International Trade in Waste in Sub-Saharan Africa: What Impact on Inclusive Growth?[1]

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Abstract

The aim of this study is to analyze the integrated circular economy model in its international waste trade dimension and in a complex African regional context. At a time when a large body of literature has developed around the notion of international pollution havens, this study provides a framework for taking stock of waste trade and analyzing the effects of this trade on growth and the environment in order to test the waste haven hypothesis. We use data on bilateral trade in waste and an index of environmental stringency for 30 African countries over the period 2000-2020. The data come from the World Bank's UNCOMTRADE (2022), WDI (2021) and UNEP (2021). Using a simultaneous equation model, we obtain 3 main results: (i) the determinants of waste imports in SSA are linked to the coupled weakness of incomes and environmental regulation; (ii) waste trade flows reflect a form of circular economy due to the positive impact on per capita income, however, the effect remains marginal, indicating the relatively low integration of SSA countries in this trade; (iii) environmental policies must be strengthened in conjunction with anti-corruption policies to hope for positive effects of waste trade on growth.

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

Commerce international de déchets en Afrique subsaharienne : Quels impacts sur la croissance inclusive ?

Résumé

L'objectif de ce travail est d'analyser le modèle d'économie circulaire intégrée dans sa dimension de commerce international de déchets et dans un contexte régional africain complexe. Alors qu'une littérature importante a fleuri autour de la notion de paradis internationaux de la pollution, cette étude offre le cadre pour faire l'état des lieux du commerce de déchets ; et d'autre part analyser les effets de ce commerce sur la croissance et l'environnement pour la vérification de l'hypothèse de paradis de déchets. Nous utilisons des données sur le commerce bilatéral de déchets et un indice de rigueur environnementale pour 30 pays d'Afrique sur la période 2000-2020. Les données proviennent de l'UNCOMTRADE (2022), du WDI (2021) et de l'UNEP (2021) de la banque mondiale A partir d'un modèle à équations simultanées, nous obtenons 3 principaux résultats : (i) les déterminants de l'importations de déchets en ASS sont liés à la faiblesse couplée des revenus et de la réglementation environnementale ; (ii) les flux de commerce de déchets reflètent une forme d'économie circulaire en raison des retombées positifs sur le revenu par habitant, cependant, l'effet reste encore marginal dénotant la relative faible intégration des pays ASS dans ce commerce ; (iii) les politiques environnementales doivent être renforcer en lien avec les politiques anti-corruption pour espérer des effets positifs du commerce de déchets sur la croissance.

Mots clés : commerce de déchets, économie circulaire, croissance inclusive, régulation environnementale

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1. Introduction

The fact that waste can have value is counter-intuitive, since, like goods, waste is destined to be abandoned by its owner, who therefore wishes to dispose of it. Yet, if some waste can be sold at a positive price, it is because it contains value (Joltreau, 2018). Waste has a value that can be positive or negative. This value depends on its treatment costs and the revenues generated by its recovery if there can be recovery. To optimize this value, economic agents can trade their waste on the global market: for example, exporting to countries where treatment costs will be cheaper, and demand will be higher (higher selling price). According to UNCOMTRADE data (2022), international trade in waste is growing steadily and steadily in volume (+3.5% per year on average over the period 2000-2020) and accelerating in value (+10% per year over the same period) with a sharp dip in 2009. This decoupling is due to the increase in the price of raw materials, for which waste for recycling/recovery is a perfect or imperfect substitute (Bernard et al., 2012). In general, importing recyclable waste allows for the recovery of low-cost raw materials, which can be fed directly back into the domestic production process (Liu et al, 2018). This is known as the circular economy.

The circular economy can be defined as an economic model (production and trade) that ideally works in a loop and systematically reuses the waste generated. In practice, it aims to limit as much as possible the consumption of raw materials, water, and the use of non-renewable energy, while providing, from the design of the product (good or service), an optimal durability and the reuse or recycling of materials at the end of the life cycle. The circular economy model is therefore directly in line with the more general framework of sustainable development. It is part of a global strategy that also calls upon, among others, the principles of the green economy, industrial ecology, eco-design, or the economy of functionality. In contrast to the traditional linear economy, which produces wealth without concern for preserving resources, the circular economy provides a response to the challenges of tomorrow's world.

