departments, which would be essential for identifying local disparities among them. For this reason, we developed a second indicator, named "Disparities," which corresponds to the absolute value of the difference between the weight of electronic waste collected per capita in a department and the national average, as defined in Equation 2. Thus, the higher the value of this indicator, the greater the disparities between departments, whether positive or negative.

$$Disparities = |Kilos\ collected\ per\ capita - Kilos\ collected\ in\ average| \tag{2}$$

These two indicators, "Target Distance" and "Disparities," will initially be used as dependent variables in our analysis.

Our research question explores the relevance of the institutional organization governing the collection activities of PROs. As described earlier in Subsection 3.1 on the institutional context, PROs operate independently for each community. One way to assess the effectiveness of this institutional organization is to examine whether the monopolistic assignment of PROs to municipalities promotes the achievement of environmental objectives. It is therefore crucial to measure the degree of presence of each eco-organization at the local level. In a duopoly context, two configurations are possible: either a territorial division between the two PROs or a monopolistic management by one PRO of the municipalities in a department. To quantify this dynamic, we used the market concentration index, the $Herfindahl - Hirschman\ Index$, calculated based on the share s of tons collected by each PRO i in each department, provided by the Equation 3. This index provides us with an insight into their presence, more or less monopolistic, in the department. An index of 10,000 indicates a perfect monopoly, while an index of 5,000 indicates an even distribution between the two actors.

$$HHI = \sum_{i=1}^{n} s_i^2 \tag{3}$$

With this indicator, we are able to test whether the exclusive allocation of a geographical area to PROs allows, on one hand, to improve collection performance and, on the other hand, if the monopolistic configuration helps reduce local disparities in terms of performance. The results will also provide insight into the motivations of the PROs, who must balance achieving the national objectives for which they are accredited and intensifying collection in areas where it is more challenging in order to standardize the level of service across the territory. This analysis will help understand to what extent current organizational structures promote or hinder the efficiency and equity of electronic waste collection.

We also incorporate the diversity of collection points into our analysis. Indeed, once a PRO is established in a geographical area, it is expected to develop various local collection channels in addition to municipalities, such as retailers or social and solidarity economy actors. To measure this diversity, we use the Shannon Index, commonly employed in biology to quantify diversity within a community. This index takes into account the abundance and evenness of the categories present, thus providing a measure of the complexity of an ecosystem.

In our context, the index is calculated from the relative proportions p of each type of collection point i (municipalities, retailers, associations, and other collection points) relative to the total tons of e-waste collected. A higher index indicates a greater diversity of collection points, which can be indicative of a richer and potentially more effective collection network.

$$Diversity\ point = -\sum_{i=1}^{n} p_i \cdot \ln(p_i) \tag{4}$$

We refine our estimates by incorporating the proportion of collection according to the type of collection point, through the variables *Share municipality*, *Share distributor* and *Share association*. We also adjust our models by taking into account the number of electronic waste reuse points per department with *Reuse points*, as well as the number of waste disposal sites with *Waste disposal*. Finally, we refine the estimation by including variables frequently used in the literature to assess collection performance, such as *Age*, *Gender*, *Population density* and *Number city* which represents the number of municipalities per department. To enhance the precision of our panel regression analysis, we incorporate controls in the form of fixed effects for time α and region γ.

In conclusion, our two models 12 and 6 for estimating the role of PROs on collection performance and performance disparities are as follows:

$$Target\ distance_{it} = \beta_0 + \beta_1 HHI_{it} + \beta_2 Diversity\ points_{it} + \beta_n X_{it} + \alpha_t + \gamma_i + \epsilon_{it} \quad (5)$$

$$Disparities_{it} = \beta_0 + \beta_1 HHI_{it} + \beta_2 Diversity\ points_{it} + \beta_n X_{it} + \alpha_t + \gamma_i + \epsilon_{it} \quad (6)$$

3.4 Panel regression on PROs' specialization

To evaluate the impact of PRO specialization on territories, we employ the same methodology used in our first analysis, namely a panel regression model. This time, we examine the effect of the presence of PROs on the composition of the waste collected within departments. To this end, we have selected five dependent variables. Four of these variables represent the proportion of waste according to their category among all the waste collected. Thanks to data provided by ADEME, we are able to distinguish four categories of waste :

- LHA (Large Household Appliances) : Washing machine, Tumble dryer, Cookers, etc.
- LCA (Large Cold Appliances) : Refrigerators, Freezers, Large size air conditioners with cooling function, etc.
- SHA (Small Household Appliances) : Irons, Toaster, Electric kettles, Mixers, etc.
- Screen : LCD screen, cathode ray screen, etc.

