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Dynamic macroeconomic factors in Recycling Industrial Gross domestic product: Empirical Evidence from Tunisia

Lamia Ben AMOR[1] , Sami Hammami [2]

[1]Doctor at the University of Economics and Management of Sfax, Tunisia.
Unit of Research, Development and Economics **(URDE)**

E-mail: lamiabenamor @yahoo.fr

[1]Professor at the University of Economics and Management of Sfax, Tunisia.
Unit of Research, Development and Economics **(URDE)**

E-mail: sami_hammami2005@yahoo.fr

Abstract

The objective of this study work is actually to look at the link between the labour force, secondary finished goods and the industrial GDP from recycling manufacturing in 24 Tunisian governorates. As a result, the yearly data collected during the period 2001-2023-were analyzed using the Vector Error Correction Model (VECM). Furthermore, the empirical results showed that the GDP and capital stock are favourably correlated with the labour component. The findings also demonstrated the existence of a one-way link between the secondary finished goods and the GDP, as well as the macroeconomic factors in the short and long term. Indeed, the personnel and capital stock are critical for the success of recycling plastic industrial production and new-finished goods.

Keywords: Waste Recycling, Industrial Gross Domestic Product, Value added, Macroeconomic factors, Vector Error Correction Model (VECM) , Granger Causality

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1. Introduction

At the beginning of the industrial revolution, no individual thought about the extinction of natural resources. Moreover, these pieces of garbage are subjects of appropriating and technical manipulation. During the last decades of the 20th century, researching for the processes and alternatives had to be inevitably implemented. Therefore, research into the processes and alternatives had to be implemented in the final decades of the 20th century. Therefore, to save the planet, we have to carefully take into account the best course of action. Furthermore, the technological development, including the recycling of materials, is a scrupulous and a crucial solution to protect the natural resources. In fact, it is the signal showing that wasting is becoming unbearable, while recycling is becoming mandatory.

In this context, waste represents a convergence of various storage solutions that facilitate material utilization and the frameworks within which we engage in recycling practices. Furthermore, this sector has recently emerged as a viable economic endeavour, contributing to the establishment of markets, including those of a commercial nature. On the other hand, waste can be perceived as a synthesis of various processes that facilitate the utilization of materials, alongside the regulation of these practices, which encompasses recycling. Additionally, the emergence of markets, especially in the commercial realm, has recently demonstrated that this sector can function as a productive economic endeavour.

Therefore, the inhabitants of the various countries have become the wizards of recycling as they know how to benefit from the worst. In fact, they believe that it is possible to repair end-of-life objects by integrating them again into the lifecycle as commercial goods. Accordingly, our society can produce some arts with waste, which become objects of decoration or reused since theyecome old, useless and off-putting objects find their place in the society. Therefore new factories and industries got organized around this production by finding a source of profit, according to conversion dialectics. Thus, a new image takes shape for waste whenit not treated. For this reason, it is necessary to recycle and reconstruct with this rubbish so that a new material can spring up.

For their part, the residents of various nations have emerged as adept recyclers, skillfully transforming what is often deemed undesirable into valuable resources. They hold the conviction that it is feasible to restore items that have reached the end of their useful life by reintegrating them into the market as commercial products. Consequently, our society has the potential to create artistic works from waste materials, which can be repurposed as decorative items, allowing once discarded and unattractive objects to regain their significance within the community. Hence, this shift has led to the establishment of new factories and industries focusing on this innovative production, identifying profit opportunities through the principles of conversion. As a result, waste is redefined when it is not simply discarded. Therefore, it is imperative to engage in recycling and reconstruction of these materials, enabling the emergence of new resources from what was previously considered refused.

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It is therefore essential to recognize that waste represents a continually expanding resource in the context of lifestyle. This phenomenon possesses some attraction, despite the fact that the employed recycling methods are often artificial rather than organic. We have actually discovered the significance of this process, which paves the way for collective insights and engaging opportunities.

This research seeks to investigate the relationships between the industrial gross domestic product associated with recycling manufacturing and significant variables, including capital stock, labour, and secondary finished products, across 24 governorates in Tunisia. The analysis will utilize data spanning from 2001 to 2022. Therefore, to fulfil our objectives, we will employ contemporary advancements in econometric techniques. In fact, our approach involves a three-phase methodology: executing unit root tests, utilizing Johansen's co-integration tests, and conducting Granger causality tests within the context of the Vector Error Correction Model (VECM).

Then, the subsequent sections of this paper are structured as follows. **Section 2** provides a review of the relevant literature, while **section 3** details the data sources, the model estimation, and the empirical findings. Finally, **section 4** offers a conclusion to the paper.