However, the fact that a significant part of waste exports is sent from developed to developing countries can present health and environmental risks if the populations treat hazardous or contaminated waste with non-adapted technology. North-North flows, on the other hand, are more likely to be the result of a strategy of industrial specialization or energy needs (imports for incineration with energy production). The lack of information on these flows, many of which are illegal, makes it impossible to characterize them with certainty. Waste is a global environmental problem. For example, of the 20-50 million metric tons of e-waste generated each year, an estimated 75-80% is shipped to developing countries, particularly in Asia and Africa, for "recycling" and disposal (Diaz-Barriga, 2013; Fuller, 2019). Several studies have reported that a large majority of e-waste is exported to China and India. In addition, other countries identified for e-waste destinations include Pakistan, Bangladesh, Ghana, Nigeria, and Kenya. However, handling and recycling techniques in these countries are often primitive and there is little regard for worker safety or environmental protection (Ladou and Lovegrove, 2008; Robinson, 2009), which are illegal under the 1992 Basel Convention or other existing national environmental legislation (UNEP, 2018). In contrast, waste recycling in developing countries is a chain of processes that are carried out in the informal economy. Informal economies constitute a considerable part of the gross national product (GNP) of developing countries or countries in economic transition (Schneider and Enste, 2003).

The facts are even more critical in Sub-Saharan Africa in terms of both recycling capacity and waste management techniques. While Sub-Saharan Africa is the world's least waste producing region, with 460 grams per capita per day, waste management is already problematic and could become even more complicated, due to a tripling of volumes by 2050 (World Bank, 2016) and low recycling rates, with only about 4% of the 70-80% of household solid waste (MSW) generated in Africa that is recyclable. Over 90% of waste generated in Africa is disposed of in anarchic dumps and landfills with open burning. 19 of the world's 50 largest dumping sites are in Africa, all in Sub-Saharan Africa (United Nations Environment Programme, 2018; 2022).

Understanding the motivations and being able to characterize the international waste trade flows is essential to be able to grasp the integrated circular economy model in its international dimension, as well as to identify the risks of this trade on the environment and populations. This rapid growth in the volume of international trade in waste raises the question of its consequences on the environment: is international trade in waste a tool for sustainable development or, on the contrary, does it contribute to environmental degradation in sub-Saharan Africa? Are exports of recyclable materials from developed to developing countries a transfer of waste pollution or are they part of the global circular economy?

It is to these questions that our work will try to bring some answers in the case of sub-Saharan African countries often described as "waste havens". The added value of our work is twofold: on the one hand, our study is one of the first to focus on the specific case of sub-Saharan African countries, and on the other hand, from a methodological point of view, the simultaneous effects between growth and trade in waste are highlighted in this work through a simultaneous equation model. Finally, this study can provide appropriate solutions to the problem of waste management in Africa, particularly in relation to the achievement of SDGs by 2030, especially SDG 12: Sustainable Consumption and Production. Indirectly, the achievement of MDG 8: Decent Work and Economic Growth.

The general objective of this work is to analyze the integrated circular economy model in its international waste trade dimension and in a complex African regional context. More specifically, it will aim to (i) Take stock of the international waste trade in sub-Saharan Africa; (ii) Identify the determinants of international trade in waste in sub-Saharan Africa. (iii) Analyze the risks of this trade on the environment and growth. The rest of the document is as follows: section 2 presents the literature review, section 3 the methodology adopted and data sources, and sections 4 and 5 present the results and economic policy proposals respectively.

2. Literature review

2.1. Definition and typology of waste

According to the WCO (2020), the term "waste" refers to a wide range of discarded materials ranging from household items to electrical and electronic appliances to industrial and agricultural wastes, including pesticides. It encompasses objects of all sizes and dimensions, from decommissioned boats to used tires.

Waste is divided into two 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.). Industry also produces "ordinary industrial waste",

waste that is neither inert nor dangerous (paper, cardboard, wood, textiles, non-ferrous metals, etc.).

Bernard et al, (2012), deepen this categorization by distinguishing other types of waste based on the origin of waste by type of producer. For these authors, agriculture, construction, and public works are, by far, the sectors generating the greatest weight of waste. In agriculture, however, the majority of waste is made up of animal manure, which is returned to the soil on the farm, while in construction, it is most often unpolluted mineral waste (concrete, tiles, ceramics, glass, aggregates, etc.), i.e. inert waste - it does not decompose, does not burn, is not biodegradable and does not produce any physical or chemical reaction - and is not very costly to treat.

Waste that is the responsibility of the community to dispose of (primarily household, small business, and commercial waste) is referred to as "municipal waste". Once collected, waste can be recycled or composted when it is organic waste (Bernard et al., 2012, WCO,2023). It can be reused, for example, used clothing, returnable glass bottles or some used electronics. If they cannot be reused, they are finally incinerated, most often with energy recovery, or landfilled.

Notion of the value of a 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] (The Guardian, 2021). 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 also contains an energy potential value (amount of energy that can be recovered per kg of incinerated waste). In recent decades, waste incineration with energy recovery has become more and more widespread, especially for plastics, whose energy potential is particularly high.

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

The market conditions of the energy sector therefore contribute to the determination of the value of the waste.

Cost of waste treatment

The cost of recovery decreases with the 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.

2.2.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 (Fisher 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 methanisation 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.