We calculate the share of each category's collection relative to the total collection (LHA, LCA, SHA, $Screen$).The last dependent variable we test is the diversity of the collected waste categories. We calculate this indicator using the same methodology as for *Diversity Points* by computing a Shannon Index on the proportions of waste categories :

$$Diversity\ waste = -\sum_{i=1}^{n} w_i \cdot \ln(w_i) \quad (7)$$

where w_i represents the proportion of waste category i in the total collected waste, and n is the number of different waste categories.

To estimate these dependent variables and identify the presence of PROs in the department, we simply use the share of waste collected by the PROs in the departments, which equates to two variables : $Share\ PRO\ 1$ et $Share\ PRO\ 2$.We also create a dummy variable to identify departments where the collection is "shared" between the PROs, meaning both are present. Thus, our variable $Mix\ PRO$ takes the value 0 if one of the two eco-organizations holds more than 75% of the collection share in the department—which we consider a PRO monopoly—and it takes the value 1 if both PROs have a market share of less than 75%. This variable will help us determine if the significant presence of both PROs in the department contributes to a greater diversity of collected waste types.

For the rest of the model, we control the estimates by accounting for the number of waste disposal sites, the shares of collection by collection points, and reuse points, as in the previous analysis. We also take into account temporal fixed effects, denoted as α.In conclusion, our five models for estimating the effect of PROs specialization are as follows :

$$LHA_{it} = \beta_0 + \beta_1 Share\ PRO\ 1_{it} + \beta_2 Share\ PRO\ 2_{it} + \beta_n X_{it} + \alpha_t + \epsilon_{it} \tag{8}$$

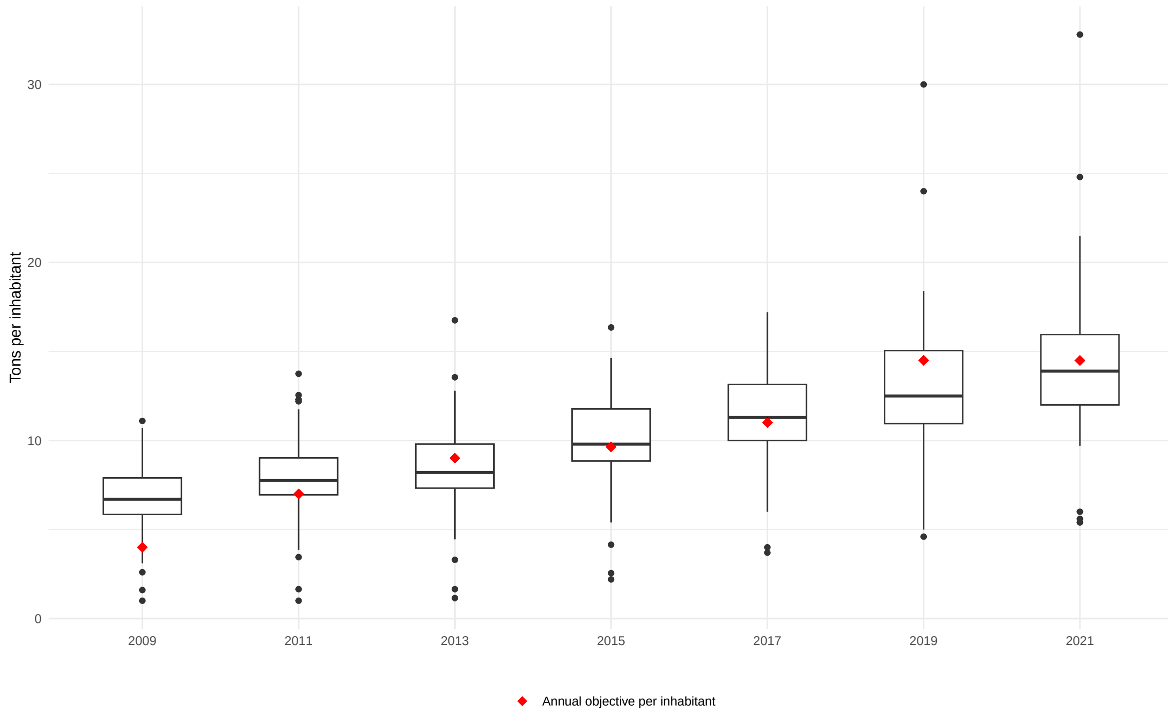
$$LCA_{it} = \beta_0 + \beta_1 Share\ PRO\ 1_{it} + \beta_2 Share\ PRO\ 2_{it} + \beta_n X_{it} + \alpha_t + \epsilon_{it} \tag{9}$$