2. Litterature Rewiew

In fact, due to urbanization and the intensive population growth, there is an aggressive accumulation of waste, which turns out to be a big problem. Therefore, we have to look for urgent solutions, such as the process of recycling in which several firms are affecting circular economic value chains. Today, the recycling process is developing as the prospective industry occasion to create a more viable and significant value chain for economic, societal and environmental aspects. Therefore, recycling is not only a universal approach but it also assists as an innovative mode of defining business processes, services and products.

This subject has actually attracted the attention of several authors, such as Hotelling (1931), who stated that the economic literature has granted more attention to the constraints imposed on economic growth, particularly the exhaustible resources. Nevertheless, the theorists ofendogenous growth, like Stiglitz (1974), ,who consider this input type, were completely optimistic, and showed the existence of three founding factors of economic growth that would make these exhaustible resources extremely effective. Let us note mainly technical progress, the factors of production, namely capital, labor) and returns to scale Infact, the dynamics of the environmental protection, which was analyzed by Bovenberg and Smulders (1995), Musu and Lines (1995), Olson and Knapp (1997)) in the models of endogenous growth, is related to intergenerational equity Moreover, other theorists, namely Kamien and

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Schwartz, (1978) as well as Barbier (1996). studied the efficiency of the exhaustible resources,. In an empirical investigation, there are three levels relating to the causal relationship between the macro economic factors and economic growth, especially the industrial gross domestic product for recycling manufacturing. The first level indicates that waste recycling is a cause of economic growth.

Moreover, this vision was maintained by Baumol, (1977), Hoel, (1978); who confirmed that the waste recycling process might improve to maintain the rate of economic growth through the protection of the environment. In the same vein, Di Vita,(2001), proved that waste can be recycled through the production process, equally an input to get secondary products. These new produces can affect the growth rate of the total output. Furthermore, Kinnaman and Fullerton, (2000), showed that the recyclable waste, is sorted out and transformed back into finished products by forming commercial goods, which are reinserted again in the production cycle. As for Stiglitz (1974), he showed the existence of an optimal path of endogenous growth in the models introducing respectively, technological changes, exhaustible resources and flows of secondary materials considering the way reusable products could affect growth rate. On the other hand, the proponents of the endogenous growth theory, such as Stiglitz (1974), exhibited a strong sense of optimism regarding this type of input. Actually, they identified three fundamental factors contributing to economic growth that would make these finite resources highly efficient. These factors primarily include technological advancement, the inputs of production—specifically capital and labor—and the concept of returns to scale. Furthermore, the dynamics of environmental protection, as examined by Bovenberg and Smulders (1995), Musu and Lines (1995), and Olson and Knapp (1997) within the framework of endogenous growth models, are closely linked to the principle of intergenerational equity. Moreover, this topic has garnered the interest of numerous scholars, including Hotelling (1931), who noted that the economic literature has focused more on the limitations affecting economic growth, especially concerning the exhaustible resources.

Therefore, other theorists studied the efficiency of the exhaustible resources, like the example of Kamien and Schwartz, (1978) as well as Barbier (1996). In the empirical investigation, there occur three levels relating to the causal relationship between macro economic factors and economic growth especially industrial gross domestic product for recycling manufacturing. The first level indicates that waste recycling as a cause of the economic growth. This vision was maintained by Baumol, (1977); Hoel, (1978); who have confirmed that waste recycling process might improve to stand the rate of economic growth with a protection of the environment. In the same vein, Di Vita,(2001), has proved that waste can be recycled through the production process, equally an input to get secondary products. These new produces can influence the growth rate of total output.Furthermore, Kinnaman and Fullerton, (2000), have showed that the recyclable waste, itis sorted out, was back, transformed into finished products by forming commercial goods, and reinserted again in the production cycle. As for Stiglitz (1974), he showed the

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existence of an optimal path of endogenous growth in the models introducing respectively technological changes, exhaustible resources, and flows of secondary materials considering the way reusable products could influence the growth rate.

Moreover, a significant number of scholars in this field have sought to quantify the growth rate of the production function by articulating macroeconomic hypotheses, specifically regarding physical capital and population growth rates, which are assumed to be two constant exogenous variables.

This theoretical analysis indeed substantiates the notion that the economy undergoes a dynamic transition period during which technological advancements and labor factors are integrated into the recycling sector, thereby enhancing the production of secondary materials, substituting depleting resources, and conserving natural resources. In a similar context, Van Beukering and Curlee (1998) proposed that recent research has identified three evident facts:

i) The industrialized countries highlighted a significant increase in the quantity of collected and reused waste;
ii) There is an increasing trend of collected waste, which could be exportedsouthward for reuse, as the developed countries are the main importers of exhaustible resources that should be secondary and commercial materials after their recycling.
iii) and the developed countries are the main importers of exhaustible resources that should be secondary and commercial materials after their recycling.

