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# An Empirical Study on the Main Determinants of Recycling Plastic Waste in Tunisia

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**Abstract:** Over the past fifteen years, numerous policies for recycling and recovering waste have been implemented throughout the world. Tunisia is among the countries considering recycling as a sustainable development path. This empirical study aimed to investigate and examine the influence of financial determinants measured by the price of waste disposal (PDI), institutional determinants measured by the collection of waste (CW) and the number of drop-off recycling centers, and ordinance and demographic determinants measured by the population density and the recycling rate for plastic as a domestic waste based on a panel of 24 Tunisian governorates over the 2001–2020 period. It is concluded from the empirical findings that all exogenous variables except population density have a significant effect on the recycling rate.

**Keywords:** waste management and recycling; environment and development; panel data model

**JEL Classification:** Q53; Q56; C23



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## 1. Introduction

The worldwide development of the plastic container industry has caused huge greenhouse gas emissions due to its downstream effects, representing one of the main contributors to global warming. In 1993, Tunisia set up a national solid waste management program aimed at implementing an integrated waste management strategy. Since its creation, the National Waste Management Agency (NWMA) has started the rehabilitation of illegal landfills, the creation of controlled landfills, and the treatment of emitted gases and leachate.

The estimated production of plastic waste will continue to increase in the coming years. In fact, one of the main challenges in this area is the management of this waste. Tunisia is the thirteenth greatest producer of plastic products in the Mediterranean area. More than one billion plastic bags are consumed each year in Tunisia, with 80% of these bags not being collected or recycled. Due to the volumes involved at the national level, recycling is an industrial issue. This problem also affects consumers, who can influence consumption, waste, and recycling rates.

In fact, the Tunisian economy is losing around USD 20 million per year due to plastic pollution according to a recent World Wide Fund for Nature (WWF) report entitled "Stop the Plastic Torrent". This waste mainly affects the tourism, navigation, and fishing sectors. Tunisia throws away about 0.08 million tons of plastic waste each year—i.e., 20% of all plastic waste thrown away in the Mediterranean area. Although its plastic product industry is small compared to that of other Mediterranean countries, Tunisia is the fourth largest consumer of plastic products per capita in the region.

According to [1], the excessive production of solid waste around the world is becoming both an environmental and an economic burden for society. In fact, the reuse of materials for production consumes less energy and produces less emission than the use of raw materials. It is, therefore, of great importance that households engage in recycling.

It is commonly believed, both explicitly (e.g., [2]) and implicitly (e.g., [3]), that environmental preoccupations are stronger predictors of actions that are relatively easy or inexpensive to perform (low-cost) compared to actions that are more difficult or costly to perform (high-cost). Our paper offers a detailed explanation of the main determinants of recycling in an emerging economy.

In addition, recycling is often seen as an example of a low-cost behavior in such studies (e.g., [4]; among others). Researchers have disentangled factors influencing recycling. In this context, an important fact neglected in previous research is that recycling involves several diverse behaviors. Starting from the observation that some waste categories are more easily recycled (here, these categories are labeled low-cost recycling) than others (labeled high-cost recycling), this study aimed to explore whether financial and institutional factors have different impacts on plastic recycling, representing its novel contribution to the literature.

Significant financial behaviors differ in both perceived economic and behavioral costs, involving time use, self-sacrifices, and inconveniences. According to other studies such as, [5], the low-cost hypothesis posits that environmental concern primarily has an impact on the development of recycling. For example, the cost difference between public transport and private cars is large in terms of waste collection; thus, having a private car is an environmentally unfriendly choice. On the other hand, the majority of people would perceive the cost difference between buying washing powder with or without an eco-label as small; thus, the eco-labeled product is an environmentally friendly choice. According to the United States Environmental Protection Agency (2013), the success of recycling programs essentially depends on several factors, such as the motivation and involvement of many participants in the formulation of policies, the decision-making process concerning waste management, and the recycling rate. Decision makers use this indicator to assess factors in terms of the amount of recycling taking place and waste generation. In fact, various programs and policy instruments are available to help policymakers improve institutional, financial, and demographic factors in the recycling sector. In this context, we can conclude that the most important factors affecting the rate of recycling appear to be important issues for both developed and developing countries. Nevertheless, the research on African countries, especially North African countries such as Tunisia, is limited, which makes this location an interesting one to use for a case study on this topic. It seems that several nations around the world featuring a young population, small geographic surface, high level of urbanization, increased pressure on ecosystems, and overexploitation of natural resources are facing the need to balance economic development with environmental concerns. In the 1990s, Tunisia began paying attention to environmental protection, especially with regard to the problem of the intensive accumulation of waste, partially due to its gradual establishment of environmental protection policies, which quickly evolved toward the promotion of sustainable development to improve the recycling sector in line with certain environmental norms.

There are several major factors that determine recycling in Tunisia. Accordingly, we aimed to develop an empirical study including 24 Tunisian governorates. Tunisia is considered to have a developing economy; thus, it was interesting to investigate the influence of financial, institutional, and demographic factors on the rate of recycling of plastic waste in 24 governorates of Tunisia with available data. The main objective of this study was to explore how these different variables or indicators affect the plastic recycling rate as a representative example of domestic waste. This paper contributes to the existing literature by examining the influence of financial, institutional, and demographic factors on the recycling rate of plastic waste in 24 governorates from Tunisia between 2001–2017, using the ordinary least squares econometric method. Specifically, we contribute to the literature in four ways. Firstly, we built a comprehensive database considering the rate of recycling and policy factors in waste management, such as institutional, financial, and demographic indicators for 24 cities scattered across Tunisia. Secondly, institutional factors such as collection services and drop-off recycling centers, as well as the ratification of recycling ordinances, which is a new concept in the literature, were explored in terms of

their link to the rate of recycling. Thirdly, we investigated financial indicators, including the price of collecting plastic waste, and demographic characteristics—e.g., population density—which are typically not considered as factors in studies on recycling programs. Lastly, we examined the impact of the above factors on the recycling rate of plastic as a form of domestic waste using the ordinary least squares methodology.