Environmental Protection in African Constitutions

According to Hans Kelsen's hierarchy of norms[3], the Constitution is the superior normative source in national law. Several African states have adopted this legal philosophy. Since the beginning of the 1990s, a movement of constitutionalizing of environmental law has been created in Africa, because of which many States have enshrined environmental protection as one of the fundamental principles guaranteed by the Constitution. There are more than forty African States (46 out of 54). On the other hand, the 8 African countries do not have provisions dedicated to the protection of the environment in their Constitution. These states are Botswana, Djibouti, Guinea-Bissau, Liberia, Libya, Mauritius, Sierra Leone, and Tunisia. By including the principle of environmental protection ("right to a healthy environment"), the Constituent in some African countries wanted to provide the legislator with a legal basis for the adoption of new laws on environmental law.

The Bamako Convention and the Basel Convention: problems of coexistence

As will have been noticed during this study, the Bamako Convention is very similar to the Basel Convention, most of whose provisions it reproduces in extenso. This is not surprising insofar as the problems dealt with are practically the same; the solutions proposed could not therefore be fundamentally different, particularly in a field of great technicality such as the environment. Although very similar, the African regional instrument is not identical to its universal counterpart, which would inevitably have raised the question of its appropriateness. The Bamako Convention has a certain specificity, as can be seen from its title, which expressly mentions the prohibition of all imports of hazardous wastes into Africa, from its much more exhaustive scope of application, and from the nature of the prohibitions prescribed. The Bamako Convention is thus a useful regional complement to the Basel Convention. Indeed, a priori, their coexistence does not pose any problem; it is even provided for by these two conventions, which authorize States Parties to conclude bilateral or multilateral treaties relating to the transboundary movement of hazardous wastes with other States Parties or not, provided that such agreements do not derogate from the environmentally sound management of the said wastes prescribed by their provisions. Both the Basel Convention and the Bamako Convention - in some respects even more restrictive than the latter - thus perfectly meet this requirement. The participation of an African State in the two conventions should therefore not pose any problems. In this connection, and in substance, it should be noted that Article 11 of the Basel Convention excludes in this case the application of the prohibition on the export or import of hazardous wastes to or from a third State. Article 11 of the Bamako Convention, for its part, does not lift the prohibition on States Parties importing wastes into Africa from non-Contracting States; its wording is certainly not such as to preclude the application of this prohibition, or any other, prescribed by Article 4 of the instrument. Thus, an African State, whether it is a party to the Basel Convention alone, may import hazardous wastes from an African State that is a party to both instruments. And the latter may import hazardous wastes from a State - African or not - party to the Basel Convention only, but on condition that the said wastes have been produced in Africa. It should also be noted that Article 4 of the Bamako Convention imposes an obligation on States Parties not to export hazardous wastes to States that have prohibited their import by means of an international agreement (such as the Basel Convention, for example). In all cases, the relations within and between these two distinct treaty communities will have to be settled

[3] Kelsen, H. (1990). On the theory of interpretation. Legal Studies, 10(2), 127-135.

based on the law of treaties, more particularly the rule on the application of successive treaties relating to the same subject-matter.

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 (Renade, 2020). Hougbeme (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 Hwa 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. Growth is measured by real GDP 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 Generalised 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, Seemengly 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.