For their part, the industrialized nations have reported a notable rise in the volume of waste, which is collected and subsequently reused. Furthermore, there is a growing trend in the collection of waste, which has the potential to be exported to southern regions for reuse, as the developed countries primarily serve as the main importers of finite resources that ought to be transformed into secondary and commercial materials following the recycling process.

In this context, Kaseva et al. (2002) proposed that informal recycling systems could be remarkably efficient, achieving high recycling rates through intensive manual sorting and specialized expertise in extracting valuable waste. Meanwhile, Kamien and Schwartz (1978) directed their focus towards the movement of secondary materials, highlighting the significance of recycling practices in contributing to economic growth over time.

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On the other hand, the recycling sector is contributing to the supply of raw materials for manufacturing at an increasing rate. Currently, approximately 50% of paper and steel, 43% of glass, and 40% of non-ferrous metals produced within the European Union are derived from recycled materials[31]

The second level indicates a bi-directional causality between macroeconomic factors, such as capital-labor dynamics and waste recycling. This perspective is supported by Romer (1990), who stated that labor acts as a rival asset by integrating technological innovations that facilitate the recycling of used products, thereby reducing waste recycling costs and enhancing the production of reusable secondary materials. Furthermore, Martina et al. (2020) contend that capital stock serves as a significant advantage in manufacturing recycling, primarily aimed at generating revenue for the company. Conversely, capital stock refers to the products purchased not for immediate consumption but for future use in the production of new items derived from waste recycling.

Additionally, the environmental issues associated with waste management drive the pursuit of new scientific advancements, particularly in the field of technological innovation related to recycling methods, which facilitates the conservation of natural resources. In this context, Romer (1986) affirmed that labour is the primary determinant of technology, as it can be applied within the research sector to generate both intermediate and final products. Consequently, the author illustrated that the waste generated from the utility function could adversely impact economic growth.

Then, the final level illustrates that the recycling sector establishes a value chain for the company and contributes to economic growth. Consequently, the accumulation of waste presents new industrial opportunities, particularly in the realm of recycling. Thus, the recycling industry can be regarded as a significant element of the environmental sector. Furthermore, the transformation of waste through recycling fosters a connection between the consumers and their environment, as it allows for a reversal of the traditional dilemma surrounding non-renewable resources and consumption. Additionally, waste serves as a raw material for various economic, agricultural, artisanal, or industrial activities. In fact, the use of this resource can positively affect all the aspects of waste management and, therefore, create jobs and financial resources, enabling the conceptualization of waste as tradable products with substantial economic value.

For their part, Van Beukering and Curlee (1998) stated that the recycling industry has the potential to serve a dual purpose by generating employment opportunities and drawing in direct foreign investments. In a similar context, Sepúlveda et al. (2010) emphasized that while recycling is intended to be a sustainable approach to waste management, its efficiency must be ensured to mitigate economic, social, and environmental risks.

I fact, the abundance of squalid raw materials hinders the development of the recycling schemes for their

[3] Questions and answers on the thematic strategy regarding prevention and waste recycling, MEMO / 05 / 496, Brussels, on December 21st, 2005

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part, Beukering and Bouman, (2001) stated. that there is a gap between the high rate of consumption and the recycling of materials. Consequently, following OECD,(2004). we can conclude that there is a positive link between the recycling rate and economic growthas the recycling ofsolid waste in the newly industrialized countries (NIC) can cause the reduction ofthe waste accumulation.

Moreover we can refer to Di Vita's works (2001) which clearly showed that the more capitalincreases, the more the fictitious price of the secondary materials tends to riseMoreover, he demonstrated that the developing countries can produce secondary materials at costs lower than the the ones in the industrialized countries.
In the same vein, Van Beukering and Bouman, (2001) added that the abundance ofcheap raw materials favors the development of the recycling schemes. Furthermore, there is a link between economic growth and the waste disposals ensuing from consumption,which should raise the rates linked to waste recycling, more particularly the mechanism of the recycling materials. In fact, as Van Beukering and Curlee, (1998) declard, the positive results of privatecompanies in strengthening the recycling process are the creation of jobs for the poorcitizens in the urban zones As for Nas and Jaffe, (2004).

They asserted that beside the activity of the formalprivate sector in the practices of recycling, the role of the informal sector should not be neglected since several thousands of people on whom the development of cities depends for recycling materials from waste assure their subsistence.