This paper is organized as follows: Section 2 presents a descriptive overview of the effectiveness of waste management policy factors on the recycling rate of plastic waste in Tunisia. Section 3 presents a literature review of recent studies examining the main factors that determine recycling development. Section 4 describes the data and used variables. The methodology and results are introduced in Section 5. Section 6 provides the conclusion, along with some policy implications.

## 2. An Overview of the Effectiveness of Waste Management Policy Factors on the Recycling Rate for Plastic Waste in Tunisia

Tunisia is the smallest country in North Africa. It is bordered by Algeria to the west, Libya to the southeast, and the Mediterranean Sea to the north and east. It was recorded as having a population of 11.134 million in 2017 (NIS, census Bureau 2017). This country, compared to many other nations around the world, has a young population, growing economy, and increasing domestic consumption. Therefore, the problem of the intensive accumulation of waste is likely to persist and it is necessary to avert this problem through changing environmental norms. In 1990, Tunisia began to pay greater attention to environmental issues, partly as a result of its insertion into the European experience as an alternative, which has compelled the nation to strive toward meeting certain environmental norms. The European experience has demonstrated the serious threat this plastic waste generation may pose and suggested building a successful recycling program. Hence, for this study we will be examining issues related to the effect of waste management policies on the recycling rate of plastic waste with regard to the case of Tunisia.

With respect to the double objective of reducing unemployment and minimizing waste, it is important to encourage Tunisian companies to recycle and be more proactive in this area. In fact, policymakers must create efficient policies to encourage this sector to engage in collecting, sorting, storing, and recycling waste. A first step towards this was the creation of the National Environmental Protection Agency (NEPA) in 1988, which was first established as a program to motivate people to recycle. This program spreads awareness about the importance of recycling and informs companies about relevant methods and procedures. Since this agency has been created, we have observed a significant evolution in the implementation of laws and legislative rules relating to waste management in Tunisia. These have come in three main stages: the implementation of the National Program of Solid Waste Management in 1990, the promulgation of the law of waste management in 1996, and the creation of the National Waste Management Agency in 2005.

Several Tunisian texts encourage the private sector to invest in the field of waste management, especially for plastic waste. These include law 93–120, from 27 December 1993, which implemented an investment incentive code, including title II (relating to the fight against pollution and the importance of environmental protection), and Decree 1993–1429 from 23 June 1993, which suspended customs duties and value-added tax for importation and internal system materials and equipment for garbage collection acquired by companies acting on behalf of local communities.

In the field of municipal solid waste management, the private sector contributes around 4.5% of the value of the collection and transportation of waste through contracts with local authorities, while contributing 100% of the value of the operation of transfer stations and landfills through contracts with the National Waste Management Agency.

While there are regulations, policies, and laws concerning the recycling of plastic waste, there is still a great deal of variation between local recycling programs due to their various contexts and priorities. In fact, a Ministerial Council created the National Environmental Protection Agency (NEPA) in January 2000 as an establishment responsible

for the national program of solid waste management. Since 1998, this agency (NEPA) has operated as a public system for the reuse and valuation of used packaging and named ecology packaging. In addition, this is a system that is concerned with packaging bags, and it relies on both the administrators and distributors of recycling waste. In this context, the National Environmental Protection Agency, in cooperation with the National Waste Management Agency (NWMA), which was created in August 2005, set up small companies that were responsible for the collection of plastic waste in all the governorates of Tunisia. This was achieved by the creation of 1000 points of collection at three levels; private collectors were to manage 600 points, and micro-companies named "The partisans of the environment", and scattered throughout the Tunisian territory, were to manage 400 points. At the third level, 100 companies were created within the framework of program 41 of the National Bottom for employment 21–21 to reduce the problem of the unemployment of graduates from higher education.

In addition, partisans of the environment and ordinary collectors contributed to the collection of 27% of plastic waste, accompanied by private collectors (who collected 39%) and a workforce of micro-companies (who collected almost 34%). Hence, this task can be carried out much more efficiently when the three sectors work together. This is clarified in Figure 1.