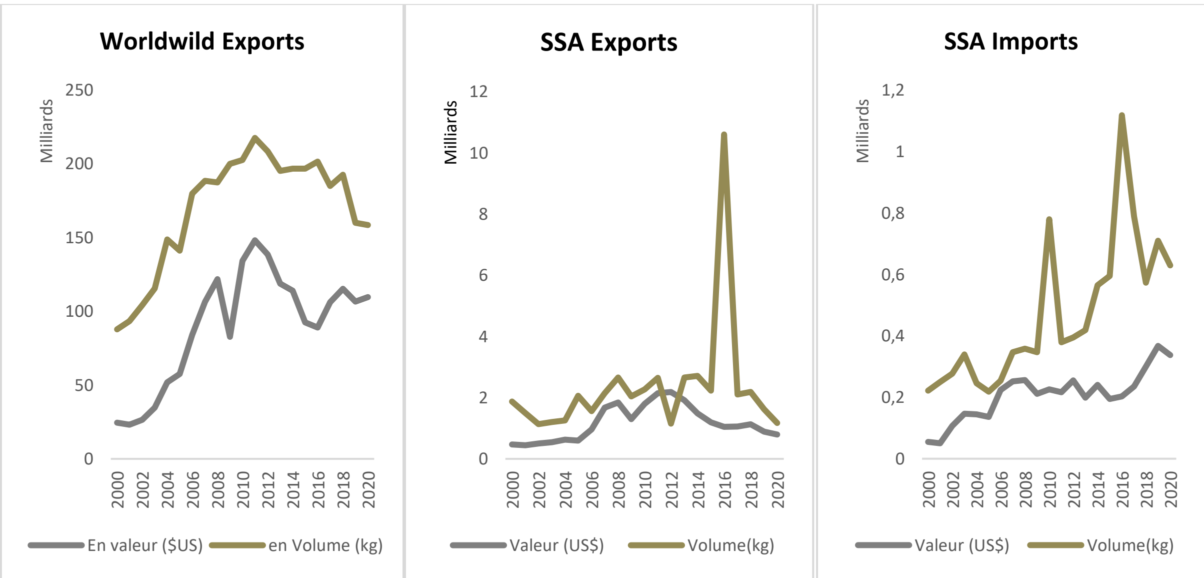
Over the period 2000-2020, Sub-Saharan Africa traded a total of about 59 million tons of waste for a value of $29 billion, or about 1.5% of international waste trade. Between 2000 and 2016, the volume of waste traded rose from 2.1 million tons to 11.7 million tons, an increase of nearly 500% in less 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, UNComtrade 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 the 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 should be noted, however, that even if globally, the trend is upward, over the last decade, the trend is rather downward. Thus, we observe two distinct periods: 2000-2011 (period of growth) and 2012-2020 (period of decline). Indeed, over the first decade the volume grew at an average annual rate of 9%; this rate falls to -3.2% over the second decade of the period considered. In value terms, the increase over the whole period is significantly higher, averaging 20.7% per year, despite the sharp decline in 2009. Over the last decade, the increase has slowed to -2.7% in 10 years, even though in 2016 the world's population generated 2 billion tons of household solid waste. This double trend in the evolution of the waste trade over the last 20 years could be due to the efforts of countries to recycle by themselves the waste they produce. This is the case, for example, of Germany, which has specialized in the treatment of waste, especially toxic waste. Also, this result could be due to the prohibition of some countries to continue to import waste that is difficult to recycle on their territory. Indeed, since January 1, 2018, China has banned the import of 24 types of solid waste and debris, including scrap metal, plastic waste, and electrical and electronic waste. Other concerned countries have followed suit, with India banning plastic waste in 2019 and Indonesia moving to send containers back to the West. More recently, some SSA countries are also getting in on the act. Since 2020, the Senegalese government has banned plastic waste imports into its territory. In addition, it would be wise to specify that this trend decline could be due to a lesser extent to the unavailability of data in terms of volume. In this respect, we have observed an unavailability or underestimation of data measuring the volume of waste trade.

4.2.Composition of waste flows

Like Bernard et al, (2014), we select 84 commodities in the six-digit Harmonized System (HS), subdivided into 14 categories to study waste flows (see Appendix). In general, the composition of waste flows in SSA, does not differ fundamentally from that of international flows. Four (04) of the identified categories alone account for over 85% of the volume imported in 2020 (Table 1). These are ferrous metals (52.8%), paper (21.4%), plastics (6.4%) and non-ferrous metals (4.4%). These easily recoverable materials are mainly imported by countries wishing to reduce their dependence on imports of primary raw materials essential for their economy (Nuss, 2022). These materials are interesting from an economic point of view, due to the high intrinsic value of the material itself and good recyclability. Export for waste incineration or landfill is much rarer because it is discouraged or prohibited in many countries (Bernard et al., 2012). However, cases of illegal export are still very common (Tojo et al., 2008; Bernard, 2015; Dato, 2017).

The composition of waste streams in terms of value highlights 5 major categories of recoverable waste (Table 2). Indeed, ferrous metals (34.7%), precious metals (22.2%), non-ferrous metals (19.4%), plastics (7.6%), and paper (5.0%) alone account for more than 90% of the total value of imported waste in 2020. The difference in proportion according to the classification criterion (weight or value) for non-ferrous metals and precious metals comes from the recovery of these materials (Bernard et al, 2012). Thus, precious metals, which include, for example, waste containing gold and platinum, have a much higher economic recovery potential than other materials such as paper. The same is true for non-ferrous metals, which include high-priced metals such as copper (Bernard and al, 2014).

For export flows, the main products remain the same as for import flows with some differences. In 2020, non-ferrous metals are the most important in terms of value (51.5%), followed by a significant proportion of industrial products at 4.9%, although in value terms the proportion remains below 1%. Thus, the main exported wastes identified in the international waste trade are the main wastes imported by SSA countries.