On the other hand, Medina (2000) stated that in addition to the possibilities of employment in the recycling activities, in both the private and public sectors, the income of vultures (collectors of waste) is generally very low due to their low position in the hierarchy of the trade of recycled materials since they are often badly exploited and paid a very low price forthe collected materials. In the same context, Rogerson and Christian (2001) pointed out that the informal recycling sector is often highly qualified to identify waste having a potential value. In fact, they collected documents, which were thrown as waste and added to them the value of sorting out and cleaning, while modifying the physical shape to facilitate the transport or the aggregation of materials.

Subsequently, we can consider recycling as an informal sector having long-lasting economic criteria, which require the capacity to generate ~~a~~ technical knowledge of theprocess. Indeed, the pariah and marginal population groups in the developing countries, like the Gypsies, the rural migrants, the immigrants and the members of religious minorities, always practice Therefore, as asserted by Van Beukering et al, (1996)) it is true that this sector is adopted by the minorities who are socially excluded and harassed by the authorities However, this social exclusion leads societies to develop and modify the living conditions by creating new efficient projects of recycling, which provide a satisfaction of their necessary need Therefore, Gerdes and

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Gunsilius (2010) demonstrated that garbage recycling builds up an economic activity that leads to others, such as collecting, transporting, storing and sorting.

Actually, this sector, which seems new by its aspects, serves to stimulate innovation, and even bring in some situations, Furthermore, the possibility of patents for export. can reduce dependency by offering substitute products to the imported ones so that it contributes to the trade balance of a country. Similarly, Lupton, (2001) stated that recyclable waste is completely the by-products of our systems of production, processing and consumption. as they represent an important dimension in the advanced economies or in development.

On the other hand, from a macroeconomic point of view, Wilson and al, (2006) have suggested that informal recycling can have important economic effects for the developing countries since the informal recycling systems are well adapted to the conditions, which prevails a plentiful offer, namely the workforce.

Moreover, from a social point of view, Di Vita (2001) asserted that the recycling process permits to reduce the rate of useof the exhaustible resources the quantity of waste thrown out in the environment, and save natural resources for the future generations.

3. Data: Nature and Source

Nature and Source

The data, which are the subject of this study, are annual and taken from four different sources: namely, the National Institute of Statistics (NIS), the Industry Promotion Agency (IPA), the National Environment Protection Agency (NEPA) and the National Waste Management Agency (NWMA) in Tunisia. In fact, these annual data cover the period from 2001 to 2022. The table below actually provides information on the used variables.The table below provides information on the variables used (Table **1**).

Table1: Variables Used

Variables	Definitions	Sources
IGDP	Industrial Gross Domestic Product from industrial plastic recycling	NIS and IPA
K	The stock of capital used by firms of plastic recycling	NEPA and NWMA
L	The number of labors in firms of plastic recycling	NEPA and NWMA
SFP	Secondary finished products	NEPA and NWMA

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The development indicator chosen in this study is the industrial GDP from recycling sector manufacturing for each governorate in Tunisia. Indeed, the manufacturing subsector that is taken into consideration comprise: other manufacturing industries, which includes recycling sector. This sector participate with 8% in added value of manufacturing industries (This information concerning the percentage (8%) of added value related to recycling plastic was obtained through interviews with the responsible of National Institute of Statistics and Industry Promotion Agency).

Furthermore, this indicator is calculated from the sum of the added value of recycling industry in millions of Tunisian dinars at current prices for the period between 2011 and 2022.

The industrial Gross Domestic Product (IGDP) in each governorate is calculated as follows:

$$IGDP\ in\ each\ tunisian\ governorate = \sum_{t}^{N} \text{total Added Value of recyling plastic} \times \text{Weighted factor } index$$

Where *N* denotes the country and *t corresponds* to the year.

1. total Added Value of recycling in Tunisia country is obtained from NIS and IPA

We follow the approach of Jones (2016) to construct the systematic weighted factor, which is calculated as follows:

2. Weighted factor index = $\frac{\text{Poulation of ecach governorate}}{\text{Total Tunisian poulation}}$

Descriptive Statistics

Table 2 below indicates the descriptive statistics associated with the four variables used in this study.

In fact, it show that the standard deviation of the (K) is the highest and that of the IGDP is the lowest.

In terms of skewness, all variables are positively biased and spread asymmetrically to the right (skewness > 0). Besides, we perceive that all variables are leptokurtic (kurtosis > 3). Lastly, the Jarque–Bera test demonstrates that all the used variables have a normal distribution.

