INTERNATIONAL TRADE IN WASTE IN SUB-SAHARAN AFRICA: WHAT IMPACT ON INCLUSIVE GROWTH?[1]

EUDOXIE BESSAN AYÉDOUN
Public Economics Laboratory/ University of Abomey-Calavi
eudoxiebessan@gmail.com

Abstract

This study examines the integrated circular economy model within the context of international waste trade, focusing on the complex and underexplored Sub-Saharan African (SSA) region. Against the backdrop of extensive literature on international pollution havens, this research evaluates the effects of waste trade on economic growth and environmental, testing the waste haven hypothesis. Using data on bilateral waste trade and environmental regulation indices for 30 SSA countries from 2000 to 2020, sourced from UNCOMTRADE, WDI, and UNEP, we employ a simultaneous equation model to derive three key findings. First, waste imports in SSA are primarily driven by low-income levels and weak environmental regulations. Second, while waste trade contributes positively to per capita income, its impact is marginal, reflecting SSA's limited integration into global circular economy systems. Third, the potential benefits of waste trade on growth require stronger environmental regulations and effective anti-corruption measures. These results highlight the need for strategic policies to enhance SSA's participation in a sustainable global circular economy.

Keywords: waste trade, circular economy, inclusive growth, environmental regulation

JEL Classification: F18, Q53, O44, O55

1. INTRODUCTION

The idea that waste can hold value may seem counterintuitive, as waste, like other unwanted goods, is often discarded by its owner. Yet, waste can possess economic value—either positive or negative—depending on the costs of treatment and the revenues generated through its recovery (Joltreau, 2018). When recovery is possible, waste becomes a tradable commodity in the global market, allowing economic agents to optimize its value. For instance, waste can be exported to countries with lower treatment costs or higher demand, where it can fetch a better

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price. According to UNCOMTRADE data (2022), international waste trade has experienced steady growth in volume (+3.5% annually on average from 2000 to 2020) and an even faster acceleration in value (+10% annually over the same period), notwithstanding a significant dip in 2009. This divergence is primarily attributed to rising raw material prices, for which recyclable or recoverable waste serves as a substitute—either perfectly or imperfectly (Bernard et al., 2012). Recyclable waste imports provide low-cost raw materials that can be reintegrated into domestic production processes (Liu et al, 2018), exemplifying the principles of the circular economy.

The circular economy is an economic model that seeks to create a closed-loop system, systematically reusing and recycling waste. Its practical aim is to minimize the consumption of raw materials, water, and non-renewable energy while ensuring the optimal durability, reuse, and recyclability of products from their design phase to the end of their lifecycle. This model aligns closely with the broader goals of sustainable development, incorporating elements of green economy principles, industrial ecology, eco-design, and functional economy strategies. Unlike the traditional linear economy, which prioritizes production and consumption without regard for resource preservation, the circular economy offers a sustainable response to global environmental and economic challenges.

However, the dynamics of international waste trade reveal significant disparities. A considerable portion of waste exports flows from developed to developing countries, where improper handling of hazardous or contaminated waste can pose severe health and environmental risks due to a lack of appropriate technology. By contrast, North-North waste trade often reflects strategies of industrial specialization or energy requirements, such as waste imports for incineration coupled with energy production.

The lack of reliable information on international waste trade flows, many of which are illegal, makes their accurate characterization challenging. Waste management is a global environmental issue, particularly with e-waste. Annually, 20–50 million metric tons of e-waste are generated, and an estimated 75–80% is exported to developing countries, primarily in Asia and Africa, for "recycling" and disposal (Diaz-Barriga, 2013; Fuller, 2019). Major destinations include China, India, Pakistan, Bangladesh, Ghana, Nigeria, and Kenya. However, recycling and disposal methods in these regions are often rudimentary, with little regard for worker safety or environmental protection. These practices contravene the 1992 Basel Convention and national environmental laws (Ladou and Lovegrove, 2008; Robinson, 2009; UNEP, 2018). In developing countries, waste recycling largely operates within the informal economy, which constitutes a significant portion of their gross national product (GNP) (Schneider and Enste, 2003). In Sub-Saharan Africa, the challenges are particularly acute. Despite being the world's lowest waste-producing region—at 460 grams per capita per day—waste management is already problematic and is expected to worsen with projected waste volumes tripling by 2050 (World Bank, 2016). Recycling rates remain exceptionally low, with only about 4% of recyclable household solid waste (MSW) being processed. Over 90% of waste is disposed of in unmanaged dumps and open landfills, often burned in the open air. Sub-Saharan Africa is home to 19 of the world's 50 largest dumping sites (UNEP, 2018; 2022).

Understanding the motivations and dynamics of international waste trade is crucial for assessing the role of the circular economy on a global scale and identifying the associated environmental and human risks. The rapid growth in waste trade volumes raises critical questions: Is international waste trade a tool for sustainable development, or does it exacerbate environmental degradation in Sub-Saharan Africa? Do exports of recyclable materials from developed to developing countries signify a transfer of waste pollution, or are they part of a global circular economy framework?

This study seeks to answer these questions, focusing on Sub-Saharan Africa, often described as a "waste haven." The contribution of this research is twofold: first, it provides one of the earliest in-depth analyses of waste trade in Sub-Saharan Africa. Second, it employs a simultaneous equation model to explore the interconnected effects of economic growth and waste trade. This study also aims to offer actionable solutions to improve waste management in Africa, particularly in the context of achieving the Sustainable Development Goals (SDGs) by 2030, including SDG 12 (Sustainable Consumption and Production) and SDG 8 (Decent Work and Economic Growth).

The general objective of this research is to analyze the integrated circular economy model in the context of international waste trade within Sub-Saharan Africa's complex regional landscape. Specifically, it aims to: (i) Assess the current state of international waste trade in Sub-Saharan Africa; (ii) Identify the determinants of waste trade in the region; (iii) Examine the risks posed by waste trade to environmental sustainability and economic growth. The structure of the paper is as follows: Section 2 reviews the relevant literature; Section 3 outlines the methodology and data sources; Sections 4 and 5 present the findings and propose economic policy recommendations, respectively.

2. LITERATURE REVIEW

2.1. DEFINITION AND TYPOLOGY OF WASTE

The World Customs Organization (WCO, 2020) defines "waste" as encompassing a diverse array of discarded materials, including household items, electrical and electronic appliances, industrial residues, agricultural byproducts, and even decommissioned objects like boats and used tires.

Waste is generally classified into two main categories: hazardous and non-hazardous. Hazardous waste is defined as waste that poses a significant or potential threat to public health or the environment. All these wastes are, in part, traded internationally and transported from developed to developing countries due to the difference in treatment and disposal costs. The movement of waste is also driven by demand. Hazardous wastes such as electrical and electronic waste contain valuable secondary raw materials, which make them "marketable products". Hazardous waste can be organic (solvents, hydrocarbons, etc.) or mineral (acids, sands, sludge, etc.). It comes mainly from the chemical, plastic, and metallurgical industries, but also from "toxic waste in dispersed quantities", produced in small quantities by households, tradesmen, and SMEs (garages, hairdressers, photographers, printers, etc. Non-hazardous waste, on the other hand, includes "ordinary industrial waste," which is not inert or dangerous. Examples include paper, cardboard, wood, textiles, and non-ferrous metals.

Bernard et al. (2012) expanded waste categorization by identifying types of waste based on their producers. According to these authors, agriculture, construction, and public works are the sectors generating the heaviest waste volumes. In agriculture, most waste consists of animal manure, which is typically recycled by being returned to the soil on farms. In the construction sector, waste predominantly includes unpolluted mineral materials such as concrete, tiles, ceramics, glass, and aggregates. These are classified as inert waste since they do not decompose, burn, biodegrade, or undergo physical or chemical reactions, and they are relatively inexpensive to treat.

Waste generated by households, small businesses, and commercial establishments is collectively referred to as municipal waste, which communities are responsible for managing. After collection, municipal waste can be recycled or composted if it is organic, reused (e.g., used clothing, returnable glass bottles, or certain electronics), or, if these options are not viable, incinerated—often with energy recovery—or disposed of in landfills (Bernard et al., 2012; WCO, 2023).

Notion of the value of waste

Waste has a value that can be positive or negative. Understanding the determinants of this value helps us to understand the motivations of the waste trade.

The value of waste is positive when the (anticipated) treatment cost of the waste is less than the (anticipated) recovery revenue (Bernard et al., 2012). Recovery can be material (mainly: recycling, reuse) or energy (incineration with energy recovery). If recovery of the waste is impossible, or very costly, then the value of the waste will be negative. Waste that cannot be recovered is eliminated by incineration (without energy recovery) or landfill. The value of the waste evolves according to these two components.