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

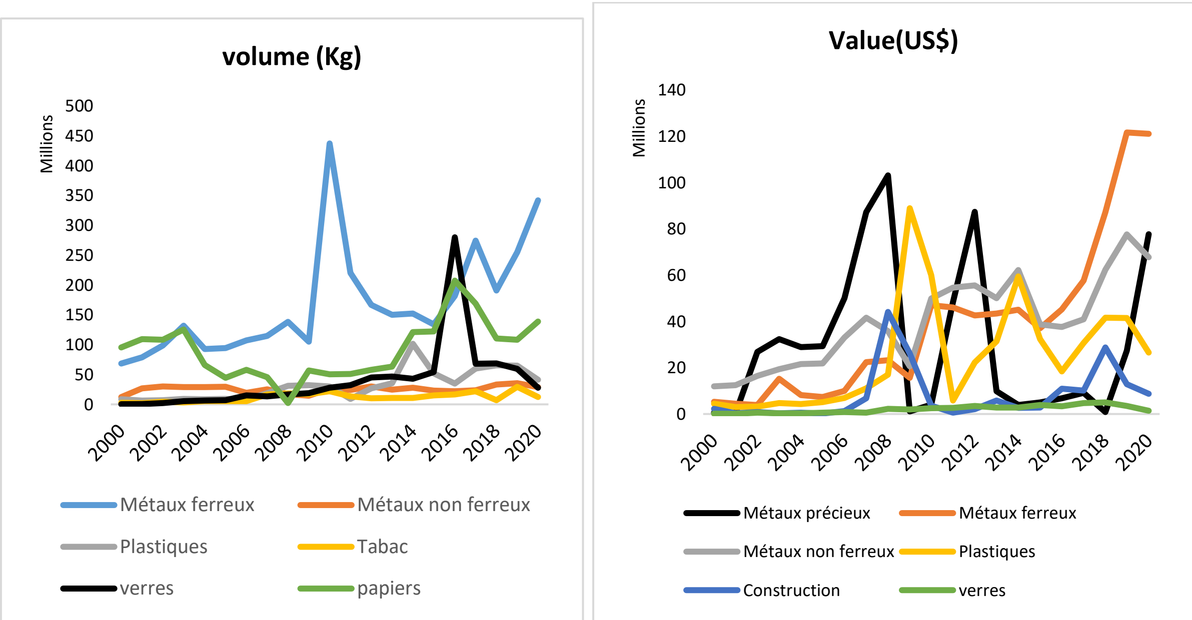
Source: United Nations, Comtrade (July 2022 version), author's calculations.

Over the period 2000-2020, glass, ferrous metals, plastics, and tobacco waste are the categories that have grown the most (Figure 2.4). The largest increase in 20 years is driven by glass waste, which increased more than 100-fold, from 266 tons to nearly 280 thousand tons between 2000-2020. However, the waste whose rapid progression in volume is worrying is the plastic waste. Indeed, the volume has increased by about 4 times in two decades. Plastic waste increased from 8.4 thousand tons at the beginning of the period to 41.5 thousand tons at the end.

In terms of value, precious metals have increased the most, by a factor of over 142 in 20 years. Then come the value of ferrous metals (21.64) and glass (8.67).

Furthermore, over the period 2000-2020, it is possible to see the impact of the volatility of waste prices on the value of waste exchanges (Figure 2). Indeed, the value of a non-recyclable waste is difficult to determine and that of a recyclable waste depends on the world prices of materials. However, an economic crisis can cause these prices to fall without trade falling, or conversely, an increased demand for certain materials will cause prices to rise without the quantity of waste exchanged changing. For this reason, some authors (Bernard and al., 2014; Kellenberg, 2012) advocate working with the weight rather than the value of waste traded if the purpose of the work is to determine the impact of waste on the environment because the intrinsic hazardousness of the waste is measurable from the physical accumulation and the capacity of the importing country to recycle the waste. However, these same authors agree that the value of trade can be used to study the impact of waste trade on national economies. We will use both measures in this work given the dual purpose (environmental impact, economic impact).

Figure 2: Changes in the composition of major waste streams, 2000-2020



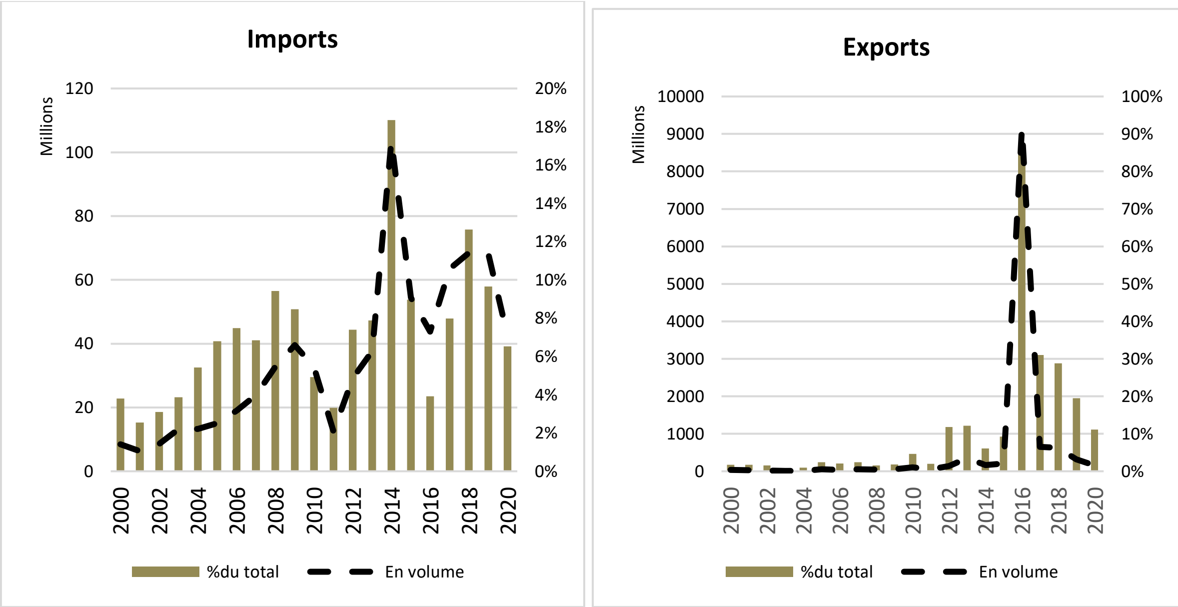
Source: United Nations, Comtrade (July 2022 version), author's calculations.