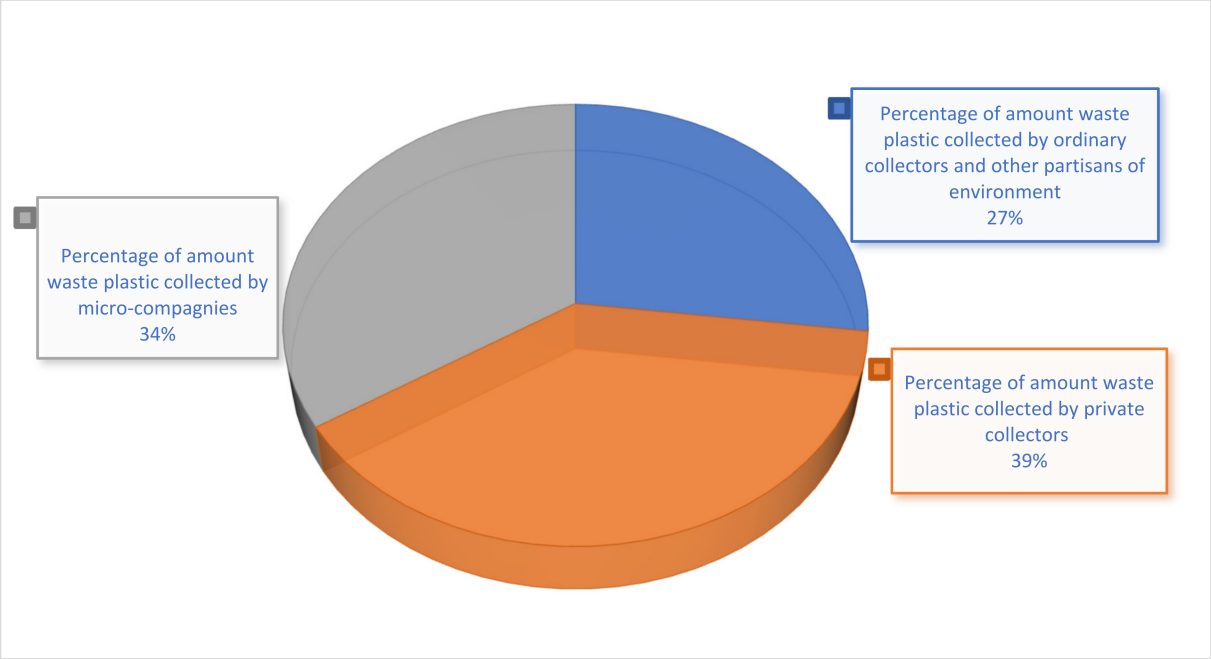


**Figure 1.** Graph showing the paid collection of plastic waste in 2005. Source: created by the authors based upon the annual data of the National Waste Management Agency.

Likewise, this paid collection shows that an important factor in encouraging recycling participation is enforcing the increased recycling of plastic waste. These upstream developments have caught the attention of a number of international recycling companies. Furthermore, the adaptation of waste management, in both a general and a more particular way in developing countries such as Tunisia, is essentially inspired by developed countries such as France, the United Kingdom, and other European countries. For our research, we have chosen to study the ecology packaging system, which was created in Europe, as an example of plastic waste. The Tunisian program for the reuse and valuation of plastic packaging was created in 1997. First, this system aims at reducing the quantity of waste and collecting it in the form of quotas for recycling later. Secondly, this program enables a slight reduction in unemployment through creating new jobs and commercial outlets. In fact, to encourage the recycling of plastic waste, various collection programs have been

implemented, such as voluntary collection, which only occurs during summer, and paid collection, which occurs the rest of the time. Thanks to this latter operation, the amount of plastic waste collected has increased progressively since the program was implemented. This is illustrated in Figure 2.

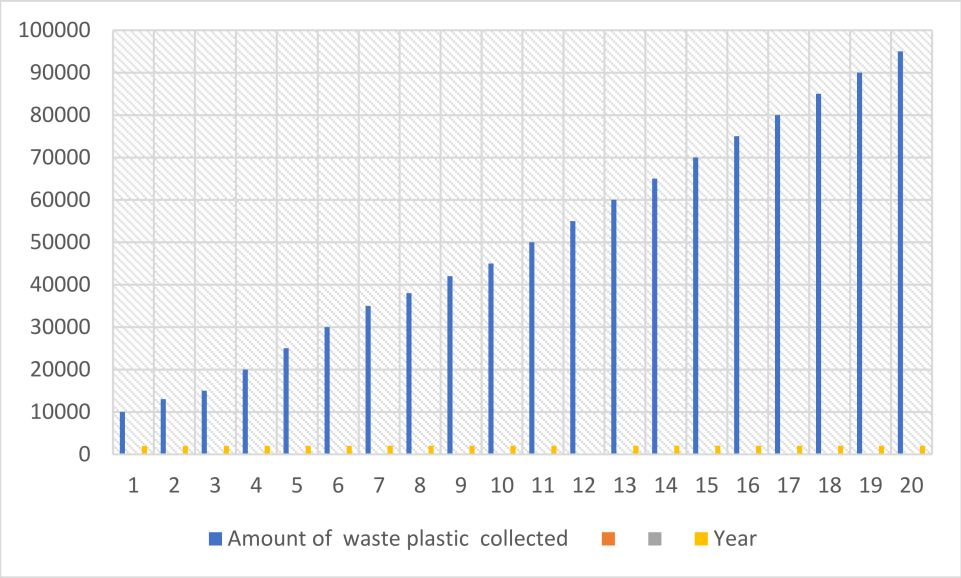


**Figure 2.** Amount of waste plastic collected in Tunisia. Source: created by the authors based upon the annual data of the Tunisian Environmental Protection Agency.

Moreover, some important attributes affecting the recycling program and attitudes towards recycling include environmental concerns. Engagement is a very important factor affecting recycling; thus, it is necessary to develop this sector to have a greater level of collector participation. This should improve the recycling rate over time in all the Tunisian governorates (see Figure 3).

The above figure represents the evolution of the rate of recycling of plastic waste in each governorate of Tunisia in the period 2001–2020. The year is illustrated on the x-axis and the rate of recycling of plastic waste in each governorate is shown on the y-axis. We note that these curves reveal an upward trend. The following arguments will explain why this is the case.

- The establishment of programs for the collection of waste and the creation of private enterprises: These were initiated by young graduates forming the system "CHEB" and involved creating a network of supporters of the environment. These two principal programs have contributed to increase the recycling rate and have encouraged private investors to create new projects relating to recycling.
- The development of drop-off recycling centers has encouraged collectors to implement better waste disposal programs. This evolution can especially be observed in the year 2005, which involved the creation of the National Waste Management Agency (NWMA). This agency encourages several collectors and other members of civil society to promote this sector for financial, economic, social, and environmental reasons.
- The increase in the price of petrol in recent years has contributed to increasing the rate of recycling. As a result, if the price of petrol increases, the price of raw material will also rise. As a consequence, the amount of plastic waste disposed of can be directly increased. Therefore, all operations associated with the recycling sector can be introduced, including the collection of waste, the depositing of waste, the sorting of waste, and the treatment of waste plastic. We have found that the rate of recycling is growing progressively on a regular basis. Hence, the evolution of this rate can increase

the value added by the waste recycling industry. In fact, all these factors contribute to improving the level of recycling in Tunisian enterprises.