Potential value of the waste = (monetary income from recovery) - (treatment costs)

Monetary receipts from valuation

The recovery of the material allows the recovery of the material from the waste (recycling) or the reuse of the waste in the same way as its first use (reuse) or in a different way (re-use). When this material is recovered by recycling, it is called secondary raw material (SRM), as opposed to virgin raw material (VRP). The closer the secondary material is to the virgin raw material in terms of technical characteristics (efficient recycling technology), the more the prices of SPM and VPM will be correlated, as the raw material can increasingly be substituted by secondary (recycled) material. The technology has its limits for now, as recyclable materials, such as plastic bottles, can lose up to 95% of their value after their first use[2]. This loss of value may explain why the recycling model can be described as unprofitable and why "profit-maximizing" economic agents are turning to other solutions. When virgin raw material tends to become scarcer than demand, then the potential value of the waste will increase through a substitution effect.

Waste possesses an energy potential value, representing the amount of energy recoverable per kilogram of incinerated material. In recent years, incineration with energy recovery has gained popularity, especially for plastics, which have a particularly high energy potential. As a result, the value of waste is increasingly influenced by market conditions in the energy sector, where factors like energy demand and pricing determine the economic appeal of energy recovery from waste.

Cost of waste treatment

The cost of recovery decreases with technological progress (cost efficiency and MPS more and more like MPV). For wastes that cannot be recovered or are difficult to recover, the potential value of the waste will be negative and will depend almost only on the costs (as there is no revenue). These treatment costs will be strongly influenced by the regulations and taxation in force on waste management. The more stringent the environmental regulations, the higher the treatment costs will be. This argument is of course only valid in the short term, because in theory, in the long term, companies adapt by adopting more environmentally friendly behaviors and technologies.

The potential value of the waste will be at the heart of decisions to export or import waste. To optimize the potential value of their waste, agents may decide to export and sell the waste in countries where treatment costs are lower (cheaper labor, more efficient technology or laxer regulations...) and demand is higher (e.g., in China, where demand for PM is very high). Conversely, the economy and world trade strongly influence the potential value of waste, through the effect of global demand and the price of raw and secondary materials.

Economic agents will seek to optimize the potential value of their waste through international trade. This strategy can have negative effects on the environment.

[2] https://www.theguardian.com/environment/2021/jun/15/scientists-convert-used-plastic-bottles-into-vanilla-flavouring

2.2. HISTORY AND PERSPECTIVE OF THE CIRCULAR ECONOMY

Early circular economy strategies were initially designed to focus on waste management but have gradually evolved to include more systematic approaches for the entire economy. Under current circular economy systems, products are designed to be restorative and regenerative, where they are used at their highest value. The principles of the circular economy include the 3Rs -reduce, reuse, recycle-, but have been expanded to include the 6Rs -reuse, recycle, redesign, remanufacture, reduce, recover- (Liu et al, 2018). The circular economy has been implemented for over two decades worldwide (Winans et al., 2017). The economy has been widely recognized and advocated by the international community as it is supposed to transform traditional economic development in a more sustainable way. For example, the United States (US), China, Japan, Germany, the United Kingdom (UK) and Canada have implemented the circular economy. However, the concept of circular economy has been applied differently due to the diversity of cultural, social, and political systems worldwide. For example, the circular economy has been implemented as a national development strategy in the UK. In contrast, it has been implemented by other European countries such as Denmark, Switzerland, and Portugal for waste management. Germany's Circular Economy Act of 1996 aimed to reduce land use for waste disposal by focusing on solid waste avoidance and closed-loop recycling. In 2000, Japan released "Sound Material-Cycle Society" to focus on solid waste management, land scarcity and resource depletion due to lack of landfill space and revitalization of stagnant local industries. China's circular economy strategies have been developing rapidly in recent years with national policy support as a mechanism to achieve the goal of cost-effective product development and improved industry management (Geng et al., 2013). In 2009, the first circular economy law was officially issued in China. In North America, companies have applied circular economy strategies to implement and improve reduce, reuse and recycle programs.

Current applications of the circular economy follow three thematic categories. First, eco-industrial networking is implemented using eco-industrial strategies to develop eco-industrial parks and industrial symbiosis. Second, circular economy concepts are applied to specific waste or recyclable resource streams, such as wood, paper, plastics, and metals. Third, circular economy concepts include system-wide technical innovation between government and industry, which aims to redesign products and services to design out waste, while minimizing negative environmental and economic impacts. However, these three themes of the circular economy are generally accepted in the jurisdiction of an individual developed country but are considered a transfer of waste or pollution once the circulation or reuse of waste is exported to a developing country (Liu et al, 2018).

2.3. INCENTIVES FOR WASTE TRADE

The factors influencing the movement of waste can therefore vary in importance depending on the type of waste involved, but also on other factors.

Economic factors are most important.

Numerous studies establish that economic factors are paramount and can strongly influence transboundary waste movements for various reasons: labor costs, national taxes, quotas, economic growth, energy prices, etc. (Bertolini, 2003; Denoiseux, 2010, Kellenberg, 2012; Liu and al, 2018, Joltreau, 2018, WCO, 2020; WCO, 2023). Typically, the treatment and disposal of hazardous wastes in accordance with national laws represent a high cost. These costs are increasing in most OECD countries. Moreover, prices differ depending on the treatment of these wastes. According to Denoiseux (2010), some member states have more technology than others to manage the waste generated. Movements may therefore occur due to the existence of specialized treatment facilities in some countries. Conversely, under-information and a lack of financial, technical, and human resources in border surveillance and staff training may encourage illegal movements of waste from one country to another.

Differences in environmental law also act as an incentive.

Specific legislation can also influence waste movements. Faced with different waste treatment requirements, authorities or waste management companies may therefore be tempted to direct more waste towards recovery rather than disposal (Fischer et al., 2008). In addition, European legislation requires member states to make certain technological advances because of the targets for emissions, recovery, recycling, or reduction of waste disposal to be achieved. Divergent applications and interpretations of these new principles can lead to waste movements. For Bertolini (2003), waste exporters are tempted to target countries characterized by "weak or non-existent domestic environmental legislation or enforcement." For example, Denoiseux (2010) notes in the Probo Koala case that Regulation 259/93 on the supervision and control of shipments of waste within, into and out of the European Community was replaced in 2006 by Regulation 1013/2006/EC, but the replaced regulation was stricter for waste destined for disposal than for waste destined for recovery.

Economic reasoning was also behind the comment in early 1992 by Larry Summers, then chief economist at the World Bank, that Africa is largely under-polluted and that "the economic logic of dumping a load of toxic waste in the lowest paying country is impeccable" (Bernard et al, 2010). Indeed, Africa had quickly become a prime site for dumping in the 1980s, as African countries generally had weak environmental laws and very limited state control over the customs officials who approved imports. In addition, Africa's weak position in the international political economy only encouraged waste exports to the continent. Thus, Kellenberg

(2012) does some preliminary work by asking whether greater environmental regulatory stringency in a country is accompanied by an increase in its net waste exports to countries with laxer environmental regulations. The environmental stringency index is calculated from responses to the World Economic Forum's Global Competitiveness Report from 7751 companies in 102 countries. The questionnaire asks companies to rank the relative severity of regulations (on water, air, waste, etc.) in their home country compared to the countries with which they do business. Using a gravity model on cross-sectional data, Kellenberg validates the hypothesis of the existence of waste havens. He shows that a 1 percent relative decrease in a country's environmental regulations compared to its trading partner leads to a 0.32 percent increase in its waste imports. This effect can be significant for developed/developing country pairs, as the latter's environmental regulation is on average 39% less stringent than that of developed countries. Brunault (2011) obtains comparable results with a fixed effects gravity model on panel data.

Other incentives...

Without being exhaustive, Denoiseux (2010) identifies a few. This is the "nimby" (Not in my back yard) syndrome. This activist movement is also an incentive to export hazardous waste. Indeed, the opposition of "nimbyists" to the establishment of landfills or treatment plants "pushes to get rid of waste by exporting it to other horizons". A high population density is an additional pressure factor. Geographic and land-use planning factors may also come into play. Waste transport increases when there are opportunities for waste treatment in a nearby country. The existence of specific infrastructures such as ports or plants for the mechanization of green waste and the combustion of forestry waste can encourage these movements of waste.

2.4. WASTE TRADE AND ENVIRONMENTAL IMPACTS

If importing countries have techniques for treating or recycling waste at a lower economic and environmental cost, international trade is virtuous. However, if this lower cost is due to poor environmental performance of treatment facilities in the importing countries, this trade is a danger to the environment and health. Countries with lax waste management regulations would become "waste havens", by analogy with the expression "pollution havens" used in discussions on the risk of relocating polluting activities to less environmentally friendly countries.