4.3.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.

4.4.The main actors in the waste trade in SSA

Globally, there are three major players in the international waste trade: China on the import side, the United States on the export side, and Germany on both sides in 2021 (see Table 2). In Sub-Saharan Africa, waste trade is dominated by one player. Over the period 2000-2020, Sub-Saharan African countries traded over 57.8 million tons of waste. The largest player in the SSA waste trade is South Africa with 28 million tons of waste traded over 20 years (Table 3). It alone accounts for 50% and 76% of SSA's waste imports and exports, respectively. For import flows, South Africa is followed in the top three by Nigeria (14%) and Zambia (7.4%). For export flows, South Africa is followed by Zambia (4%) and Sudan (2%).

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 ranking is not surprising, as it is the largest economy in SSA with a significant recycling capacity. Indeed, South Africa ranks third behind countries like Sweden in recycling rates. These impressive rates are almost entirely due to the work of informal recyclers who form the backbone of the recycling economy but are often ignored by policymakers and industry. Also, until recently, the legal framework for the export and import of waste was not yet formalized in South Africa, which facilitated the uncontrolled entry and exit of waste imports and exports (GN 22 of January 21, 2019). Regardless of the time chosen (20 years, or 1 year), South Africa remains the leading player on the continent and the order of the top 20 countries participating in waste trade varies little.

By region, of the top 20 importing countries, 4 West African countries (Nigeria, Côte d'Ivoire, Senegal, and Ghana) import the largest share, 19.3%. Followed by East African countries (Kenya, Uganda, Rwanda, Sudan, Tanzania, and Ethiopia) and South African countries outside South Africa (Eswatini, Botswana, Zambia, Zimbabwe and Angola) with 14%. Central Africa (Congo, DRC, and Cameroon) imports only 2.2%.

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.

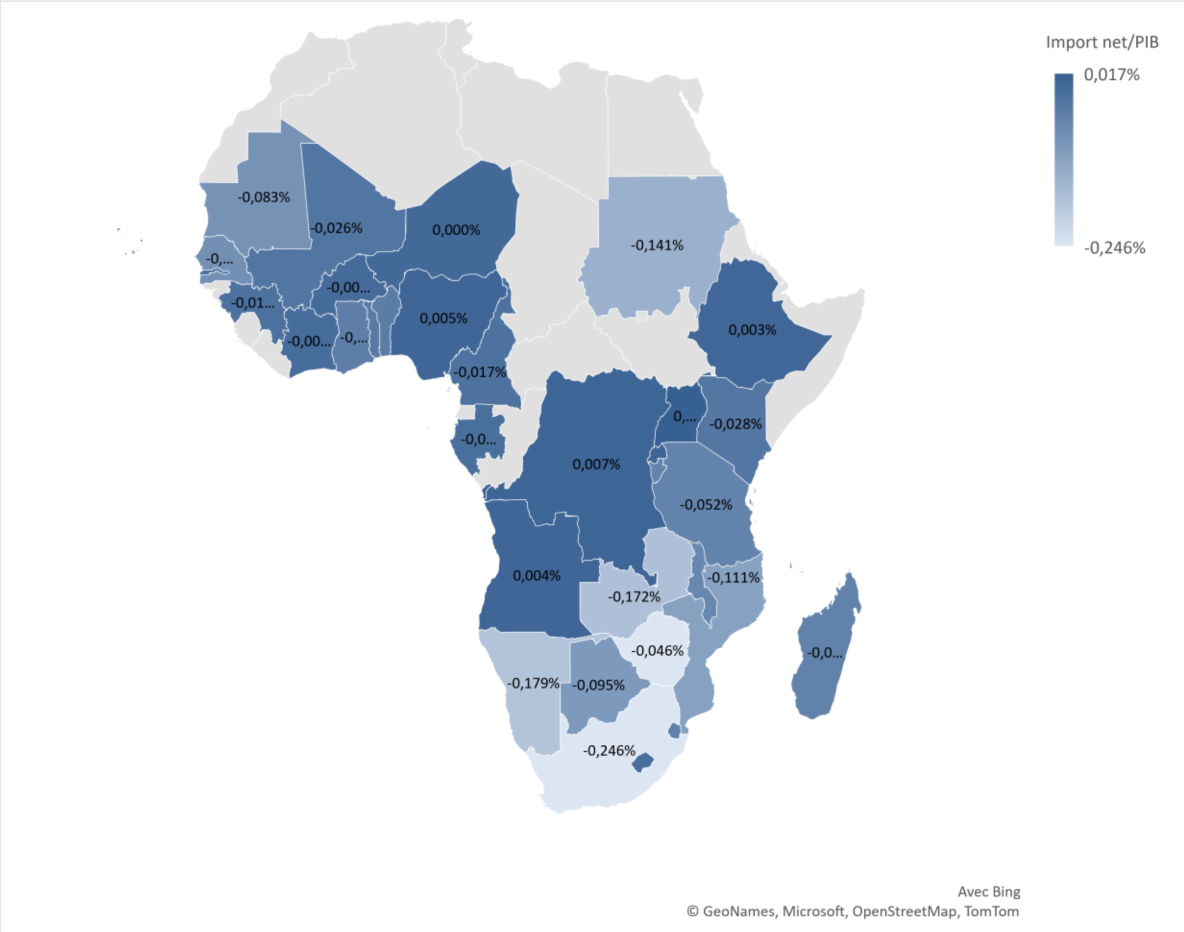
4.5.Importance of waste trade in the economy of SSA countries