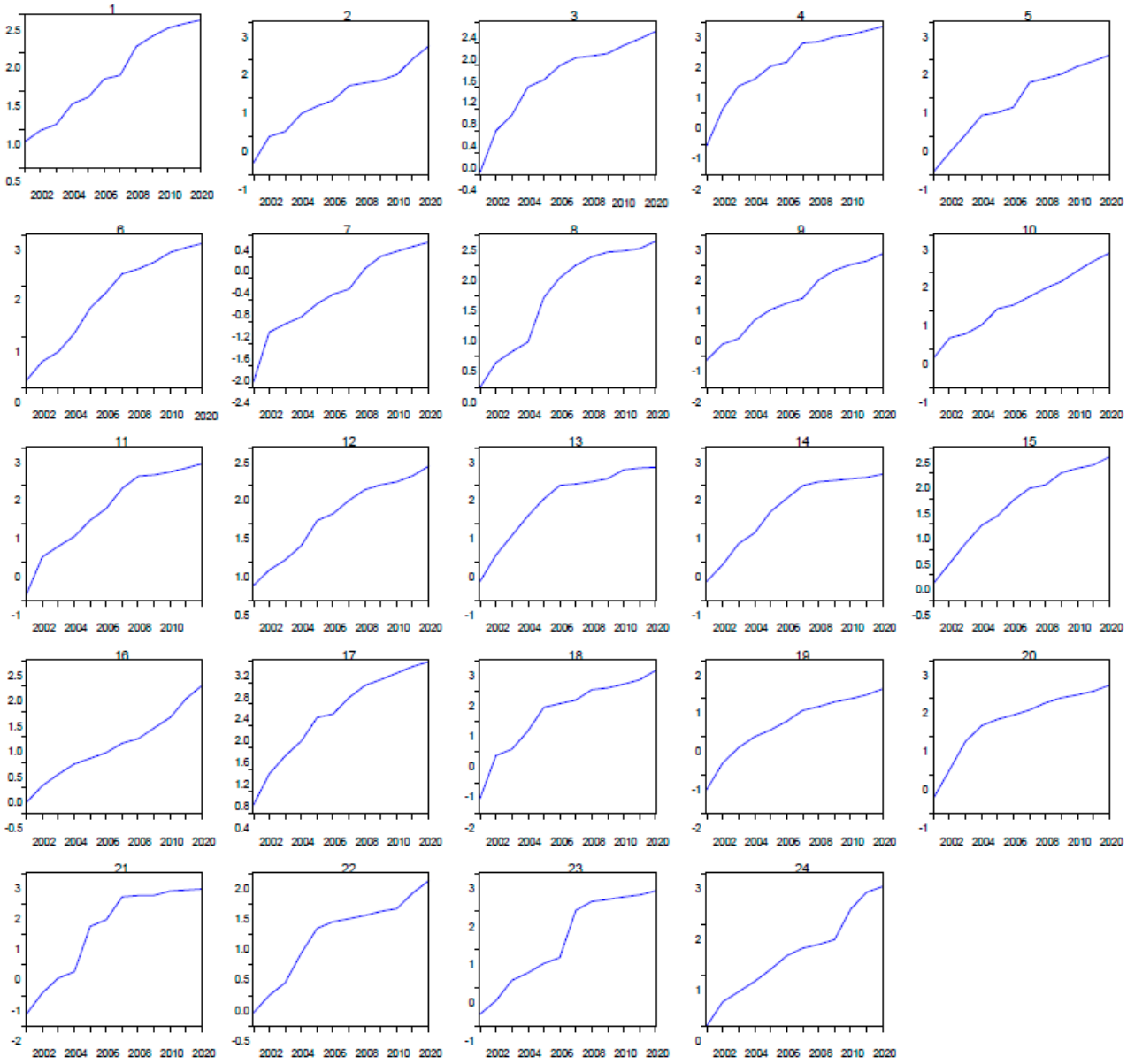

**Figure 3.** Analysis of the evolution of the rate of recycling of plastic waste in Tunisia. Source: created by the authors based upon the annual data of the National Waste Management Agency (NWMA) and the National Environmental Protection Agency (NEPA).

## 3. Literature Review

Some recent studies have discussed and investigated the determinants of recycling in different countries. An example of this is the seminal work by [6], who presented the determinants of recycling behavior on islands. Their findings showed a significant relationship between recycling behavior and waste collection. They also indicated the existence of a significant and positive relationship with recycling attitudes and a negative relationship with materialism.

In another article by [7], the authors stated that plastic materials, due to their low cost and high performance, have been widely used in horticulture in various forms and shapes. Plastic containers, trays, and flats have been used extensively in environmental horticulture and landscaping. Returning to the study of [8], while the use of plastic containers increases

the competitiveness of environmental horticulture, these items represent a challenge in terms of disposal. Attributes that make plastic materials highly desirable in production and landscape services become significant problems when disposing of them [9,10].

According to EPA, plastic waste from the environmental horticulture sector is discarded in landfills. Reducing the amount of plastic waste that is disposed of in landfills will make environmental horticulture more sustainable. Ref. [5] mentioned that an added benefit is the improvement of the visual appearance of a landscape that is not littered with pieces of plastic film, as can be seen in some areas of Georgia. An empirical study by [11], was elaborated to the case of Spain and other countries by [12]. These studies presented the main factors affecting the development of recycling. In contrast, several types of plastic are widely used in the environmental horticulture industry, including low-density polyethylene, high-density polyethylene, polypropylene, and high-impact polystyrene. Ref. [13], supported by [9,10], stated that the hierarchy of plastic waste management includes waste minimization, waste reuse, and waste recovery, with landfill disposal being treated as the lowest priority.

Kinnaman and Fullerton [14] used a theoretical model to derive the recycling and waste disposal demand function for a community. They estimated the impact of waste disposal fees and curbside programs on recycling and waste generation. Their research demonstrated that the demand for waste disposal and recycling is a function of curbside recycling, the price of waste disposal, mandatory recycling policies, deposit refund systems for recyclables, bans on yard waste disposal, income, and institutional characteristics. In this context, ref. [15] showed that the use of a waste collection fee paired with aggressive recycling programs was more effective in reducing the amount of waste disposed of than an increase in the collection fee without the implementation of a recycling program. Ref. [16] studied the effect of drop-off recycling activities on recycling rate and waste generation. They indicated that an increase in the amount of drop-off recycling contributes to raising the demand for recycling, and they also found that an increase in drop-off recycling had a positive effect on the demand for waste disposal.