From this point of view, the geographical distribution of flows is worrying. The flow from North to South - where environmental conditions for treatment and recovery are a priori less favorable - is relatively more important for waste than for all traded goods: it represents more than a quarter of trade compared to 16% for all goods. It should be noted that this is largely a flow from the United States (41% of the North-South flow). Among importers from the South, China is the largest, followed by Turkey. China, for example, imports a large quantity of wastepaper and cardboard for recycling and then to produce packaging for its industrial production for export. Turkey has many electric arc furnaces that it feeds with imported scrap metal. The African continent accounts for only 3% of North-South flows reported in official statistics.

The question of the environmental impact of international trade is particularly acute when it comes to hazardous waste (e.g., chemicals, used batteries, etc.). This question also arises for other wastes - plastics, scrap metal, mixed household waste - whose treatment remains polluting.

2.5. WASTE TRADE AND INCLUSIVE GROWTH

Inclusive growth is a multidimensional concept that includes poverty reduction, equity among different groups and regions, and the concept of an open society for technology and institutions (Ranade, 2020). Houngbeme (2015) identifies several approaches to defining and measuring inclusive growth adopted by different international institutions. We note, for example, that the World Bank, uses "inclusive growth" to refer to the pace and pattern of economic growth, concepts that are interrelated and assessed simultaneously. According to the World Bank's approach, strong economic growth is necessary to reduce absolute poverty. However, for this growth to be sustainable, it must involve a wide range of sectors and large segment of a country's population. The Asian Development Bank (ADB) defines "inclusive growth" as a concept that goes beyond broad-based growth. It is "growth that not only creates new economic opportunities, but also ensures equal access to these opportunities for all segments of society, especially the poor" (Ali and Son, 2007).

From the perspective of the United Nations Development Programme (UNDP), inclusive growth is seen as both an outcome and a process. On the one hand, it allows everyone to participate in the growth process, by being involved in decision-making and being an actor in growth. On the other hand, inclusive growth provides benefits that are equitably shared. It therefore implies participation and sharing of benefits. The African Development Bank (AfDB) defines "inclusive growth" as economic growth that results in more sustainable socio-economic development opportunities for the greatest number of people, regions, and countries, while protecting vulnerable groups, all in an environment of equity, equal justice, and political plurality.

In summary, these different definitions all refer to new approaches to addressing social inequalities, particularly in the developing world. These include inequalities in income and assets, both financial and human, inequalities in access to education, health, and economic opportunities, and in all aspects of life. With regard to the different definitions of inclusive growth, it can be noted that inclusive growth is characterized firstly as (i) economic growth is a prerequisite, i.e. a necessary but not sufficient condition for inclusive growth; secondly, it is (ii) growth that emphasizes productive employment, growth that creates new economic opportunities, growth that guarantees equal access to these opportunities for all segments of society, growth that ensures social protection and the strengthening of social cohesion and finally, it is growth linked to the concepts of "broad-based growth, shared growth and pro-poor growth".

The economics of waste production and consumption has been built in direct correlation with GDP growth in most countries, which was illustrated in a paper presented by Robinson (2009). Lu et al. (2015) validated the relationship between China's GDP per capita, urbanization rate, and e-waste generated from 2001 to 2012. The per capita waste generation is even higher than the GDP per capita is almost double the urbanization rate, indicating that waste generation will create a great challenge for all countries (Shamim et al. 2015). All these growth projections clearly paint the picture and raise the apprehension of unmanaged and untreated waste unless appropriate recycling measures are taken.

3. METHODOLOGY ANALYSIS

3.1. THEORETICAL MODEL AND SPECIFICATIONS

The model will be based on the existence of a trilateral relationship between waste imports, growth, and the environmental regulation index.

The first relationship is mainly inferred from the work of Kellenberg (2012) and reinforced by the findings of Brunault (2011). The main idea conveyed by this work is that variation in GDP per capita (growth) and variation in the level of environmental regulation are the two primary and statistically significant sources of variation in waste trade. This further implies that macroeconomic and infrastructural variables must influence waste trade, either through their effect on growth potential or (and/or) through their effect on the level of environmental regulation, which finally justifies the third relationship. Finally, the existence of two-way links between growth and trade in waste, which is little discussed in economic theory and supported by some empirical results, justifies the relevance of the second relationship.

The three conditions mentioned above can be accounted for by the following structural system:

$$wt_{it} = \alpha_0 + \alpha_1 y_{it} + \alpha_2 e_{it} + \mu_{it} \quad (1)$$

$$y_{it} = \beta_0 + \beta_1 E_{it} + \beta_2 Y_{i,\,t-1} + \beta_3 x_{it} + \varepsilon_{it} \quad (2)$$

$$e_{it} = \partial_0 + \partial_1 y_{it} + \partial_2 E_{i,\,t-1} + \partial_3 x_{it} + \partial_{it} \quad (3)$$

Where all variables are expressed in linearized form of these to allow us to interpret the coefficients in terms of elasticity. Wt is the waste trade indicator, y is GDP per capita, e is the environmental regulation index, Y is the level of GDP per capita at the beginning of the sample period, E is the level of the Gini index at the beginning of the sample period, x is an economic policy variable, the coefficients α, β, and ∂ are the elasticities to be estimated, and μ, ε, and ∂ are error terms. Finally, i indicates a generic country and t the reference period (t-1) thus represents the level of Y and E at the beginning of period t).

3.2. CHOICE OF VARIABLES

The three endogenous variables are (i) waste trade, (ii) growth, and (iii) environment. For waste trade, we will use import and export flows. Real GDP measures growth per capita, thus measuring the impact of waste on the population, while the environment is measured by the environmental policy score.

Policy options are represented through 7 exogenous variables, grouped into 3 categories: (i) macroeconomic framework, (ii) institutional quality, (iii) infrastructure.

The macroeconomic framework considers the following variables: the urbanization rate and trade openness. Trade openness is measured by the ratio of the sum of exports and imports of goods and services in GDP. This ratio reflects the impact of globalization on the poor. African countries are also open to the outside world because of their natural endowment.

Institutional Qualities: The Corruption Control Index. Corruption can be defined as the abuse of a public or private office for personal gain. The objective of anti-corruption policy is to reduce the burden that corruption places on governments and economies in the region.

Infrastructure plays an important role in development through its effects on economic growth. In our model, we consider as infrastructure: the quality of road and port infrastructure and a dummy variable to consider ECOWAS membership. The variable will take 1 if the country is in ECOWAS and 0 otherwise.

3.3. ESTIMATION METHOD

Our model is a dynamic panel in which one or more lags of the dependent variables appear as explanatory variables. The presence in the simultaneous equations of endogenous variables as explanatory variables of other endogenous variables implies that the error term of each equation is generally not independent of all the explanatory variables of this equation (Wooldridge, 2002). Moreover, our model is a non-cylindrical panel because the environmental gradients and Gini indices are not collected every year. Standard econometric techniques such as OLS do not provide unbiased estimates of such a model, because of the presence of the lagged dependent variable on the right side of the equation. This results in biased estimates. The estimator proposed in this work is the GMM estimator of Arellano and Bover (1995). This method relies on the orthogonality conditions between the lagged variables and the error term, both in first differences and in level. It also provides solutions to problems of simultaneity bias and is the most appropriate for dynamic panels (Kpodar, 2007).

Indeed, as far as the error terms are concerned, GMMs have a very general structure that incorporates heteroskedasticity, contemporaneous correlation of errors between equations and correlation between some regressors and the error terms in each equation. Under these assumptions, the Generalized Method of Moments (GMM) gives statistically robust estimates of the model parameters, without the need to make further assumptions about the shape of the error distribution. Nevertheless, several other estimators (Ordinary Minimum Squares, Seemingly Unrelated Regressions) can be defined as special cases of the GMM Wooldridge (2002) and Carmignani (2007).

In the GMM implementation, using Stata software, the covariance matrix with the correction for White's heteroskedasticity is incorporated. The list of instrumental variables includes the exogenous variables Yt-1 and Et-1, as well as the economic structure variables. In our application, we retain the initial income and the initial environmental regulation index as proxies for the one-period lagged GDP per capita growth and the one-period lagged environmental regulation index, respectively.

The treatment of panel data is generally subject to several tests such as: specification tests (Hausman test) of the model for the choice of the best specification, unit root tests, error autocorrelation, error heteroscedasticity, error normality test etc... But in our application where we use a system of equation in un-cylindrical dynamic panel data all these tests are not necessary, because the Generalized Moment Method allows to control all the individual and temporal specific effects and to compensate for the endogeneity biases of the variables. Moreover, the use of GMM presupposes the quasi-stationarity of the variables of the model in level and the absence of autocorrelation of the residuals (Kpodar, 2007).