$$SHA_{it} = \beta_0 + \beta_1 Share\ PRO\ 1_{it} + \beta_2 Share\ PRO\ 2_{it} + \beta_n X_{it} + \alpha_t + \epsilon_{it} \tag{10}$$

$$Screen_{it} = \beta_0 + \beta_1 Share\ PRO\ 1_{it} + \beta_2 Share\ PRO\ 2_{it} + \beta_n X_{it} + \alpha_t + \epsilon_{it} \tag{11}$$

$$Diversity\ waste_{it} = \beta_0 + \beta_1 Share\ PRO\ 1_{it} + \beta_2 Share\ PRO\ 2_{it} + \beta 3 Mix\ PRO_{it} + \beta_n X_{it} + \alpha_t + \epsilon_{it} \tag{12}$$

Figure 2: Collection rate compared to national objectives



4 Preliminary results

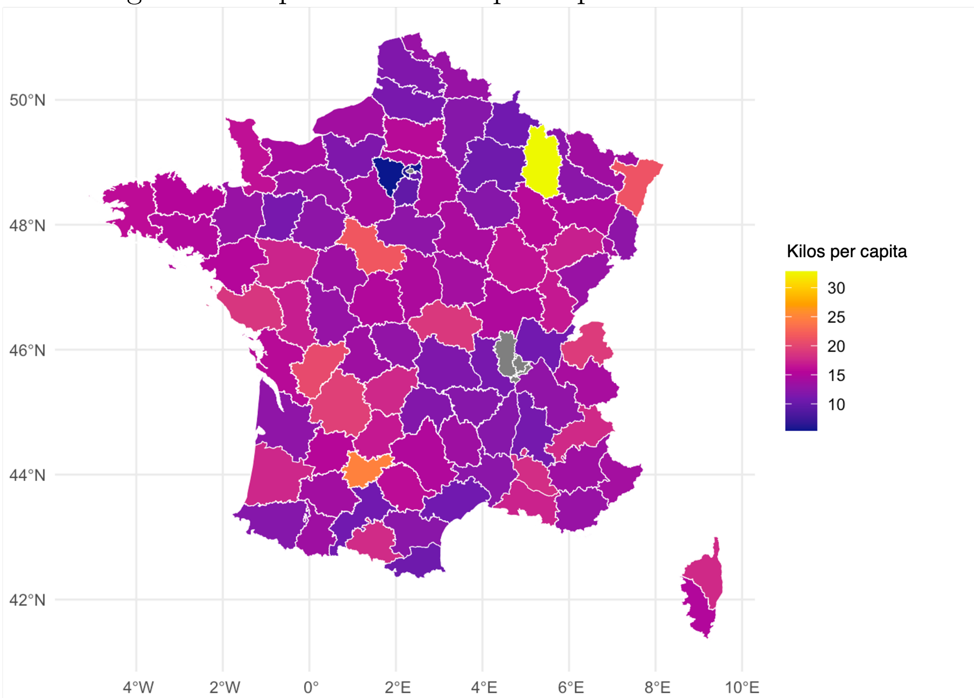
This document is a preliminary draft, and the results are subject to change following more detailed analyses.