Table 2: **Descriptive Statistics**

Designation	lnIGDP	lnK	lnL	lnSFP
Mean	3.654862	14.86508	3.991129	0.121897
Median	3.735882	14.95893	4.094345	0.020203
Maximum	4.765417	18.29422	5.720312	5.768321
Minimum	2.200552	11.55556	1.945910	2.302585
Std. Dev.	1.577123	1.658811	1.757358	1.021580
Skewness	0.486824	0.198398	0.532836	0.398310
Kurtosis	3.005612	3.322417	3.740552	6.927562

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Jarque-Bera	19.28473	8.209915	11.43383	229.8660
Probability	0.000065	0.016491	0.003290	0.000000
Sum	1228.034	4994.666	1341.019	40.95734
Sum Sq. Dev.	111.5790	921.8042	192.1530	349.6148

Source: authors' estimates from the data source.

Correlation between used Variables

Table 3 demonstrates the correlations between Industrial gross domestic product (IGDP), stock of capital (K), number of labors (L) and secondary finished products (SFP).

Table 3: Correlation matrix of variables

Designation	K	lnL	lnIGDP	SFP
K	1			
lnL	0.223879	1		
lnIGDP	0.586284	0.489310	1	
SFP	-0.178938	-0.423363	-0.302558	1

From this table, the results indicate that the variables IGDP, K and L are correlated positively. Nevertheless, SFP is correlated negatively with IGDP, K and L. We notice the strong correlation between IGDP and L (0.489310). Similar to K, which is correlated positively with IGDP (0.586284).

Presentation of the Model

In fact, the key objective of this study is to analyze the relationship between industrial gross domestic product (IGDP), capital stock (K), Labor (L) and secondary finished products (SFP) for 24 Tunisian governorates using annual data over the period of 2001/2022 period. In our empirical investigation, we used a log transformation to calculate these variable because it makes it possible to mitigate the trend of the series, eliminating strong asymmetries in the distributions.

The specification of our model takes the following form:

$$ln\, IGDP_{it} = \alpha_{it} + \alpha_1 \ln K_{it} + \alpha_2 \ln L_{it} + \alpha_3 \ln SFP_{it} + \varepsilon_{it}$$

For i = 1… N; t = 2001 to 2022

where α_i represents the fixed-effect parameter; α_{1i}, α_{2i}, and α_{3i} denote the slope parameters; and ε_{it} are the estimated residuals which represent deviations from the long-run relationship.

Empirical Results and Interpretation

We will follow the recent developments in econometrics to examine the causal relationship between the industrial gross domestic product (IGDP), capital stock (K), labor (L), and secondary finished products (SFP). This approach will be conducted in three steps; the unit root tests, the Johansen co-integration tests, and Granger causality tests as part of an error-correction vector model.

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Study of stationarity and cointegration of series

The unit root tests have become a common approach for the analysis of stationary timeseries. However, the implementation of these tests on panel data is recent. Indeed, we find that the tests most frequently used are those of Levin and Lin (LL) and Im,Pesaran and Shin for (IPS). Indeed, these two tests are used to study the non-stationary series. To overcome the low power of tests "LL" and check the stationary state of the group, we use the IPS method, which suggested a unit root test in the context of a panel data model using the average individual statistics regressions "ADF". The longitudinal cross-sectional data should ideally meet the assumptions necessary for the application of the alternative statistic t-bar to test the null hypothesis of unit root for all β_i **=0)** :

$$\bar{t}_{NT}(p_i) = \frac{1}{N}\sum_{i=1}^{N} t_{iT}(p_i)$$

Where: ti T(pi) : represents ADF testsestimated withdelayeddifferences ;N : is the number of governorate N = 1,2,… ....24.
T:The period of time T =1,2,… .... 22.

IPS suggests the use of the following standardized studies :

$$Z_i = \frac{\sqrt{N}(\bar{t}_{NT} - E(\bar{t}_{NT}))}{\sqrt{var(\bar{t}_{NT})}}$$

Where **E** $\bar{t}_{NT}$ **)** and **Var (** $\bar{t}_{NT}$ **)** are respectively the arithmetic means and variances of the individual ADF statistics, $\beta_i = 0$.

The IPS study shows that the standardized Statistics converges weakly to the normal standard distribution, allowing comparing it to the critical values of distribution. The application of the unit root tests show that LL and IPS are all statistics assigned to a unit root.