Moreover, ref. [17] came to a similar conclusion after analyzing the cross-sectional data of more than 800 U.S. communities. They also found that curbside recycling programs encourage recycling. In the same area, ref. [18] analyzed the factors determining the collection rates of household plastic packaging in British homes following the passage of the producer responsibility ordinance, which mandates that producers collect and recycle packaging materials. Likewise, ref. [19] showed that this collection operation refers to the reassembly of detritus in specific containers, which will be taken to a sorting site. In fact, the debris reassembly operation means that designated sites are set up to collect a range of recyclable materials, and in general, the recyclers themselves are required to deposit sorted material into specially identified containers; it has been shown to be more appropriate to implement depository centers [20]. On the other hand, recycling locations are less expensive to operate, as recycling center operators can save transportation and labor costs by passing them on to recyclers. In their empirical study, these authors used cross-sectional data from 900 communities located in the United States. They also found that selective collection services encourage this environmental practice by gradually increasing the recycling rate.

The last category consists of links between the rate of recycling and demographic factors; in this study, we use the density of the population and the date of availability. In this context, ref. [21] stated that recyclable waste disposal sites are adopted by local governments in rural areas with a low population density as a financially viable option. Additionally, [22] as well as [23] those social norms are an important demographic element affecting the recycling rate; therefore, in this study we use a few variables such as gender, age, education, and income. Similarly, ref. [24] showed that women are often more enthusiastic about engaging in recycling than men. Arcury et al. [25] also suggested that women are most interested in this type of activity.

Calvin et al. [26] examined the importance of the financial factor in the recovery of recyclable waste using a static panel method in the Ontario province of Canada. Referring

to the "polluter pay" principle, he proved the existence of a strong and positive relationship of high significance between the cost of pricing imposed on the disposal of types of waste and their recycling rate. This result seems consistent with that found by [27] in their econometric study of the state of Minnesota for the period 1996–2004; they found that the financial factor has a positive influence on the rate of recycling. Additionally, the seminal work by [28] found the same results—i.e., they found that the price contributes to increasing the rate of recycling for used lubrication oil as an example of hazardous waste in a case study of the Tunisian Company of Lubricants.

Recently, ref. [29] examined the determinants of recycling behavioral intentions in Malaysia, specifically among the general public in Penang. For example, they investigated attitudes, social norms, social media use, and self-efficacy, and analyzed the moderating roles of governmental and non-governmental organizations. Their results showed that attitude and self-efficacy appeared to be strong predictors of behavioral intentions, whereas social norms and social media use, to a lesser degree, predicted recycling intentions. According to [29], recycling behavior among the wider community can be promoted through the influence of both social media and non-governmental organizations.

From this literature review, we determined that mixed results were found by many researchers in different cases. These differences between studies may be due to the specific characteristics of the different countries investigated. In this study, Tunisia is considered as a specific example due to its geopolitical characteristics.

## 4. Data and Descriptive Statistics

Our sample covers the recycling of plastic waste in 24 Tunisian governorates. The choice of these governorates was not random; rather, they were a targeted selection. Indeed, we efficiently collected the annual data of the recycling area, the environment, and the waste management employed. This step required us to appeal to several bodies and necessitated following a precise administrative and bureaucratic procedure.

Subsequently, we built our database from three sources. First, we used the National Institute of Statistics (NIS) [30]; second, plastic recycling and waste management data were obtained from two complementary sources—the National Waste Management Agency (NWMA) and the National Environmental Protection Agency (NEPA) [31].

Indeed, Tunisia began a statewide effort to recycle plastic waste in 2001 after the adoption of legislation based on NEPA recommendations under the supervision of the Ministry of Environment and Sustainable Development. This legislation provides state funding for waste reduction, recycling programs, and household domestic waste management.

The waste management and recycling program for plastic waste is deemed to be one of the most successful state-level programs in Tunisia in terms of both local government investment and public participation. The NWMA database [32], compiles data from annual surveys of waste management and recycling across the entirety of Tunisia.

The NWMA survey is administered by the NEPA and completed by solid waste officers. The survey collects information on Municipal Solid Waste (MSW) materials collected for recycling, solid waste collection systems, source reduction programs, and other MSW policy initiatives. Hence, this pilot study aims to determine the recycling rate of plastic waste using the institutional, financial, and demographic data of Tunisian provinces from the various databases mentioned above for the period from 2001 to 2020. Consequently, we built our panel model using the available variables for 456 observations representing the 24 governorates. The selected variables are listed and defined in Table 1.

The variable rate was used as a proxy for the recycling rate. We computed this dependent variable by dividing the amount of plastic waste recycled by the total amount of waste generated in each governorate (Total waste generated is the summation of amount of recycling for plastic waste and MSW land-filled.). In addition, the amount of recycling was equal to the amount of waste plastic collected decreased to 15% of the impurities (This information concerning the percentage (15%) of impurities in plastic waste was obtained through interviews with Tunisia Environmental Protection Agency officers from different

governorates.) that the recycler must avoid before treatment is carried out, which includes grinding, densification, extrusion, and blowing of waste. According to [22]., the recycling rate can be described as a ratio of the waste recycled to the total amount of solid waste collected for disposal or incineration.

**Table 1.** Description of the variables.

| Variable | Definition |
|---|---|
| Rate | Recycling rate of plastic waste for each governorate (percentage) |
| Price | Price of the collection of plastic waste |
| Ordinance | Number of recyclers who have an ordinance that requires them to recycle their plastic waste disposal |
| Collection | Urban population with access to waste plastic collection |
| Drop | Number of drop-off recycling centers |
| Density | Population density per square mile |

Source: created by the authors based upon the annual data of the NWMA, the NEPA, and the NIS of Tunis, Tunisia.