The only main tests in dynamic panels accepted after estimation are the Sargan/Hansen over-identification test (Instrument Validity Test) and the second-order autocorrelation test, suggested by Arellano and Bond (1991), Arellano and Bover (1995) and Blundel and Bond (1998).

The j- and p-statistics of the Sargan test and the Portmanteau autocorrelation test, respectively, will be reported in the results tables: if the j-statistic obtained is less than the chi-square reading then the instruments are valid. If the p-value of the p-statistic is higher than 5% then there is no second order autocorrelation.

3.4. DATA AND DATA SOURCES

For reasons of availability of reliable data, we will use several data sources. For waste trade flows, data will come from UNCOMTRADE (July 2022), while the main source of data for growth and policy variables is the World Bank's World Development Indicators database (World Indicators Development, 2022). The environmental regulation index will come from the UNEP database. The study period is from 2000 to 2020 and will cover all 48 Sub-Saharan African countries unless data are not available for some countries.

4. DESCRIPTIVE ANALYSIS OF WASTE TRADE

4.1. EVOLUTION OF INTERNATIONAL TRADE IN WASTE

International trade in waste has an upward trend. Figure 1 shows its evolution in tons and in value from 2000 to 2020. In value terms, international trade in waste has increased by a factor of more than 3.5 from about $24.5 billion in 2000 to $109.5 billion in 2020. This corresponds to an average annual increase of more than 10% per year since 2000. However, in volume terms, the increase is more moderate. It is about 80%, from 93.4 million tons of waste to 158 million tons between 2000 and 2020, an average increase of about 3.5% per year.

Over the period 2000-2020, Sub-Saharan Africa traded a total of about 59 million tons of waste for a value of $29 billion, or about 1.5% of international waste trade. Between 2000 and 2016, the volume of waste traded rose from 2.1 million tons to 11.7 million tons, an increase of nearly 500% in less than two decades before falling to 2.3 million tons in 2019 and then to 1.7 million tons in 2020 under the impact of the Covid-19 crisis. Interpreting this low proportion as marginal SSA participation in the international waste trade would be a mistake, as most of this trade occurs illegally and is therefore difficult to trace (Dénoiseux (2010); Bernard et al, (2012), World Customs Organization, (2020)). Indeed, illegal activities can take different forms: selling waste on the black market, mixing different types of waste, declaring hazardous waste as non-hazardous or even classifying waste as second-hand goods are all ways to circumvent the rules. In effect, these products are classified as second-hand items, are no longer governed by international waste regulations, and can be traded with developing countries. For example, used e-waste and auto parts can often be "passed off" as used items and end up being recycled in a hazardous manner. It may be that these low proportions are evidence of the illegal waste trade. However, this part of the issue is not the focus here.

Contrary to the work of Dénoiseux (2010) who found that Sub-Saharan African countries are more waste receivers than exporters, we note that Sub-Saharan African countries export on average 5.6 times as much as they import waste, although there has been a decline in export volumes since 2016 exacerbated by the occurrence of Covid-19 in 2020. Indeed, UN Comtrade data show that exports are experiencing a decline of about 37% in volume between 2000-2020 while their value has grown by 69% over the same period, averaging 5.6% growth per year. According to Bernard et al (2012), this difference between volume and value is due to changes in the price of raw materials, which directly determines the price of certain wastes that can be transformed into secondary raw materials that can be used as a total or partial substitute for virgin raw materials (scrap metal, used paper and cardboard, etc.).

However, there is an upward trend in imports, both in value and volume. In terms of value, waste imports have increased by a factor of more than 5.1 from about $54.8 million in 2000 to $337.1 million in 2020. This corresponds to an average annual increase of nearly 13% per year since 2000. However, in volume terms, the increase is more moderate. It is multiplied by a factor of about 2, from 221 thousand tons of waste to 628 thousand tons between 2000 and 2020, an average annual increase of about 12% per year. This trend of increasing waste imports should be of concern because when local waste management is already a problem, how could it be possible to recycle waste from other countries? It is estimated that 70-80% of MSW produced in Africa is recyclable, yet only 4% of MSW is currently recycled.

For example, Lagos is the most populous metropolitan area in Africa, with approximately 21 million people. 10,000 tons of waste are generated every day, creating major health and environmental risks in many communities. Currently, it is estimated that only about 40% of the city's waste is collected and 13% is recycled.

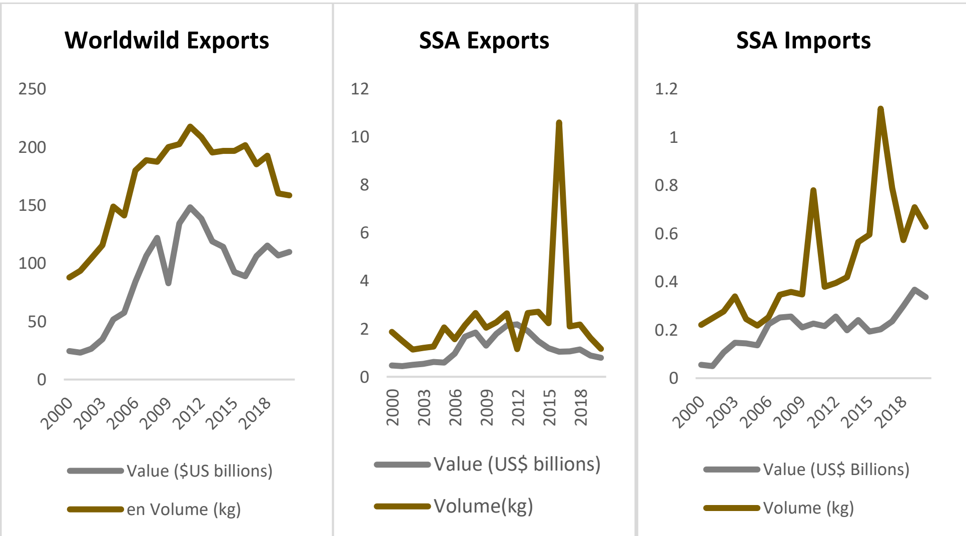

Figure 1: *Evolution of Waste Trade in Sub-Saharan Africa and the World, 2000-2020*
Source: United Nations, Comtrade (July 2022 version), author's calculations.

With a much higher increase in value for waste than for all goods (about +10% per year), the share of waste in world trade has substantially increased from 0.3% to 0.5% of total trade between 2000 and 2020, whereas it was estimated at 0.9% in 2010 (Bernard et al., 2012). For SSA countries, however, this share falls to 0.38% in 2020 from 0.43% in 2000, meaning that trade in commodities will increase significantly between now and 2020.

Slowing down of the waste trade or dynamics of the circular economy?

It is important to note that, although the global trend has generally been upward, there has been a decline over the past decade. Two distinct periods can be observed: 2000-2011 (a period of growth) and 2012-2020 (a period of decline). During the first decade, the volume of waste grew at an average annual rate of 9%, but this rate dropped to -3.2% in the second decade. In terms of value, the overall increase for the entire period was much higher, averaging 20.7% per year, despite a sharp decline in 2009. However, in the last decade, the rate of increase slowed to -2.7%, even though the global population generated 2 billion tons of household solid waste in 2016. This dual trend in waste trade over the past 20 years may be attributed to several factors. One possible explanation is the growing efforts by countries to manage and recycle the waste they produce domestically. For instance, Germany has become a leader in waste treatment, particularly for hazardous waste. Another factor is the increasing number of countries that have prohibited the import of difficult-to-recycle waste. Since January 1, 2018, China has banned the import of 24 types of solid waste, including scrap metal, plastic waste, and electronic waste. Other countries followed suit, with India banning plastic waste in 2019 and Indonesia returning waste containers to Western countries. More recently, some Sub-Saharan African (SSA) countries have taken similar steps; for example, Senegal banned plastic waste imports in 2020. Additionally, the decline in waste trade could, to a lesser extent, be attributed to a lack of reliable data on waste volumes. In some cases, there has been a lack of available or accurate data regarding the volume of waste traded.

Composition of waste flows

Following the approach of Bernard et al. (2014), we examine 84 commodities categorized by the six-digit Harmonized System (HS), divided into 14 categories to analyze waste flows (see Appendix). In general, the composition of waste flows in Sub-Saharan Africa (SSA) closely mirrors international waste flows. Four categories alone accounted for over 85% of the volume of imported waste in 2020 (Table 1): ferrous metals (52.8%), paper (21.4%), plastics (6.4%), and non-ferrous metals (4.4%). These materials are primarily imported by countries aiming to reduce their reliance on imports of primary raw materials critical to their economies (Nuss, 2022). These materials are valuable due to their high intrinsic worth and good recyclability. Exporting waste for incineration or landfill is much less common, as it is discouraged or prohibited in many countries (Bernard et al., 2012). However, illegal exports continue to occur frequently (Tojo et al., 2008; Bernard, 2015; Dato, 2017).