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Table4: Unit Root Test

	Test of Levin,Lin,Chu Without tendency	Test of Levin,Lin,Chu With tendency	Test of Breitung Without tendency	Test of Im, Pesaran and Shin Without tendency	Test of Im, Pesaran and Shin With tendency
lnIGDP	2.98587	-6.57556	0.50043	8.9062	0.04877
	(0.9986)	(0.0000)*	(0.6916)	(1.0000)	(0.5194)
ΔlnIGDP	-13.8826	12.7610	-10.3018	-10.1175	-7.68076
	(0.0000)*	(0.0000)*	(0.0000) *	(0.0000)*	(0.0000)*
lnK	-3.96820	0.86169	-1.49823	4.66432	2.15405
	(0.0000)*	(0.8056)	(0.0670)	(1.0000)	(0.9844)
ΔlnK	-10.6944	-12.3565	2.50175	8.02632	-7.78513
	(0.0000)*	(0.0000)*	(0.9938)	(0.0000)*	(0.0000)*
lnL	-18.2345	-30.3285	8.14249	-10.3603	-6.22493
	(0.0000)*	(0.0000)*	(1.0000)	(0.0000)*	(0.0000)*
ΔlnL	-31.5265	-29.6392	7.47503	-7.75770	-13.6758
	(0.0000)*	(0.0000)*	(1.0000)	(0.0000)*	(0.0000)*
lnSFP	-4.72813	-6.37215	-0.78848	-1.77572	-3.62839
	(0.0000)*	(0.0000)*	(0.2152)	(0.0379)	(0.0001)*
ΔlnSFP	-19.3871	-18.5899	-2.66949	-14.4544	-11.6005
	(0.0000)*	(0.0000)*	(0.3177)	(0.0000)*	(0.0000)*

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	Test ADF Without tendency	**Test ADF With tendency**	**Test PP without tendency**	**Test PP With tendency**	**Test Hadri Without tendency**	**Test Hadri With tendency**
lnIGDP	3.45362	48.0399	8.09533	28.5163	12.7591	9.33851
	(1.0000)	(0.4712)	(1.0000)	(0.9886)	(0.0000) ***	(0.0000) ***
ΔlIGDP	-180.421	136.780	-184.097	171.641	5.78702	17.7868
	(0.0000) ***	(0.0000) ***	(0.0000) ***	(0.0000) ***	(0.0000) ***	(0.0000) ***
lnK	55.0136	46.9794	84.8707	55.8569	6.69638	10.0572
	(0.02236)	(0.5146)	(0.0008) *	(0.2035)	(0.0000) *	(0.0000) *
ΔlK	-160.826	148.222	-202.729	214.998	4.69252	15.4900
	(0.0000) ***	(0.0000) *	(0.0000) *	(0.0000) *	(0.0000) *	(0.0000) *
LnL	165.452	73.2340	332.451	98.8918	13 .2282	11.3909
	(0.0000) *	(0.0110)	(0.0000) *	(0.0000) *	(0.0000) *	(0.0000) *
ΔlL	-81.2072	81.2072	-87.83322	116.252	11.4063	7.67754
	(0.0019) *	(0.0019)	(0.0004) *	(0.0000) *	(0.0000) *	(0.0000) *
LnSFP	78.9414	92.3876	92.8925	141.317	11.3005	9.58333
	(0.0032)	(0.0001) *	(0.0001) *	(0.0000) *	(0.0000) *	(0.0000) ***
ΔlSFP	-247.556	192.594	-359.607	330.220	3.53123	10.1021
	(0.0000) *	(0.0000) *	(0.0000) *	(0.0000)***	(0.0002) ****	(0.0000)***

***, **, *** indicates that the parameter estimates are significant at 1%, 5%, and 10%**

In this study, we used Levin et al. (2002) (LLC), Im et al. (2003), ADF, (1979), tests. From the table above, the results are presented in Table 4. The results show that all variables are non-stationary and integrated of order one (*I* (1)).

Cointegration Test Results

We have used the Johansen co-integration test (1988), which has utilized two statistics: the trace statistic and the maxi- mum eigenvalue. The results are shown in the following Table:

Table 5 Results of the Johansen Cointégration test

Hypothesized No. of CE(s)	Fisher Stat.* (from trace test)	Prob	Fisher Stat.* (from max-eigen test)	Prob
None	79.50	0.0000	79.50	0.0000
At most 1	269.79	0.0000	235.6	0.0000
At most 2	113.6	0.0000	100.4	0.0000
At most 3	98.8	0.0000	89.65	0.0000
At most 4	45.75	0.0000	45.75	0.0000

*, **, *** indicates that the parameter estimates are significant at 1%, 5%, and 10%

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Fully Modified Ordinary Least Square

In order to accomplish cointegration tests on panel data and to attain an estimate ofthe cointegration vectors, it is essential to do an efficient estimation method.

In this context, we use the method fully modified ordinary least square (FMOLS) (leastsquare completely modified) used by Pedroni.The estimates by the method FMOLS were presented in Table 6.