Concerning the explanatory variables used, we included the financial variable, which was represented by the price of the collection of plastic waste. This indicator was chosen by two complementary agencies, NEPA and NWMA, under the supervision of the Ministry of Environment and Sustainable Development. This survey did not collect information on the actual unit prices charged. Contrary to studies that use community-level data, the current study used county-level data with aggregate information for different governorates, and this made it difficult to deduce the county waste price, as prices usually vary across communities.

Furthermore, the recycling regulation and institutional variables were represented by ordinance, to indicate whether the Ministry of Environment and Sustainable Development enacts recycling ordinances to make recycling compulsory for subsidized recyclers. Secondly, we used collection and drop variables to represent recycling programs in each governorate. In addition, the variable collection measured the population with access to the collection of plastic waste, while the drop measured the number of drop-off recycling centers in an area. Finally, the demographic variable was represented by density. This indicator was collected from the National Institute of Statistics (NIS) of Tunis, which is the capital of Tunisia.

We provided the main characteristics of each series, such as recycling rate as an endogenous variable, the price of the collection of plastic waste, the number of recyclers who have an ordinance that requires them to recycle plastic waste, the urban population with access to the collection of plastic waste, the number of drop-off recycling centers in an area, and the population density per square mile. Table 2 summarizes the descriptive statistics associated with the six used variables in this paper. In fact, this empirical study was based on 456 annual observations. In summary, in Tunisia, the mean value of the recycling rate (Rate) is 15.3% and the rate varies from 0.75% to 36%. The mean price of the collection of plastic waste is 471,000, and the mean number of recyclers who have an ordinance that requires them to recycle plastic waste is 20. The mean population with access to collection recycling services is 1700. and the mean number of drop-off recycling centers in an area is 11. The mean population density is 285.56 people per square mile, and this varies from as low as 3.68 people per square mile to 2966.66 people per square mile. It is remarkable from this table that the standard deviation of collection is the highest and that of the rate is the lowest. The different variables spread asymmetrically to the right (skewness > 0). Furthermore, we observe that all variables are leptokurtic (kurtosis > 3). Finally, the Jarque–Bera statistic shows that all the variables used have a normal distribution.

**Table 2.** Descriptive statistics.

| Designations | Rate | Price | Ordinance | Collection | Drop | Density |
|---|---|---|---|---|---|---|
| Mean | 15.30 | 471.63 | 20.00 | 1700.00 | 11.00 | 285.56 |
| Median | 14.79 | 468.22 | 19.45 | 1695.00 | 10.11 | 280.49 |
| Maximum | 36.00 | 750.00 | 138.00 | 14,500.00 | 40.00 | 2966.66 |
| Minimum | 0.75 | 250.00 | 5.00 | 50.00 | 1.00 | 3.68 |
| Std. Dev. | 6.39 | 151.73 | 22.38 | 2039.98 | 6.88 | 584.92 |
| Skewness | 0.15 | 1.55 | 0.12 | 0.16 | 0.19 | 1.65 |
| Kurtosis | 3.25 | 4.87 | 3.33 | 4.45 | 3.96 | 4.98 |
| Jarque–Bera | 1.87 | 2.56 | 1.25 | 2.86 | 1.76 | 3.89 |

Source: authors' estimates from the data source.

## 5. Methodology and Results

The main objective of this study was to estimate the effect of financial influence, environmental institutions measured by the collection of waste (CW), the number of drop-off recycling centers, ordinance, and demographic determinants measured by the population density on the recycling rate for plastic. Since this investigation was based on a panel of 24 Tunisian governorates over the period of 2001–2017, the appropriate model was that of panel data estimation. In fact, we used a dynamic panel with the OLS (ordinary least squares) method to estimate the relationship between the endogenous variable ($y$) and the different exogenous variables ($x_i$). Indeed, we investigated the links between the rate and policy variables of plastic waste management. We used *Rate* as a proxy for the recycling rate and institutional, financial, and demographic factors—namely, collection (Collect), drop, ordinance (*Ordin*), price, and density (*Den*)—as indicators for improving environmental quality. We also investigated the impact of these institutional, financial. and demographic indicators on the recycling rate of plastic waste and found them to be effective measures for increasing this rate.

Subsequently, the governorate recycling rate of plastic waste (*Rate*) was described as a function of institutional, financial, and demographic variables. The following model was formulated to determine the influence of these indicators on the recycling rate:

$$\begin{aligned}\mathrm{Log}Rate_{it} = {} & \alpha_i + \beta_1 \mathrm{Log}Price_{it} + \beta_2 \mathrm{Log}Ordin_{it} + \beta_3 \mathrm{Log}Collect_{it} + \beta_4 \mathrm{Log}Drop_{it} + \\ & \beta_5 \mathrm{Log}Collect_{it} \cdot \mathrm{Log}Drop_{it} + \beta_6 \mathrm{Log}Den_{it} + a_i + \varepsilon_{it}\end{aligned} \quad (1)$$

To further explain, ($i$) stands for the i$^{th}$ cross-sectional individual (i.e., governorate) and $t$ stands for the t$^{th}$ time period. It is interesting to examine the links between these variables using cross-sectional and time-series data together with longitudinal or panel data sets.

Indeed, the key advantage of panel data is that one can increase the number of degrees of independence and the authority of the test by using more information on the behavior of a large number of entities at a similar time.

### *5.1. Specification Test*

In this section, unobserved individual heterogeneity correlated with regressors is discussed. Ref. [33] proposed the Hausman specification test for detecting fixed effects in individual–specific effects models. The use of the Hausman test in dynamic models is very interesting. This test aims to compare the results in an individual–specific effects model with those in the dynamic model. In order to estimate the empirical model, we started our analysis with the implementation of the panel static test. The individual effect was introduced on the level of the intercept ($\alpha_i$), as is the case in most empirical studies. The endogenous variables in our study have values that are determined by other variables as determining factors. In contrast, having endogenous regressors in a model will cause OLS estimators to fail, as one of the assumptions of OLS is that there is no correlation between an exogenous variable and the error term, which is the case in our application.