When considering the value of waste streams, five major categories stand out (Table 1). Ferrous metals (34.7%), precious metals (22.2%), non-ferrous metals (19.4%), plastics (7.6%), and paper (5.0%) together represent more than 90% of the total value of imported waste in 2020. The disparity between proportions based on weight versus value for non-ferrous metals and precious metals stems from the recovery potential of these materials (Bernard et al., 2012). Precious metals, such as waste containing gold and platinum, hold far greater economic recovery potential than materials like paper. Similarly, non-ferrous metals, such as copper, have a high market value (Bernard et al., 2014).

For export flows, the key products are largely the same as those for imports, though with some differences. In 2020, non-ferrous metals represented the largest share by value (51.5%), followed by a significant proportion of industrial products at 4.9%. However, in terms of value, industrial products accounted for less than 1%. Thus, the primary wastes exported by SSA countries largely mirror the materials imported into the region.

Table 1: *Composition of waste streams (%) in SSA, 2020*

	SSA					**World**		
	Imports			Exports		Exports		
	Value	Volume		Value	Volume		Value	Volume
Ferrous metals	34.7	52.8	Non-ferrous metals	43.8	24.8	Ferrous metals	28.4	50.1
Precious metals	22.2	0.0	Precious metals	31.4	0.3	Non-ferrous metals	28.2	8.0
Non-ferrous metals	19.4	4.4	Ferrous metals	10.7	38.2	Precious metals	27.1	0.2
Plastics	7.6	6.4	Industrial products	4.1	0.5	Papers	5.7	18.0
Paper	5.0	21.4	Tobacco	3.7	4.3	Other	3.4	10.5
Textiles	3.0	0.8	Plastics	1.7	9.1	Industrial products	2.6	2.4
Other	2.7	5.4	Paper	1.4	11.2	Plastics	2.3	3.0
Construction	2.5	2.5	Batteries	0.8	1.5	Batteries	1.0	0.2
Tobacco	2.2	1.9	Other	0.8	4.7	Textiles	0.6	0.3
Glass	0.4	4.3	Construction	0.7	2.6	Glass	0.4	1.8
Chemical products	0.2	0.1	Textiles	0.6	0.9	Construction	0.3	3.9
Pharmaceutical products	0.0	0.0	Glass	0.1	1.9	Rubber	0.2	0.8
			Chemical Products	0.1	0.1	Chemical Products	0.1	0.8
			Pharmaceutical products	0.1	0.0	Pharmaceuticals products	0.0	0.0

Source: United Nations, Comtrade (July 2022 version), author's calculations.

Between 2000 and 2020, certain waste categories, including glass, ferrous metals, plastics, and tobacco waste, experienced the most significant growth (Figure 2). The most notable increase was in glass waste, which surged more than 100-fold, growing from 266 tons in 2000 to nearly 280,000 tons by 2020. However, the rapid growth in plastic waste is particularly concerning. Over the two decades, the volume of plastic waste increased nearly fourfold, from 8.4 thousand tons at the start of the period to 41.5 thousand tons at the end.

In terms of value, precious metals saw the largest increase, rising by a factor of over 142 during the 20 years. Following this, the value of ferrous metals increased by 21.64 times, and glass by 8.67 times.

Additionally, the period from 2000 to 2020 also highlights the impact of price volatility on the value of waste exchanges (Figure 2). The value of non-recyclable waste is challenging to determine, while the value of recyclable waste is closely tied to global material prices. Economic crises can lead to a decrease in material prices without necessarily affecting the volume of trade, while higher demand for certain materials can drive prices up without altering the quantity of waste exchanged. For this reason, some researchers (Bernard et al., 2014; Kellenberg, 2012) recommend using the weight of waste rather than its value when assessing its environmental impact, as the physical accumulation of waste and the importing country's recycling capacity are more directly linked to environmental harm. However, these authors also agree that the value of waste trade is crucial for studying its impact on national economies. In this study, we will use both measures, considering the dual objective of assessing both the environmental and economic impacts of waste trade.

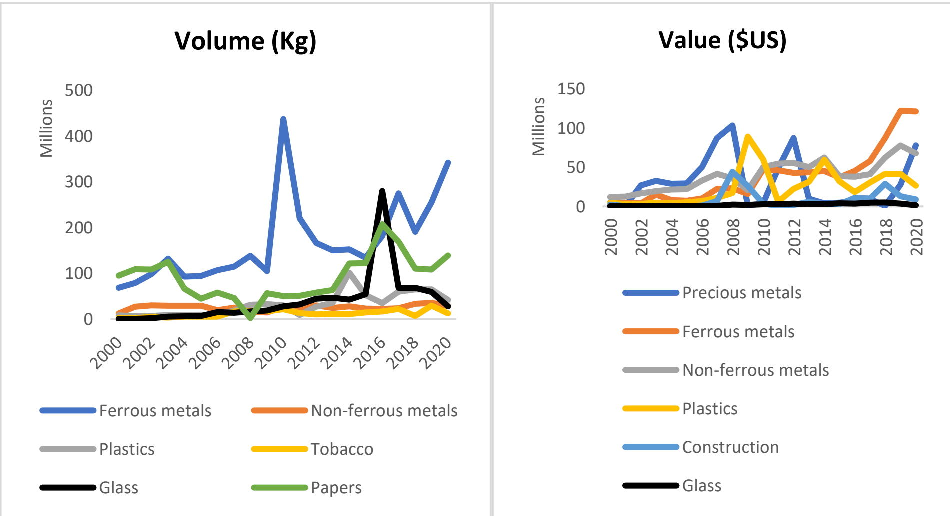

Figure 2: Changes in the composition of major waste streams, 2000-2020
Source: United Nations, Comtrade (July 2022 version), author's calculations.

4.2. FOCUS ON HAZARDOUS WASTE

In practice, international trade in waste is mainly about waste for recycling or reuse (Bernard et al., 2014; Kellenberg, 2012). Following the distinction between hazardous and non-hazardous waste made by Bernard et al, (2012), we can classify the following products as potentially hazardous because they pose risks to human health or the environment: industrial products, chemicals, pharmaceuticals, batteries, and plastics. The last group of products is not dangerous per se but can present a significant risk if the treatment infrastructure does not exist or is not adapted.

Thus, in terms of volume, it appears from the data that imports of hazardous wastes represent about 7% on average of the imports of SSA countries between

2000-2020. From 8.4 thousand tons of waste to 42.3 thousand tons, they have increased by a factor of more than 4 over the period 2000-2020. The same trend is observed for export flows, but in more moderate proportions, with a multiplication factor of about 3.5, but a higher average rate of about 11%, over the same period. Also, it should be noted that the spike observed in 2016 is a result of the large volume of industrial products (over 9 million tons) exported by Ghana. It should also be noted that 2016 was the year that nearly 2 billion tons of waste were produced, which partly explains this increase in exports.

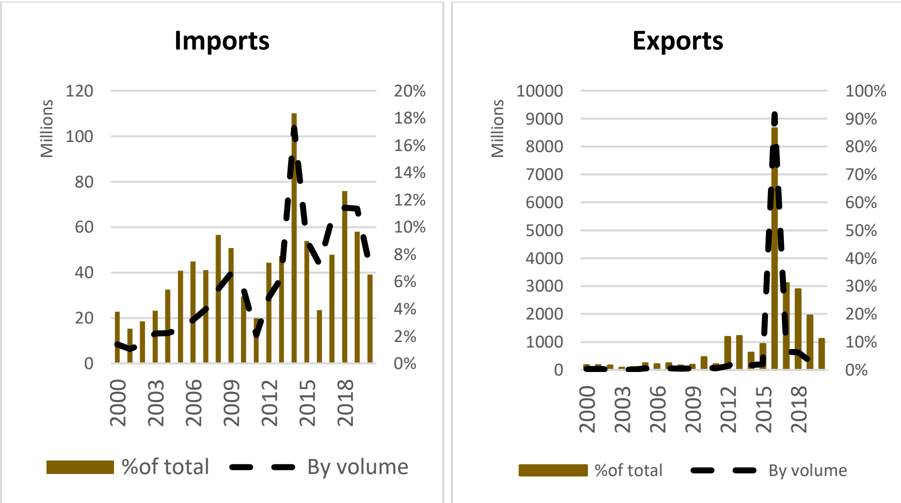

***Figure 3:** Evolution of hazardous waste trade (Kg)*
Source: United Nations, Comtrade (July 2022 version), author's calculations.