Before presenting our results, it is essential to provide an initial understanding of the data. As mentioned in our data description, ADEME's annual reports set national targets in terms of the weight of electronic waste collected per capita. The WEEE Directive sets collection rates of 45% between 2016 and 2019, then 65% from 2019 onwards. These rates are calculated based on the tons collected relative to the average of equipment placed on the market over the previous three years. Figure 4 illustrates these targets, represented by red dots, compared with actual per capita collection and the median. Several observations can be drawn from this graph. First, it is notable that per capita collection has significantly increased over the 12 years covered by our

data. Additionally, the data show that recycling targets were generally met until 2019. However, the government has criticized the lack of ambition in these targets, which led to their increase in 2019. Since then, PROs have struggled to meet the new 65% target. This issue is frequently mentioned in feedback from the latest European public consultation on the WEEE Directive, where several stakeholders believe that the 65% collection target is unachievable, despite continuous improvements in collection performance. More significantly, disparities between the quartiles have widened over the years, with increasingly marked differences between them. This observation suggests that although the general average of per capita collection has increased, not all departments or regions have benefited equally from this improvement, leading to increased inequalities in collection performance across the country.
However, it is not straightforward to find a clear geographical explanation for these disparities. As shown on the map in Figure 4, there is no notable regional effect, contrary to what Bruno et al. (2021) suggest. However, regions along the Ocean generally exhibit better collection rates than those bordering Belgium and Spain. This difference could be explained by the difficulties these latter regions face in exporting their waste to other countries, similar to Corsica, which, as an island, sees its waste movements limited. Nevertheless, an exceptional case draws our attention: the department of Meuse, which shows an abnormally high collection rate (32.80 kg per inhabitant). One might assume this is due to a large number of collection points or waste disposal sites facilitating the importation of waste, but this is not the case; this department does not have more collection facilities than other departments. In general, these geographical effects are very subtle and do not allow for the identification of clear trends in geographical disparities.

Here, we present the preliminary results of our first phase of analysis regarding the impact of PROs on collection performance and local disparities. Figure X, located in the appendix, illustrates the Herfindahl-Hirschman Index (HHI), which measures the market concentration of the PROs. The data show that PRO 2 predominantly dominates the market, which can be attributed to the market share of equipment put into

Figure 3: Map of collections per capita in France for 2021



circulation by its affiliated producers, as well as its corresponding collection targets. It is also interesting to note that PRO 1 is more present in areas shared between the two PROs rather than in situations of departmental monopoly. These observations highlight complex market dynamics and provide an insight into the competitive structure between the PROs across various territories.

Our preliminary results from the first model presented in Table 1, analyzing the gap between departmental performances and set targets, reveal a significant positive effect of PRO concentration on performance. This supports existing research on the role of PROs and their potential economies of scale in electronic waste collection. For instance, Spasova (2014) argues in favor of a monopolistic market for PROs to minimize transaction costs with municipalities.

Another interesting finding indicates that the shares collected by municipalities and retailers have a negative effect on performance, whereas the diversity of collection points has a positive impact. To interpret these results, our hypothesis is that the diversity of collection points, by enabling the collection of multiple types of waste and offering a more extensive presence across the territory, improves accessibility. This setup could also play a role in raising awareness among users, encouraging them to recycle more effectively when they observe a variety of places to deposit their waste. These observations require further exploration to confirm these connections and integrate these insights into a more comprehensive theory on electronic waste management.Population density, age, and gender have also shown significant effects on collection performance, validating the conclusions of previous research on these topics (Marinella Favot and Grassetti (2017); Bruno et al. (2021)).

To delve deeper into the analysis of the effect of PROs, we applied our model to the study of geographical disparities using our *Disparities* indicator, presented in Section 3.3. We observe that the variable HHI is not significant when estimated alone. However, when interacting this variable with the diversity of collection points, we note a significant negative effect on disparities, thus supporting the argument in favor of a PRO monopoly. This interaction suggests that the effectiveness of a PRO monopoly could be conditioned by a high diversity of collection points. This interpretation is relevant because the diversity of collection points proves to be a significant factor in all three of our models, indicating its importance in the formulation of public policies aimed at improving collection performance. This discovery highlights the importance of considering the diversity of collection infrastructure to maximize the efficiency of e-waste management systems.

It is also interesting to note that a larger share of the collection carried out by retailers and associations contributes to reducing disparities. This observation can be explained by the crucial role these two actors play in improving the accessibility of collection points, thanks to their increased proximity to the population. Retailers and associations are often more easily accessible to consumers, which facilitates the deposit of e-waste and increases collection rates in various regions. This role of accessibility is essential to ensure a balanced and effective coverage of collection across the territory, thereby helping to mitigate geographical disparities in the collection of e-waste.