Subsequently, we estimated Equation (1) and used the preliminary step for the determination of the type of individual effect involved; it is a fixed or random effects. For this reason, we used the Hausman Test, to tell us which model was appropriate (see Table 3).

**Table 3.** Results of the Hausman test.

| Test Cross-Section Random Effects | | | |
|---|---|---|---|
| Test Summary | Chi-Sq. Statistic | Critical value of Hausman statistics | Prob. (*p*-value) |
| Cross-section random | 12.318639 | 0.05 | 0.0151 |

Source: authors' estimates.

According to this table, we observed that the value of the Hausman statistics was lower than the critical value of Chi-2 (The statistics of Hausman is defined as follows: $H = ((V(\hat{Y}LSDV) - V(YGLS))' (V\hat{Y}LSDV - YGLS))^{-1} (V(\hat{Y}LSDV) - V(YGLS)) \sim \chi_k^2$) Similarly, the probability value (*p*-value) was lower than the significance level at 5%. Furthermore, we accepted the hypothesis of the presence for correlation between the unobserved variable ($a_i$) and the exogenous variables ($X_{it}$). Consequently, we chose the fixed effect model (FEM) as the most appropriate for this study. Relating to ref. [34], in an FEM the null hypothesis implies that all units (governorates in this model) share the same intercept, whereas the alternative hypothesis states that they have different intercepts across units.

### *5.2. Results of OLS Estimation*

Since OLS regressions are considered as a standard approach in the literature for analyzing economic and environmental variables, Table 4 shows the main results from panel OLS estimation, where the exogenous variables have a positive and significant impact on the recycling rate for all the governorates from Tunisia, with the exception of the population density variable. As a result, the explanatory power of the fixed effects model ($R^2$) is equal to 0.97 and tends toward 1. Consequently, the main regression is great and the model is globally significant. This implies that the recycling rate is elastic with respect to the policy variables for plastic waste management.

**Table 4.** Results of panel OLS estimation.

| Variables | Coefficient | t-Statistics | *p*-Value |
|---|---|---|---|
| **Constant** | 6.94 | 2.46 | **(0.014)** *** |
| **L Price** | 2.58 | 10.06 | **(0.000)** *** |
| **L Ordinance** | 0.12 | 1.75 | **(0.081)** * |
| **L Collection** | 0.64 | 3.47 | **(0.025)** ** |
| **L Drop** | 0.83 | 4.75 | **(0.018)** *** |
| **L Collection. Drop** | 1.53 | 6.78 | **(0.000)** *** |
| **L Density** | −2.28 | −3.44 | **(0.000)** *** |
| **R-squared ($R^2$)** | 0.97 | **F-Statistic** | 132.80 |
| **Adjusted R-Squared** | 0.96 | **Prob (F-statistic)** | 0.0000 |
| | | **D-W** | 1.98 |

Notes: Values in parenthesis are the estimated *p*-values. *, **, and *** indicate significance level at the 10%, 5%, and 1% levels, respectively. D–W is the Durbin–Watson Test for autocorrelation; $R^2$ is the coefficient of determination, which represents the ratio of "explained" variance to the "total" variance of the dependent variable y.

In this analysis, we found that the variable "price of the collection of plastic waste" (price) has a greater effect on increasing the rate of recycling than other exogenous variables. In fact, this factor has a positive and significant impact on the recycling rate, with a 1% increase in price causing a 2.58% rise in the recycling rate. This result is consistent with the findings of [28] for Tunisia, with the findings of Calvin (27) for Canada, and with the findings of [16] for Minnesota. This strong relationship between the cost and rate of recycling can be explained by the fact that the waste management services in an area are

sources of revenue for several types of people, especially people who live in unfavorable conditions. In addition, the variable ordinance seems to be significant in this model. Its coefficient can be clearly seen to affect the recycling rate positively, as the results show that an increase in the number of people recycling in each year causes this rate to increase. In fact, with this authorization, Tunisian recyclers can develop a reflection upstream in this sector under favorable conditions. In this context, we cite as an example Law 1996–1941 of 10 June 1996, which was amended by Law 2001-14 of 30 January 2001, which set the rates and the granted amounts in order to improve waste management and encouraged people to participate in recycling. We can note the high level of participation of local communities in association with the Ministry of Environment and Sustainable Development as well as other actors in civil society. This is due to a set of intervention strategies and actions launched by the Tunisian government to promote entrepreneurial efforts in this area and encourage recyclers to create new projects and reduce their generation of waste. This result is in agreement with different studies that have examined the links between recycling rate and ordinance, such as the findings of [35] for Swedish municipalities and [16] for counties in Minnesota, USA.

Concerning the two variables "collection service" and "drop-off recycling centers", similarly to other exogenous variables discussed previously, they remain significant in this model. From the estimation presented above, we note that their coefficients are positive in both cases, which are either separated or implemented together. In addition, it is evident that their effect on the rate of recycling plastic waste is positive. These findings show that the interaction composite variable "collect-drop" increased the recycling rate at the 1% level of significance.

This means that these two parameters seem complementary for improving the recycling rate in particular and are absolutely necessary in the overall recycling field. These results are similar to the findings of recent research by [28] for the Tunisian company, Lubricants; Shaufique et al. [36] for the United States, Callan and Thomas [37] for 351 Massachusetts municipalities and [38] for selected regions in the USA and Europe. Contrary to these findings, the results reveal that the coefficient associated with population density, as measured by people per sq. km of land area, is significantly negative. These results indicate that a decrease in the density of a Tunisian city by 1% increases the rate of recycling by 2.28%. This can be explained by the following factors: We observed that people living in densely populated urban areas are more likely to become engaged in recycling activities than people living in rural areas; as a result, there is an absence of procedures aimed at raising awareness and consciousness for rural citizens, who need to be more motivated and educated regarding waste management and recycling. It may be possible that the density variable will make a difference in these urban governorates in terms of recycling attitudes and behaviors. A further possible reason for this is the revolution of 14 January 2011, which affected attitudes towards the environment as part of the events which shook Tunisia.