4.3. THE MAIN ACTORS IN THE WASTE TRADE IN SSA

Globally, three key players dominate the international waste trade: China on the import side, the United States on the export side, and Germany as a major player on both sides in 2021 (see Table 2). In Sub-Saharan Africa (SSA), one primary player largely controls the waste trade. From 2000 to 2020, SSA countries traded over 57.8 million tons of waste, with South Africa emerging as the dominant force. Over the 20-year period, South Africa accounted for 28 million tons of traded waste, representing 50% of SSA's waste imports and 76% of SSA's waste exports (Table 3).

In terms of import flows, South Africa is followed by Nigeria (14%) and Zambia (7.4%). For export flows, South Africa is followed by Zambia (4%) and Sudan (2%). This data highlights South Africa's central role in both importing and exporting waste in the region.

Table 2 : *Key players worldwide, 2021*

Importers		Importers	
Germany	**12,0**	USA	**23,3**
China	**9,3**	Germany	**10,3**
Turkey	**7,9**	United Kingdom	**7,4**
India	**6,8**	Netherlands	**5,6**
Belgium	**6,6**	Japan	**5,5**
Total	**42,5**	Total	**52,1**

Source : United Nations, Comtrade (July 2022 version), author's calculations

South Africa's leading position in the SSA waste trade is not surprising, given its status as the largest economy in the region and its significant recycling capacity. South Africa ranks third globally in recycling rates, following countries like Sweden. These impressive rates are largely driven by the efforts of informal recyclers, who form the backbone of the recycling sector but are often overlooked by policymakers and industry. Furthermore, until recently, South Africa lacked a formalized legal framework for the import and export of waste, which contributed to the uncontrolled movement of waste (GN 22 of January 21, 2019). Regardless of the time frame considered (20 years or 1 year), South Africa remains the dominant player in the region, with little variation in the rankings of the top 20 countries involved in waste trade.

Regionally, among the top 20 importing countries, four West African countries—Nigeria, Côte d'Ivoire, Senegal, and Ghana—together import the largest share, accounting for 19.3%. East African countries (Kenya, Uganda, Rwanda, Sudan, Tanzania, and Ethiopia) and South African countries outside South Africa (Eswatini, Botswana, Zambia, Zimbabwe, and Angola) collectively account for 14%. Central Africa, which includes Congo, DRC, and Cameroon, imports only 2.2% of the region's waste.

Table 3. *Major waste players, (% of trade in dollars)*

On average 2000-2020				**En 2020***			
Imports		**Exports**		**Imports**		**Exports**	
South Africa	49.8%	South Africa	76.1%	South Africa	61.1%	South Africa	62.8%
Nigeria	13.7%	Zambia	3.8%	Uganda	11.8%	Congo DR	9.5%
Zambia	7.4%	Sudan	1.9%	Nigeria	7.5%	Kenya	4.0%
Uganda	4.3%	Tanzania	1.9%	Kenya	7.0%	Mozambique	3.1%
Kenya	4.0%	Kenya	1.9%	Ethiopia	2.7%	Mauritius	3.1%
Ivory Coast	3.3%	Congo DR	1.8%	Togo	1.8%	Malawi	2.7%
Tanzania	2.3%	Mauritius	1.5%	Mauritius	1.7%	Namibia	2.5%
Eswatini	2.3%	Namibia	1.5%	Tanzania	1.4%	Zambia	2.4%
Angola	1.9%	Ghana	1.4%	Senegal	0.8%	Tanzania	1.8%
Senegal	1.6%	Senegal	1.3%	Congo	0.7%	Zimbabwe	1.6%
Ethiopia	1.5%	Mozambique	1.2%	Zimbabwe	0.5%	Madagascar	1.4%
Sudan	1.4%	Botswana	1.1%	Botswana	0.5%	Botswana	1.3%
Zimbabwe	1.3%	Nigeria	0.8%	Benin	0.4%	Nigeria	0.8%
Botswana	1.0%	Ivory Coast	0.8%	Madagascar	0.3%	Ethiopia	0.5%
Congo	0.8%	Zimbabwe	0.7%	Congo DR	0.3%	Senegal	0.5%
Congo DR	0.8%	Eswatini	0.5%	Burkina Faso	0.3%	Togo	0.4%

Ghana	0.8%	Cameroon	0.5%	Zambia	0.3%	Eswatini	0.4%
Mauritius	0.7%	Madagascar	0.5%	Mozambique	0.3%	Uganda	0.4%
Rwanda	0.7%	Uganda	0.5%	Malawi	0.2%	Seychelles	0.2%
Cameroon	0.6%	Mauritania	0.4%	Gambia	0.1%	Benin	0.2%

NB: *The countries considered are those that provided the year.

Source: United Nations, Comtrade (July 2022 version), author's calculations.

4.4. IMPORTANCE OF WASTE TRADE IN THE ECONOMY OF SSA COUNTRIES

To assess the significance of waste trade in the economies of Sub-Saharan African (SSA) countries, it is useful to relate the value of trade flows (both imports and exports) to a country's Gross Domestic Product (GDP), as suggested by Bernard et al. (2014). While the value of waste trade is subject to fluctuations due to commodity price volatility, it still serves as a valuable indicator of the economic importance of waste trade.

Figure 4 presents the ratio of average import value (USD) to average GDP (USD) for 41 countries over the period from 2000 to 2020. This ratio ranges from 0.132% to 0.001%. The five countries with the highest ratios are Eswatini (0.132%), Zambia (0.092%), Lesotho (0.043%), Uganda (0.042%), and Seychelles (0.035%). The relatively low ratio of imports to GDP in most countries can be attributed to the weak integration of the circular economy in SSA, compounded by the lack of necessary recycling infrastructure for recoverable waste (Denoiseux, 2010).

A more refined measure of this economic importance involves using net imports (imports minus exports) rather than just imports (Figure 3). Among the 41 countries studied, eight countries have a positive net import balance, although small. These countries are Uganda (0.017%), Seychelles (0.008%), Congo (0.007%), Rwanda (0.007%), Nigeria (0.005%), Angola (0.004%), and Ethiopia (0.003%). Only Niger has a near-zero balance. However, most countries in the region show a negative balance, indicating that SSA countries tend to export more waste than they import.

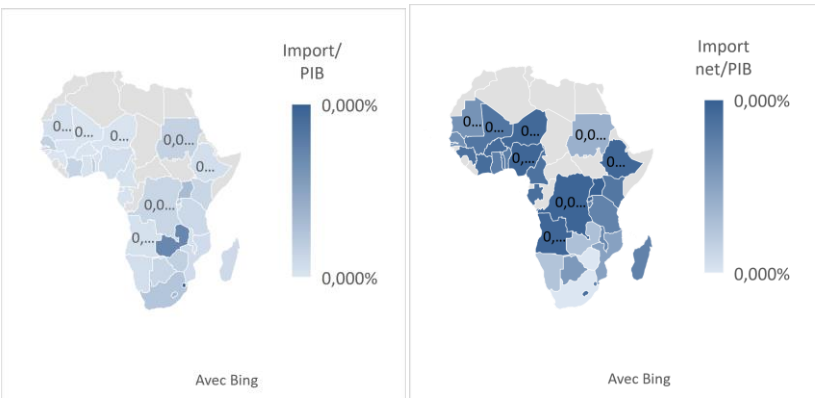

Figure 4: *Average share of waste trade in GDP, 2000-2020*

Source: United Nations, Comtrade (April 2022 version), author's calculations.

For this category, the net import/export ratio proves to be more significant. This difference highlights that waste trade has at least a non-negligible role in the economies of these states. The first five countries with the highest negative net import/export ratios are: South Africa (-0.246%), Namibia (-0.179%), Zambia (-0.172%), Mauritius (-0.168%), and Sudan (-0.141%). This slightly higher propensity to export waste suggests that SSA countries are more inclined to recover waste through export, likely because they lack the necessary technologies for adequate treatment and recycling of these materials.

5. ANALYSIS OF THE ESTIMATION RESULTS

5.1. DESCRIPTIVE STATISTICS AND CORRELATION BETWEEN VARIABLES

Table 4 summarizes the statistics for our sample, revealing that overall, the standard deviations are high, except for the relatively low standard deviations of the score variables (such as PES, anti-corruption policy, and infrastructure quality). To normalize the data and enable the interpretation of coefficients in terms of elasticities, a logarithmic transformation will be applied in the regressions.

Additionally, an analysis of the correlation coefficient matrix (see appendix) indicates that certain variables are correlated with each other. To address potential multicollinearity— which could lead to instability in the estimated coefficients— these variables will be introduced one by one in the estimations. The Generalized Method of Moments (GMM) will be used to correct for multicollinearity and improve the robustness of the results.