Table 6 Results of FMOLS estimation

Dependent variables	Independent variables	Coefficient	Prob
ΔlnIGDP	ΔK	2.012306	0.0825***
	ΔlnL	1.024159	0.4385
	ΔlnSFP	0.772381	0.0000*
ΔlnK	ΔlnGDP	111.353	0.2263
	ΔlnL	4.19653	0.6987
	ΔlnSFP	2.72245	0.7898
ΔlnL	ΔlnGDP	0.35 381	0.2078
	ΔK	7.771112	0.0421**
	ΔlnSFP	0.042484	0.0018*
ΔlnSFP	ΔlnGDP	−9.125302	0.0675***
	ΔK	1.256385	0.0077*
	ΔlnL	0.1 56689	0.0007*

*, **, ***Significance respectively at 1%, 5%, and 10%

The econometric results showed that the industrial gross domestic product of recycled plastic is more elastic with both capital and labor than with secondary finished products. This indicates that the recyclers use more capital in cooperation with the workers in the plastic recycling process. We have found that the elasticity of the industrial gross domestic product in relation to the capital is 2.0123, while that of labor is1.024.

Besides, the industrial gross domestic product appears to be slightly elastic compared to the secondary products, obtained from recycling plastic. Then, the estimated values of the individual effects are consistent with the expected results which are positive in cities where the recycling process is developed, such as the cities of Tunis(0833),Sfax(0.57), Nabeul (0.47), Bizerte (0.31). However, these effects are not significant in the cities where the recycling industry is not too advanced, such as the towns, such as the towns of Tozeur (-1.13) Tataouine (-0.63) Zaghouan (-0.52) Kef (-0.27) etc[2].

[2] Ariana (0.25), Ben Arous (0.42),Béja (0.12), Bouzid (0.160), Gabes (-0.103), Gafsa (-0.152),Jendouba (-0.29), Kairouan (0.39), Kasserine (-0.12), Kebelli (-0.97), Mahdia (0.35), Manouba (0.11),Médenine (0.050),Monastir (0.27), Sousse (0.62), , Siliana (-0.14),

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Granger Causality and VECM Model

Following the results of the cointegration test, we estimate the VECM panel to test the causality of Engle and Granger (1987). We adopt the two-step procedure, first estimating the long-term model for obtaining the residues.

$$\ln IGDP_{it} = \alpha_{it} + \delta_{it} + \delta_{it} lnK_{it} + \delta_{it} \ln L_{it} + \delta_{it} + \ln SFP_{it} + \varepsilon_{it} \qquad (2)$$

where i keep for each country in the panel and t represents time. The parameters of α_i and $ð_i$ are for the possibility specific of fixed effect of country and the trend.The s_{it} is for the estimated residual.

Then, the residuals of the Eq. (2) were used to estimate the error term in the fol- lowing equations:

$$\Delta lnIGDP_{it} = \beta_{10} + \sum_{i=1}^{p} \beta_{11i} \ln IGDP_{it-k} + \sum_{i=1}^{p} \beta_{12i} lnK_{it-k} + \sum_{i=1}^{p} \beta_{13i} lnL_{it-k} + \sum_{i=1}^{p} \beta_{14i} SFP_{it-k} + \beta_{16} ECT_{it-1} + \varepsilon_{1it} \qquad (3)$$

$$\ln k_{it} = \beta_{20} + \sum_{i=1}^{p} \beta_{21i} ln\, k_{it-k} + \sum_{i=1}^{p} \beta_{22i} \ln IGDP_{it-k} + \sum_{i=1}^{p} \beta_{23i} \ln L_{it-k} + \sum_{i=1}^{p} \beta_{24i} SFP_{it-k} + \beta_{25} ECT_{it-1} + \varepsilon_{2it} \qquad (4)$$

$$\ln L_{it} = \beta_{30} + \sum_{i=1}^{p} \beta_{31i} ln\, L_{it-k} + \sum_{i=1}^{p} \beta_{32i} \ln IGDP_{it-k} + \sum_{i=1}^{p} \beta_{33i} \ln K_{it-k} + \sum_{i=1}^{p} \beta_{34i} SFP_{it-k} + \beta_{35} ECT_{it-1} + \varepsilon_{3it} \qquad (5)$$

$$SFP_{it} = \beta_{40} + \sum_{i=1}^{p} \beta_{41i} SFP_{it-k} + \sum_{i=1}^{p} \beta_{42i} \ln IGDP_{it-k} + \sum_{i=1}^{p} \beta_{43i} \ln K_{it-k} + \sum_{i=1}^{p} \beta_{44i} SFP_{it-k} + \sum_{i=1}^{p} \beta_{45i} L_{it-k} + \beta_{46} ECT_{it-1} + \varepsilon_{4it} \qquad (6)$$

where Δ is the first difference operator, p is the lag order, and ECT is the error correction.