Table 1: Panel regression - Performance and local disparities

	Target distance	*Disparities*	
	(1)	(2)	(3)
Waste disposal	−0.031	−0.004	0.005
	(0.050)	(0.037)	(0.037)
Population density	−0.423**	0.033	−0.009
	(0.165)	(0.123)	(0.123)
Herfindahl-Hirschman-Index	0.310*	−0.025	−0.384**
	(0.175)	(0.130)	(0.173)
Number city	0.211	−1.183***	−1.231***
	(0.300)	(0.224)	(0.222)
Share municipality	−1.585***	0.179	0.107
	(0.311)	(0.232)	(0.231)
Share distributor	−0.717***	−0.859***	−0.804***
	(0.215)	(0.161)	(0.160)
Share association	−0.022	−0.097***	−0.087***
	(0.039)	(0.029)	(0.029)
Age	10.225***	−0.417	−0.218
	(2.915)	(2.174)	(2.160)
Gender	−83.135***	−24.250**	−23.533**
	(14.403)	(10.742)	(10.667)
Reuse points	0.363	0.129	0.185
	(0.269)	(0.201)	(0.200)
Diversity point	1.600***	1.880***	31.440***
	(0.541)	(0.403)	(9.488)
HHI * Diversity point			−3.302***
			(1.059)
Observations	630	630	630
Adjusted R^2	0.368	0.253	0.264
Time FE	✓	✓	✓
Region FE	✓	✓	✓
Note:			*p<0.1; **p<0.05; ***p<0.01

We are now examining the impact of PRO specialization on local collection, given by the Table 2. Our observations reveal that the contributions of PRO 1 and PRO 2 vary in opposite ways depending on the models and therefore the categories of waste assessed. PRO 1 has a significantly positive effect on the collection of screens and a negative effect on the collection of Large Household Appliances (LHA), while PRO 2 positively contributes to the collection of these appliances but negatively to the collection of Small Household Appliance (SHA) and Screens. Moreover, the nature of the collection points plays a significant role in most waste categories, except for municipalities in the case of Large Cooling Appliances (LCA). Additionally, departments where many reuse points are present tend to collect fewer LHA and Screens, but more LCA and SHA. This trend seems logical, given the increased interest in the reuse of these types of waste.

Finally, when estimating our model on the diversity of collected waste categories, it appears that only PRO 1 shows a significant effect. However, this effect is actually attributable to departments where both PROs are present, as evidenced by the significance of the $Mix\ PRO$ variable. This observation suggests that a combined presence of the two PROs is preferable for collecting a variety of waste types. This reinforces the argument that a targeted collection strategy, based on the respective specializations of the PROs, can improve the overall efficiency of the collection. This conclusion underscores the importance of collaboration and complementarity between PROs to effectively cover all waste categories, exploiting their specializations to maximize the reach and efficiency of electronic waste collection across various territorial environments.

5 Conclusion and discussions

In our paper, we proposed a method for assessing the effectiveness of the institutional organization governing the activities of PROs across French territory. Through an

Table 2: Panel regression - PROs specialization

	LHA	*CFA*	*SHA*	*Screen*	*Diversity waste*	
	(4)	(5)	(6)	(7)	(8)	(9)
Share PRO 1	-0.004^{**}	-0.019^{**}	0.001	0.003^{**}	0.001^{*}	0.001
	(0.002)	(0.008)	(0.002)	(0.002)	(0.001)	(0.001)
Share PRO 2	0.026^{***}	-0.019	-0.063^{***}	-0.024^{***}	-0.002	-0.001
	(0.008)	(0.040)	(0.012)	(0.008)	(0.003)	(0.003)
Waste disposal	-0.004	-0.001	0.001	0.001	-0.001	-0.001
	(0.004)	(0.019)	(0.005)	(0.004)	(0.001)	(0.001)
S. Municipality	0.534^{***}	-0.048	0.607^{***}	0.699^{***}	0.099^{***}	0.099^{***}
	(0.020)	(0.101)	(0.030)	(0.020)	(0.006)	(0.006)
S. Distributor	0.301^{***}	0.496^{***}	0.092^{***}	0.157^{***}	-0.007	-0.007
	(0.013)	(0.066)	(0.019)	(0.013)	(0.004)	(0.004)
S. Association	0.015^{***}	0.038^{***}	0.019^{***}	0.008^{***}	0.005^{***}	0.005^{***}
	(0.002)	(0.013)	(0.004)	(0.003)	(0.001)	(0.001)
Reuse point	-0.026^{**}	0.117^{*}	0.044^{**}	-0.087^{**}	-0.007	-0.007
	(0.013)	(0.068)	(0.020)	(0.014)	(0.005)	(0.005)
Diversity waste	-2.867^{***}	8.485^{***}	-0.735^{***}	0.098^{*}	-	-
	(0.115)	(0.593)	(0.173)	(0.119)		
Mix PRO	-	-	-	-	-	0.007^{*}
						(0.004)
Observations	651	651	651	651	651	651
Adjusted R^2	0.725	0.380	0.508	0.789	0.385	0.385
Time FE	✓	✓	✓	✓	✓	✓
Note:				*p<0.1; **p<0.05; ***p<0.01		