Table 4: *Descriptive statistics of the variables*

Variable	Obs	Mean	Std.	Dev.	Min
import_waste	630	6884272	2.26e+07	323	2.06e+08
export_waste	630	3.90e+07	1.79e+08	274	1.76e+09
PIBh	630	1645.798	2005.363	111.9272	11208.34
SPE	630	4.004762	1.525087	1	8
open	630	62.23015	29.28861	.7846308	175.798
Turb	630	35.1385	14.25789	8.246	70.877
ConCorrup	630	3.852381	1.457818	1	8
InfQual	630	3.137554	.87933	1.4	5.619339
CEDEAO	630	.3333333	.4717791	0	1

Source: Author's calculation

5.2. IDENTIFICATION CONDITIONS

The estimation method in the context of simultaneous equation models depends on the identification criterion of the model, (Andrei, et al, 2009). Thus, we check that each of the three specified equations satisfies both the order condition (the necessary condition) and the rank condition (the necessary and sufficient condition) for identification. According to Greene (2003), equation j satisfies the order condition of identification if Kj (the number of exogenous variables excluded from equation j) is greater than or equal to Mj (the number of endogenous variables included in equation j). The rank condition, on the other hand, imposes a restriction to a submatrix of the reduced form coefficient matrix to ensure that there is exactly one solution for the structural parameters given the reduced form parameters. The procedure is as follows:

- Construct a matrix in which each row represents an equation, and each column represents a variable in the simultaneous equation model.
- When a variable appears in an equation, mark it with a "1" and if a variable does not appear in an equation, mark it with a "0».
- Delete the row of the equation that you want to identify.
- Form a sub-matrix from the columns corresponding to the elements containing "0" in the line that has been deleted.
- For this submatrix, if at least (G-1) rows and columns are found that are not all zero, the equation is identified. Otherwise, the equation is unidentified. (Gbeing the number of endogenous variables).

The results of these tests for our different equations, presented in Table 5, indicate that the equations in the model satisfy the order and rank conditions, so the system is overidentified. This result supports the choice of the appropriate method is GMM to proceed to the estimation of the model.

Table 5: *Tests of identification*

Identification rank condition for equation *j*	**kj**	**Mj**	**Kj et Mj**	**Conclusion**
Equation 1 (waste)	2	2	2=2	Just identified
Equation 2 (PIBh)	7	2	7>2	over-identified
Equation 3 (SPE)	6	2	6>2	over-identified
Identification rank condition for equation *j*				
Sub-matrices				**Conclusion**
Equation 1 (waste)			$\begin{pmatrix} 1 & 1 & 0 \\ 1 & 0 & 1 \end{pmatrix}$	identified
Equation 2 (PIBh)			$\begin{pmatrix} 0 & 1 & 1 & 0 & 0 & 0 & 0 \\ 1 & 0 & 1 & 1 & 1 & 1 & 1 \end{pmatrix}$	identified
Equation 3 (SPE)			$\begin{pmatrix} 0 & 1 & 1 & 0 & 0 & 0 \\ 1 & 1 & 0 & 1 & 1 & 1 \end{pmatrix}$	identified

Source: Author's calculation

5.3. ESTIMATION RESULTS

The availability of data limits the analysis to 30 Sub-Saharan African (SSA) countries over the period from 2000 to 2020. The econometric model is designed to highlight the role of waste trade by estimating the interactions within the triangle of waste trade, inclusive growth, and the environment.

First, we note that the model is globally significant, as evidenced by the high Wald coefficients for the different equations. The p-values, which represent the probability of rejecting the null hypothesis of spurious regression (as tested by the χ^2

and F-stat tests), are all equal to 0.000, indicating that they are well below the 0.05 threshold for statistical significance. Furthermore, the GMM estimation method passes the validation tests for all models, confirming its robustness. However, it is worth noting that an error autocorrelation problem persists for the growth model, suggesting a potential issue with the time-series structure of the data.

The results presented in Table 6 warrant several observations concerning the equations related to waste trade, growth, and the environment, which will be discussed in more detail in the following sections.

Determinants of waste trade

The results from equations 1A and 1B reveal key determinants of waste trade for Sub-Saharan African (SSA) countries. The main factors influencing import flows are per capita income and environmental regulation. Both variables have positive and statistically significant effects on waste imports. Specifically, import flows increase by 0.59% when per capita income rises by 1%, and by 0.65% when environmental regulation improves by 1%. This seemingly paradoxical result can be explained by the relatively low per capita income levels in developing SSA countries, despite recent improvements. According to World Bank data (2021), of the 30 selected countries, only Seychelles qualifies as a high-income country, and 12 countries are classified as upper-middle-income. These income levels, along with environmental regulations that are, on average, 39% lower than those in developed nations, are insufficient to significantly reduce waste imports. These findings align with Kellenberg & Levinson (2011), who studied the impact of international regulations on waste trade. While they found that the Basel Convention amendment reduced the trade of the 20 most hazardous wastes, the overall effect was not significant. They attribute this surprising outcome to a loophole in the Basel Convention that allows member countries to exchange waste through a derogatory process, enabling some nations to continue waste exchanges despite the Convention's restrictions. This issue highlights the weaknesses of both the Basel and Bamako Conventions in curbing waste trade effectively.

Another important determinant for import flows is the rate of urbanization. As urban populations grow, waste imports tend to increase, reflecting the growing demand for materials and waste management services in urban areas. For waste export flows, the only statistically significant positive factor is per capita income, which is understandable given that higher income levels are linked to increased consumption and, consequently, the generation of more waste. This reinforces the hypothesis that low levels of environmental regulation and low per capita income are key drivers of waste import flows in SSA, while higher income is a major determinant for waste exports.

Impact of waste trade on inclusive growth

The results from equations 2A and 2B reveal a positive and statistically significant relationship between waste flows and per capita income in Sub-Saharan African (SSA) countries. While this outcome may initially seem surprising, it can be explained by the nature of the waste exchanged with SSA countries. Two key points from the qualitative analysis of waste flows provide insight into this result: (i) Nature of waste traded: Like Western countries, international trade in waste involving SSA countries primarily concerns waste that is suitable for recycling or reuse. A significant portion of the waste, over 90%, has high potential for recovery, particularly non-hazardous materials like paper, plastics, and metals, which can be reused or recycled. (ii) Proportion of hazardous waste: Data shows that imports of hazardous waste represent only around 7% of the total waste imported by SSA countries between 2000-2020. Similarly, exports of hazardous waste represent a higher average proportion of about 11%. Therefore, the bulk of the waste trade involves recyclable or reusable materials, which contribute positively to SSA economies.

A second explanation for the positive effect on per capita income can be found in the context of the circular economy. As highlighted by Liu et al. (2018), importing recyclable waste provides a source of low-cost raw materials, which can be reintegrated into domestic production processes. This reuse of materials boosts local production and economic activity, contributing positively to per capita income. However, the effect is relatively marginal in SSA countries. Specifically, a 1% increase in import flows results in a 0.0042% increase in per capita income, while a 1% increase in export flows leads to a 0.032% increase. The low impact is due to the region's still developing capacity for processing and recycling, as well as the smaller overall scale of trade compared to high-income countries. Additionally, energy recovery from waste, particularly plastics, contributes another potential economic benefit. In recent decades, waste incineration with energy recovery has grown, with plastics offering particularly high energy potential when incinerated. This recovery process provides an additional economic advantage for countries engaged in the trade of recyclable waste.

Lastly, a potential reason for the unexpected positive relationship could be the underreporting or illegal nature of some waste flows. Official data shows that Africa accounts for less than 2% of global waste trade, but illegal or hidden flows may be much more significant. These unreported transactions could mean that the actual volume of waste being traded is far higher than what is captured in official statistics, further strengthening the observed effect on economic performance.

Impact of waste trade on environmental policy

The results from equations 3A and 3B highlight several key points regarding the relationship between economic development, waste trade, and environmental policy in Sub-Saharan African (SSA) countries. Firstly, the positive and significant effect of GDP per capita on the environmental policy score indicates that as SSA countries experience economic growth, they are more likely to strengthen their environmental policies. A 1% increase in GDP per capita is associated with a nearly 0.60% improvement in the environmental policy score. This suggests that higher income levels enable countries to allocate more resources towards environmental protection and policy enforcement. Similarly, the export of waste flows also contributes positively to the strengthening of environmental policies. Countries involved in the export of waste are likely to improve their environmental governance, possibly due to external pressures or the need to comply with international regulations related to waste exports. Furthermore, when countries have better control over corruption, this is also positively correlated with stronger environmental policies. This underscores the importance of good governance in enabling the development of effective environmental frameworks.