On the other hand, these findings show that the influence of these factors on the recycling rate of plastic waste is not highly elastic, despite the statistical significance of these parameters. This is justified for the following reasons.

In Tunisia, several recyclers in the informal sector have practiced their recycling activities without authorization from the Tunisian Government. This situation can be explained by the difference in the cost between the prices of plastic disposal provided to collectors, which are fixed by the Ministry of Environment and Sustainable Development, and the prices fixed by private recyclers. Indeed, the ordinary collectors have received a greater amount of money from private recyclers than the amount given by the Ministry of Environment.

Moreover, we note that there is an imbalance in the level of waste management between recyclers who are included in a formal sector and follow the laws relating to waste management and those who engage in this activity in an informal way. The Tunisian Government also excluded from its instructions submissions from anonymous recyclers who do not follow its conventions and those who follow them in an inappropriate way.

Concerning the individual effects associated with each Tunisian governorate, the estimates of the constants in most cases turned out to be positive and expected results that will contribute to developing a powerful industry for recycling in such cities as Tunis (7.26), Ariana (5.33), and Sfax (5.50) (For the various areas one finds the effects individual deterministic considered following: Tunis (7.26), Ben Arous (6.98), Bizerte (5.88), Nabeul (6.36), Ariana (5.33), Manouba (5.97), Monastir (4.16), Mahdia, (4.10), Medenine, (3.96), Sfax (2.12), Sousse (8.15), Gafsa (3.12), Gabes (2.98), Sidi-Bouzid (2.23), Beja (4.00), Kairouane (4.12), Kef (1.25), Kasserine (0.76),Kebelli (0.95), Tozeur (1.13), Jendouba (−0.89), Siliana (−1.15), Zaghouane (−1.11), Tataouine (−0.96)).

These findings suggest that in order to improve recycling rates, Tunisia needs to implement recycling policies that will induce informal or formal recyclers to adopt new techniques and technologies to help them to practice this activity in favorable conditions. Compared with the global activity of a country and its capacity to treat raw materials, the role of informal recycling can be very important and of strategic importance.

### *5.3. Finding and Policy Implications*

In Table 4, we show that the exogenous variables have a positive and significant impact on the recycling rate for all the governorates from Tunisia, with the exception of the population density variable, which, as a result of the explanatory power of our fixed-effects model ($R^2$) is equal to 0.97, tending toward 1. As a result, the main regression is great and our model is globally significant. This implies that the recycling rate is elastic with respect to policy variables for plastic waste management.

We can explain this result by the efficiency of factors that Tunisian policymakers can consider to raise its rate of recycling of plastic waste. By actively raising these factors, all the governorates of Tunisia can obtain the many advantages that recycling can supply. Yet, it is important to note that this study is only interested in the influence of policy indicators on the recycling rate of plastic, as the material most frequently used by the Tunisian people and which can be considered an important material in the industrial sector.

On the contrary, it should be noted that the demographic factor "density" will negatively affect the rate of recycling of plastic waste. These findings suggest that in order to improve recycling participation, Tunisia needs to create a recycling sector, which may raise the awareness of the benefits of recycling. Our results revealed that the Tunisian people should be more educated with regard to how to collect recyclable waste, how to sort and separate it, where to deposit it, and why it should be recycled. Hence, policies should encourage people and private entrepreneurs to create small- and medium-sized industries in the recycling sector. Moreover, these could lead to reducing waste generation and increasing recycling activities.

To sum up, our empirical findings prove that the majority of the exogenous variables we have chosen for the studied model contribute to increasing the rate of recycling of plastic waste. Other variables could be incorporated into future models to further the research on this subject, especially in terms of demographic factors such as gender, age, income, and education, which have been noticed to influence the recycling rate.

## 6. Conclusions

In this paper, we explored different factors related to the plastic recycling rate in Tunisia. We also focused on problems related to plastic waste that pose a serious threat to the environment in Tunisia. In fact, we found mixed results related to the key factors that determine the rate of plastic recycling in Tunisia in 24 governorates.

This study examined the influence of institutional, financial, and demographic factors on the rate of recycling of plastic waste during the period 2001–2020 using panel data and the OLS (ordinary least squares) method for estimation. The empirical results implied that there is a strong relationship between the institutional, financial, and demographic factors and the rate of recycling, indicating that an increase in this rate is dependent on an increase

in these indicators (e.g., price, the collection of plastic waste, drop-off recycling centers, ordinance, and density).

It should be indicated that other diverse factors are not taken into account in this study—for example, education regarding recycling programs and waste separation, the introduction of systematic procedures for traceability of waste, etc.

In fact, as we show, educating the public on the need to recycle waste will also contribute to increasing the recycling rate. In addition, people will be better educated, motivated, and informed, making the success of the recycling program more likely in the long term (EPA, 2016). Consequently, policymakers must consider the importance of the recycling sector and give priority to its diverse stages, especially the quality of factors influencing the rate of recycling, which has a significant impact on the economic growth of the government and may lead to improving sustainable development for both regional cities and Tunisia as a whole. Hence, this could lead to a major improvement in the Tunisian waste management ecosystem.

Finally, this paper offers a strong public benefit; following our recommendations will allow Tunisia to achieve the best waste management possible, resulting in the lowest cost with the highest circular economy benefits in the context of an emerging economy such as Tunisia.

From this perspective, future research will need to extend the study area used and investigate the links between the rate of recycling and the different recycling behaviors of people who live in rural areas as well as urban citizens. Moreover, it is essential to make recycling an efficient practice in Tunisian industries in order to design the best policy response. As a result, it is necessary to develop waste recycling to become a more labor-intensive sector. This would serve the triple objective of reducing the unemployment rate, the incidence of poverty, and pollution.

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