To measure the importance of waste trade in the economy of SSA countries, it is relevant to relate the value of trade flows (imports and exports) to the country's Gross Domestic Product (GDP) (Bernard et al, 2014). Although the use of the value of waste is subject to caveats given its volatility with commodity prices, it is still a good indicator when discussing the economic importance of waste trade.

Figure 3 takes data for 41 countries and presents the ratio: average import value (USD)/average GDP (USD) over the period 2000-2020. The ratio ranges from 0.132% to 0.001%. The five countries with the highest ratio are Eswatini (0.132%), Zambia (0.092%), Lesotho (0.043%), Uganda (0.042%) and Seychelles (0.035%). The low ratio of imports to GDP can be explained by the weakness of SSA countries in integrating the circular economy and taking advantage of it, notably because of the lack of infrastructure needed for the recycling of recoverable waste (Denoiseux, 2010).

A refinement of the previously detailed ratio is to use net imports (imports - exports) instead of imports (Figure 3). Of the 41 countries considered, eight (08) have a positive balance, albeit small, and are therefore net importers. These are Uganda (0.017%); Seychelles (0.008%) ; Congo (0.007%) ; Rwanda (0.007%) ; Nigeria (0.005%) ; Angola (0.004%) ; Ethiopia (0.003%). Only Niger has a balance very close to 0. However, the clear majority have a negative balance, which confirms that African countries export more 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 ratio is more important. This difference proves that the waste trade has taken a place at least not negligible in the economy of the States. Thus, we identify the first five countries that are: South Africa (-0.246%), Namibia (-0.179%) Zambia (-0.172%), Mauritius (-0.168%) and Sudan (-0.141%). This slightly higher propensity shows that SSA countries have a greater interest in recovering waste through export because they do not have the appropriate technologies for adequate treatment.

5. Analysis of the estimation results

5.1.Descriptive statistics and correlation between variables

Table 4 summarizes the statistics for our sample and shows that overall, the standard deviations are high, except for the relatively low standard deviations of the score variables (PES, anti-corruption policy, infrastructure quality). To normalize the series and to be able to interpret the coefficients in terms of elasticities, we choose to use a logarithmic transformation in the regressions.

Furthermore, the analysis of the correlation coefficient matrix between the different variables of the study (see appendix), shows that there is a correlation between certain variables. To avoid possible multi-collinearities between these different variables, which could lead to instability of the estimated coefficients, they will be introduced one by one in the different estimations and the GMM method will correct this multi-collinearity.

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, (Bourbonnais, 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
Condition de rang d'identification pour l'équation *j*				
Les sous-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 forces us to select 30 SSA countries over the period 2000-2020. The econometric model highlights the role of waste trade, through the estimation of the interactions within the triangle of waste trade-inclusive growth and environment. First, we note that the specified model is globally significant. Indeed, the Wald coefficients of the different equations are high. Similarly, we then observe that the p-values, which represent the probability of the $\chi 2$ and F-stat tests rejecting the null hypothesis of spurious regression, are all equal to 0.000 and thus less than 0.05. Finally, the validation tests of the GMM estimation method are also satisfactory for all models. Nevertheless, an error autocorrelation problem persists for the growth model.