However, the analysis also reveals some negative effects. The urbanization rate and the quality of infrastructure have significant negative effects on the environmental policy score. This finding is particularly important, as it suggests that rapid urbanization and inadequate infrastructure may strain a country's ability to implement effective environmental protection measures. When countries invest heavily in infrastructure for waste treatment, there may be a tendency to neglect broader environmental protection policies, which can hinder overall environmental governance. The application of the pollution haven hypothesis further complicates the relationship between environmental policy and waste trade. Kellenberg (2012) explored the effect of national environmental policies on international waste trade and found that for every 1% deterioration in environmental regulations, waste imports increase by 0.32% (Kellenberg and Levinson, 2011; Kellenberg, 2012). This suggests that weaker environmental regulations in developing countries, like those in SSA, make them attractive destinations for waste imports from countries with stricter environmental policies. Given that many SSA countries have environmental regulation scores 39% lower than the global average, this dynamic could lead to an influx of waste that may not be adequately managed, exacerbating the challenges to environmental protection in these regions. In conclusion, the findings suggest that economic growth and the ability to export waste can lead to stronger environmental policies in SSA countries. However, the negative effects of urbanization and infrastructure quality need to be addressed to avoid undermining environmental progress. Furthermore, the pollution haven hypothesis suggests that weaker environmental regulations in SSA could lead to an increase in waste imports, highlighting the importance of strengthening environmental governance to manage waste flows effectively.

Table 6: *Estimation results*

	Waste_import Model						Waste export Model	
	Equation 1A	Equation 1B	Equation 2A	Equation 2B	Equation 3A	Equation 3B	Equation 1A	Equation 1B
Limport_waste L1.	0,4060303*** (0,0481715)	0,2424673** (0,1081652)						
Lexport_waste L1.							0,590484*** (0,0558154)	0,5685246 *** (0,0804733)
LPIBh L1.			0,8129201 (0,0095567)***	0,7970245*** 0,0221941				
LSPE L1.					0,5671986*** (0,0041755)	0,5543557*** (0,0075733)		
LPIBh	0,5986657*** (0,1214427)	0,0888021 (0,1429487)			0,0379152*** (0,0088507)	0,0503476*** (0,0093484)	0,5321089*** (0,1325624)	0,8394583** (0,4243546)
LSPE	0,6575218*** (0,1954767)	1,014623*** (0,2148005)	0,1771895*** (0,0144569)	0,1608656*** (0,0174257)			-,0267397 (0,2405569)	-0,1009303 (0,2278683)
Limport_waste			0,0038758** (0,0019107)	0,0042233** (0,0020023)	0,0025655 (0,0020091)	0,0023922 (0,0038149)		
Lexport_waste			0,0353096*** (0,0023549)	0,0327116*** 0,0033584	0,0082079*** (0,0007611)	0,0086592*** (0,0015123)		
Lopen				0,0519733** (0,0215714)				
LTurb		2,162589*** (0,5605184)		0,1272208* (0,0657688)	-0,0422595 (0,030849)	- 0,1017443*** (0,0363821)		-1,222118 (0,895973)
L,ConCorrup		0,9906763 (0,6308257)		0,0221066 (0,0408612)		0,1507659*** (0,0293797)		0,1375469 (0,3725289)
L,InfQual		-0,1000073 (0,3246171)		0,0204491 (0,0399565)		-,1474757*** (0,019881)		0,0661076 (0,5619811)
Const	3,31399*** (0,59119930	-0,0101283 (1,222563)	0,5029445*** (,0550433)	-0,0287553 (0,2330075)	0,3021029*** (0,0539648)	0,3981923*** (0,1141714)	2,581914*** (0,338534)	4,870776 (1,547721)
Number of observation	570	570	570	570	570	570	570	570
Wald chi 2 (Prob)	386,87 (0,0000)	277,51 (0,0000)	24854,78 (0,0000)	23309,95 (0,0000)	62881,15 (0,0000)	15381,64 (0,0000)	1722,15 (0,0000)	1586,72 (0,0000)

Arellano-Bond test for zero autocorrelation in first-differenced errors	1,3429 (0,1793)	1,1168 (0,2641)	-2,197 (0,0280) **	-2,1542 (0,0312) **	-1,6074 (0,1080)	-1,674 (0,0941)	0,67677 (0,4986)	0,66282 (0,5074)
Sargan test of overidentifying restrictions	chi2 (189) = 27,43576	chi2(189)= 24,33595	Prob > chi2 = 1,0000	chi2(189)= 28,17138	chi2(67) = 29,12288	chi2(67) = 29,28555	chi2(189) = 29,94669	chi2(189) = 29,24827

NB : ***,**,* are the significance at 1%, 5% and 10% respectively
standard errors are between brackets

Source : Author's calculation, stata

6. CONCLUSION

The objective of this work was to analyze the integrated circular economy model in the context of international waste trade, particularly within the complex African regional context. The complexity arises from the lack of waste treatment infrastructures and the illegal nature of waste trade in many countries. Using data from COMTRADE, WDI, and UNEP, two main findings were derived: a descriptive analysis that assesses the state of waste trade in Sub-Saharan Africa (SSA) and an econometric analysis that qualifies the character of waste trade in the region.

The descriptive analysis reveals several important findings. (i) Between 2000 and 2020, SSA traded approximately 59 million tons of waste worth $29 billion, representing about 1.5% of global waste trade. (ii) Both the value and volume of waste imports in SSA have been increasing. Waste imports grew from $54.8 million in 2000 to $337.1 million in 2020. In terms of volume, imports increased from 221 thousand tons to 628 thousand tons, reflecting an average annual growth rate of about 12%. (iii)The composition of waste flows in SSA is largely consistent with global trade patterns, with four categories (ferrous metals, paper, plastics, and non-ferrous metals) accounting for over 85% of imports in 2020. These categories all have significant recycling potential. (iv) South Africa is the leading player in the SSA waste trade, accounting for 50% of the region's waste imports and 76% of its waste exports, with a total of 28 million tons of waste traded over 20 years. (v) Despite the growth, the weight of waste trade in SSA's GDP remains low. Countries like Eswatini, Zambia, Lesotho, Uganda, and Seychelles have the highest ratios of waste trade to GDP, but this ratio is still very small. This reflects the region's limited integration into the circular economy, primarily due to inadequate infrastructure for recycling waste. Furthermore, the large informal trade flows suggest that Africa may not fully function as a "waste haven," as significant quantities of waste evade official monitoring.

The econometric analysis, conducted through a simultaneous equation model, yields the following key findings. (i) The main determinants of waste imports in SSA are low per capita income and weak environmental regulation. Countries with lower income and weaker environmental policies are more likely to import waste, reflecting a challenge in controlling waste flows. (ii) Waste trade flows in SSA demonstrate a form of circular economy, as imports and exports of recyclable waste positively impact per capita income. However, the effect remains marginal, indicating that SSA countries are still not fully integrated into the global circular economy. (iii) For waste trade to contribute significantly to growth, environmental policies must be improved, alongside efforts to control corruption. A robust regulatory environment can help harness the positive impacts of waste trade on economic development.

In conclusion, for SSA countries to better integrate into the circular economy and overcome barriers to sustainable development, two key actions are needed. First, there is a need for massive investment in infrastructure for waste treatment, recycling, and reuse to manage imported waste effectively. Second, SSA countries should take advantage of the circular economy to create formal, quality jobs, transitioning informal workers in the waste sector to formal employment. By addressing these challenges, SSA countries can improve their participation in the global circular economy, enhancing their economic growth and environmental sustainability.

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ANNEXE

. correlate import_waste PIBh SPE open Turb ConCorrup InfQual CEDEAO
(obs=630)

	import~e	PIBh	SPE	open	Turb	ConCor~p	InfQual	CEDEAO
import_waste	1.0000							
PIBh	0.3819	1.0000						
SPE	0.3166	0.6023	1.0000					
open	-0.0864	0.3723	0.2902	1.0000				
Turb	0.3222	0.5138	0.3379	0.2112	1.0000			
ConCorrup	0.1701	0.5534	0.5509	0.3900	0.2968	1.0000		
InfQual	0.1875	0.6125	0.5432	0.3490	0.3151	0.5414	1.0000	
CEDEAO	-0.0893	-0.2284	-0.2541	-0.1545	0.2299	-0.0647	-0.1674	1.0000

. correlate export_waste PIBh SPE open Turb ConCorrup InfQual CEDEAO
(obs=630)

	export~e	PIBh	SPE	open	Turb	ConCor~p	InfQual	CEDEAO
export_waste	1.0000							
PIBh	0.4405	1.0000						
SPE	0.3589	0.6023	1.0000					
open	-0.0363	0.3723	0.2902	1.0000				
Turb	0.3320	0.5138	0.3379	0.2112	1.0000			
ConCorrup	0.2004	0.5534	0.5509	0.3900	0.2968	1.0000		
InfQual	0.2568	0.6125	0.5432	0.3490	0.3151	0.5414	1.0000	
CEDEAO	-0.1304	-0.2284	-0.2541	-0.1545	0.2299	-0.0647	-0.1674	1.0000