econometric panel study, we explored two main questions. On one hand, we demonstrated that the monopolistic assignment of PROs within departments improves collection performance and reduces disparities between departments. On the other hand, we observed that the joint presence of multiple PROs allows for the collection of a more complete range of waste, heavily influenced by their specializations.

This result is crucial for public policy as it highlights the trade-off between two distinct objectives. If the goal is to improve collection performance and reduce disparities, our results suggest that public policies should favor monopoly, which, according to the literature, would allow for capitalizing on economies of scale. However, if the goal is to collect all types of waste, it would be more prudent to combine the strengths of different PROs to cover the broadest possible spectrum of equipment.

In terms of policy recommendations, two approaches are conceivable. The first would involve mitigating the effects of specialization by reinforcing the "generalist" role of PROs to collect a wider variety of waste while maximizing economies of scale in a monopoly context. The second approach would recommend specifying more clearly the environmental objectives post-collection, such as reuse and recycling. Thus, it would be appropriate to differentiate equipment more suited to recycling from that better destined for reuse. This would involve allocating environmental objectives to PROs according to their specialization and better distributing their missions, not only in terms of collection but also in terms of environmental goals to be achieved.

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6 Appendix

Table 3: Descriptive statistics

Statistic	*Mean*	*St. Dev.*	*Min*	*Max*	*Median*	N	*Sources*
Target distance	0.250	2.919	−9.900	18.300	0.200	651	Ademe
Disparities	1.875	1.881	0.004	18.520	1.404	651	Ademe
Waste disposal	10.045	5.079	0.00000	31.000	10.000	651	Ademe
density	353.840	1,277.790	15	9,312	82	651	Ademe
HHI	7,798.48	1,927.36	3,497.97	9,991.97	8,290.53	651	Ademe
Number city	388.444	174.991	40	893	347	630	Ademe
Share municipality	0.806	2.646	0.085	67.001	0.701	651	Ademe
Share distributor	0.222	0.669	0.029	16.672	0.165	651	Ademe
Share association	0.057	0.099	0.00000	1.343	0.036	651	Ademe
age	42.482	2.681	35	49	42	658	Insee
Gender	0.514	0.005	0.497	0.530	0.514	658	Insee
Reuse points	54.149	38.309	11	240	45.5	658	Ademe
Diversity points	0.802	0.205	0.261	1.337	0.786	651	Ademe
Diversity waste	1.283	0.100	0.529	1.379	1.314	651	Ademe
CFA	0.210	0.635	0.00000	15.967	0.179	651	Ademe
LHA	0.469	1.698	0.120	43.078	0.373	651	Ademe
SHA	0.340	1.311	0.080	33.099	0.261	651	Ademe
Screen	0.177	0.296	0.018	7.349	0.170	651	Ademe
Share PRO 1	0.206	0.272	0.00000	0.923	0.050	651	Ademe
Share PRO 2	0.747	0.286	0.074	1.000	0.894	651	Ademe
Mix PRO	0.314	0.465	0	1	0	665	Ademe