Table 7 Panel VECM causality test results

Dependent variables	Short-run causality				Long-run causality
	ΔlnIGDP	ΔK	ΔlnL	ΔSFP	ECT
ΔlnGDP	------------------------	5.603428 (0.0426)**	2.785612 (0.0285)**	-10.56782 (0.0025)*	25.78532 (0.0004)*
ΔK	11.30522 (0.0025)**	--------------------------	0.356741 (0.7563)	9.8 6723 (0.0001)*	18.05643 (0.0006)*
ΔlnL	4.7 83673 (0.0533)***	0.617315 (0.5102)	--------------------	0.125326 (0.6482)	1.75685 (0.5725)
ΔSFP	1.975632 (0.1126)	0.023456 (0.5223)	0.287946 (0.5332)	-------------------	8.37525 (0.1254)

*, **, *** indicates that the parameter estimates are significant at 1%, 5%, and 10%

Therefore, this table shows the existence of a one-way relationship from the small form-factor pluggable (SFP) to the IGDP in the short run. Besides, there is a one-way relationship going from SFP to L. These results were confirmed by Jones and Williams, (1999), while the one employed in waste recycling is 1.5%. The rate denoted to human capital working in secondary material production is veryclose to the result expected by Di Vita, (2001) in Italy and by Van Beukering and Curlee, (1998) in Colombia.

Additionally, we have indicated that the Granger causality test proposes a one-way relationship from SFP to K. This relationship can be explained by the creation of projects in order to invest in the recycling sector. Moreover, we

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noted the existence of a two-way relationship between the IGDP and K.This effect is a result identified by Ramsey Rule', (1928), representing the trade-off between investment and production, in which the case to raise the wellbeing over a change of capital, must be completed. The results also demonstrated atwo-way relationship between L and K in the short run. In fact, in the developing countries, such as Tunisia, waste management, especially recycling , has headed to even serious problems because there is a lack of consciousness about this sector. Besides, we have found a two-way relationship between L and the IGDP in the short run. These results were also confirmed in the findings of Jones and Williams (2000).

In this situation, the growth rate is countless when these factors, namely physical capiltal, labor and secondary finished products, were taken into account in the recycling process. It therefore, looks interesting to note that even in the developing countries, plastic waste recycling can improve the industrial gross domestic product for manufacturing recycling.
The implication of the error coefficient term (ECT) in. equation (1) proves the presence of a long-term equilibrium of the causal relationship between the IGDP, K, L, L and the SFP., which implies that there is a significant bidirectional causality between the IGDP and K. Additionally; there is a unidirectional causality running from the IGDP to the SFP. Correspondingly, in equation (5), there is a long-term relationship, where the ECT is significant at the 1% level). Indeed, we can note the manifestation of bidirectional causality concerning the IGDP and L. Hence, there is a long-term unidirectional causality running from the SFP to the GDP, K, and L.

4. Conclusion and findings

In conclusion, we can say that this study is to examine the link between the industrial gross domestic product, capital stock spending, labor , and secondary finished products for 24 Tunisian governorates, which include Ariana, Tunis, Ben Arous, Manouba, Nabeul, Bizerte, Sfax, Sousse, Monastir, Mahdia, Kairouan,Sidi-Bouzid, Gabes, Gafsa, Kasserine, Kebeli , Medinine, Kef, Beja, Jendouba, Seliana, Zaghouan,Tozeur, Tataouine. Then, using the unit root tests of the IPS and LLC, co-integration was tested as well as panel Granger causality on data series during the period 2001–2023.
By means of the Johansen cointegration test, we have proved the presence of a long-term relationship between the different variables in our model. Empirical results by the FMOLS method revealed that determinants factors such as capital , labor and secondary finished products have a significant impacton industrial gross domestic product from manufactrunig recycling in in Tunisia's various government departments. In this sense, the recycling technique modifies the image of waste because garbageis reused again. In other words, we sort out and recycle to enable the technology to continueits way, the production to remain and the consumption to always offer us more and better, while paying more attention to the environment. The recycling technique introduces the end of antagonisms between

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production and waste, to make consumption pursue its lifecycle.

Moreover, this study demonstrates that manufacturing recycling stimulates economic growth in Tunisia. Subsequently, policy makers would ruminate on the significance of the recycling sector and contribute to the prevalence of the diverse platforms, principally the features and the measurements of its services as it has a substantial effect on the added value of the firm's and can lead to more sustainable development for both the government and Tunisia as a whole. Consequently, we have to think of the adequate alternatives to ensure a fair balance between the economic and environmental sphere.

From this perspective, the incorporation of the recycling plastic in the production cycle requires an alliance between the R&D and technology, which involves a new vision of the manufacturing recycling in the future research activity. Further issues will be the estimation of our model with the a new data base that will contain the "Technology Stock" as a new variable. In the statement, as we have previously indicated, the available technology of plastic recycling will decrease the usage of exhaustible resources.

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