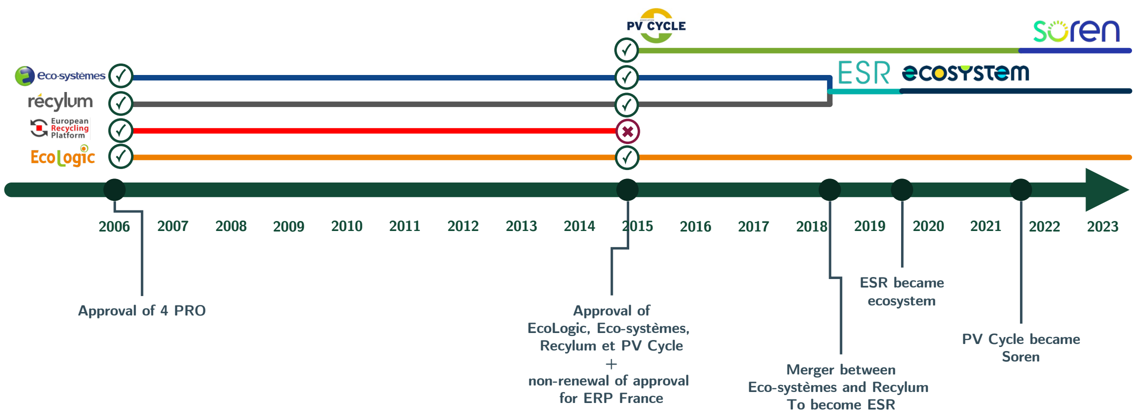

Figure 4: Ecolution of PROs in the french WEEE sector

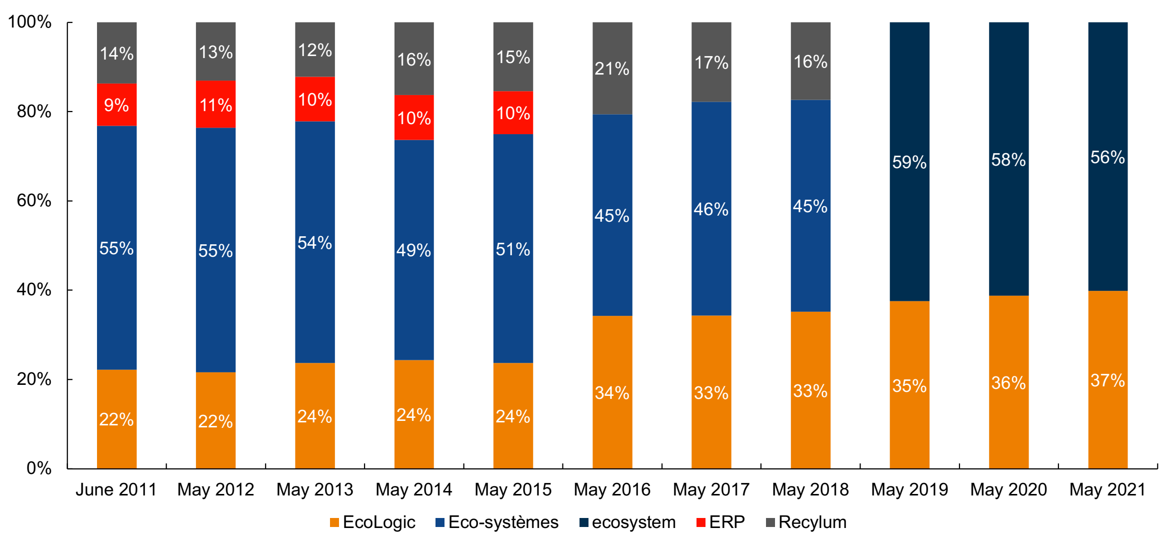

Figure 5: Evolution of market shares of PROs in terms of members (Ademe, 2021)

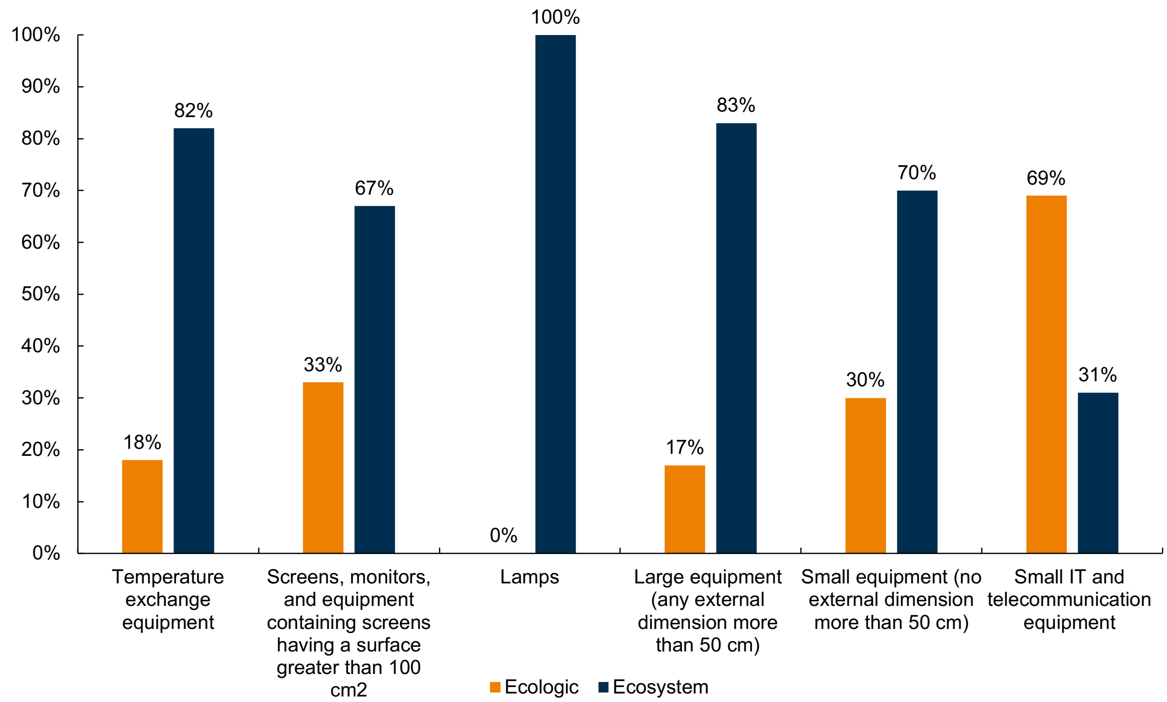

Figure 6: Market share in terms of tonnage of household appliances placed on the market (Ademe, 2021)

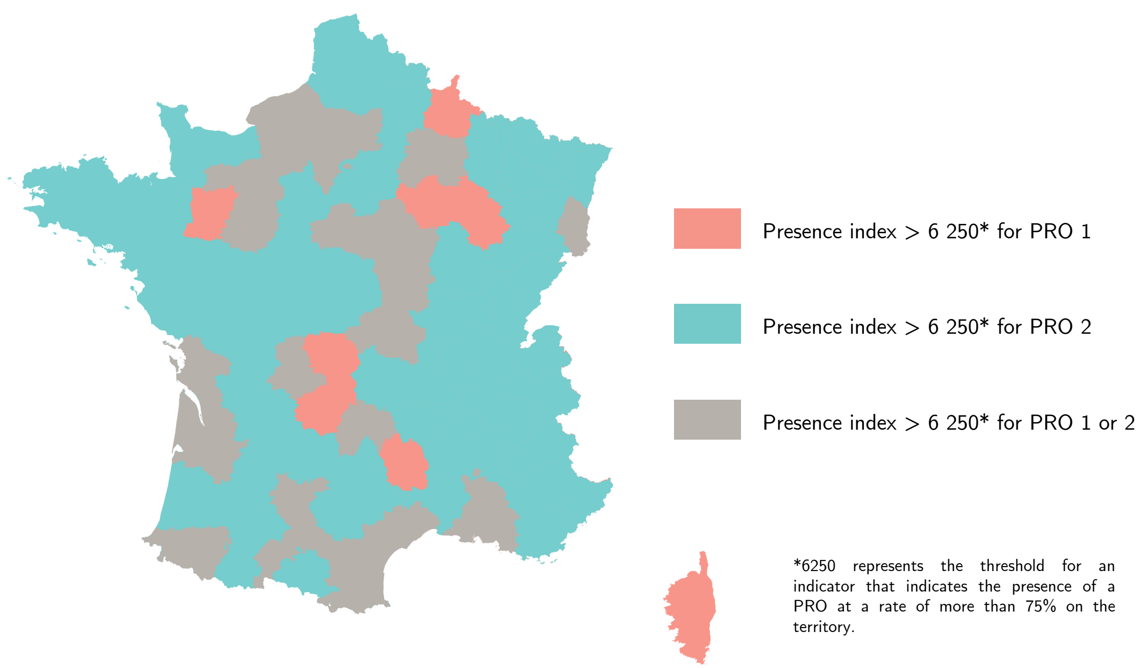

Figure 7: Mapping of the PROs presence with HHI on ton collected per PRO