The results in Table 7 inspire several comments regarding the waste trade, growth, and environment equations.

Determinants of waste trade

The results of equations 1A and 1B show that for Sub-Saharan African countries, the main determinants of waste trade are the level of per capita income and environmental regulation. Indeed, these two variables have positive effects and significantly different from 0 for import flows. These flows increase by 0.59% and 0.65% when per capita income and regulation increase by 1%. This paradoxical result is simply explained by the low per capita income in developing countries, despite the progress made in recent years. According to World Bank data (2021), of the 30 countries selected, only Seychelles is among the high-income countries, and 12 are in the upper middle bracket. These levels of income and regulation do not yet allow SSA countries to reduce waste imports, as the severity of their environmental regulation is on average 39% lower than in developed countries. These results confirm those of Kellenberg & Levinson (2011) who tested the impact of international regulations on waste trade. While they find that the implementation of the Basel Convention amendment leads to a reduction in the flows of the 20 most hazardous wastes, the Basel Convention has not led to a significant decrease in trade. They explain this surprising result at first sight by a weakness of the Basel Convention which allows two members of the convention to exchange wastes according to a derogatory process. Thus, several countries have joined the Basel Convention to continue to exchange waste with other countries that had already joined the Convention. Our results thus clearly show the weakness of the Basel and Bamako conventions. Another determinant of waste import flows is the rate of urbanization. The more the population of urban areas grows, the more waste imports tend to increase. In contrast, for waste export flows, only per capita income has a statistically significant positive effect. This is understandable when income growth is linked to consumption. This result confirms our hypothesis that a low level of environmental regulation coupled with a low level of gross domestic product per capita determines waste import flows.

Impact of waste trade on inclusive growth

The results of equations 2A and 2B, show that waste flows have positive and statistically different from 0 effects on per capita income. This result, although surprising, can be explained at first glance, if we look at the nature of the waste exchanged with SSA countries. Indeed, the qualitative analysis of waste flows made above indicates two (02) major points: (i) like Western countries, international trade in waste from SSA countries is mainly in waste for recycling or reuse. (ii) in terms of volume, the data show that imports of hazardous wastes represent only about 7% on average of the imports of SSA countries between 2000-2020. Similarly, for export flows with a higher average rate of about 11%, over the same period. It is thus understandable that more than 90% of the waste imported to the continent has a high potential to be reused or recycled. Thus, a second argument for this result can also be found in the developments of the circular economy. Indeed, according to Liu et al, (2018), importing recyclable waste allows the recovery of low-cost raw materials, which can be directly re-injected into the domestic production process hence the positive effect on per capita income. However, in the case of SSA countries, the effect is marginal, amounting to 0.0042% and 0.032% increase in per capita income, after a 1% increase in import and export flows respectively. Also, waste also contains an energy potential value (the amount of energy that can be recovered per kg of waste incinerated). In recent decades, waste incineration with energy recovery has become more and more widespread, especially for plastics, whose energy potential is particularly high.

A final argument for this result could be the lack of information on these flows, many of which are done illegally, thus preventing them from being characterized with certainty. According to official data, Africa participates very little in the waste trade (less than 2% of the international waste trade). But in a totally illegal or hidden way, these flows can be much larger.

Impact of waste trade on environmental policy

From equations 3A and 3B, we note a positive and significant effect of GDP per capita, and of the waste export flow on the environmental policy score, import flows being insignificant. We can thus note that when the GDP per capita increases by 1%, SSA countries have the capacity to strengthen their environmental policy by nearly 0.60%. Similarly, when the country can export its waste flows and can exercise control over corruption, the score is strengthened. On the other hand, variables such as urbanization rate and quality of infrastructure have significant negative effects. This last result is relevant and calls for further attention because it shows that when the country has a significant infrastructure for waste treatment, environmental protection policy may be neglected. Now, taking the pollution haven hypothesis and applying it to waste, Kellenberg studies the impact of national environmental policies on international trade in waste (Kellenberg and Levinson, 2011; Kellenberg, 2012). Using 2004 imports of 62 commodities considered waste from UNComtrade, Kellenberg shows that for every 1% deterioration in environmental regulations, there is a corresponding 0.32% increase in waste imports. Considering that developing countries have an environmental regulation index 39% lower than the world average, the above relationship has major implications.

Table 7: Estimation results

	Modele waste_import						Modele Waste export	
	Equation 1A	Equation 1B	Equation 2A	Equation 2B	Equation 3A	Equation 3B	Equation 1A	Equation 1B
Limport_waste	0,4060303***	0,2424673**						
L1.	(0,0481715)	(0,1081652)						
Lexport_waste							0,590484***	0,5685246 ***
L1.							(0,0558154)	(0,0804733)
LPIBh			0,8129201	0,7970245***				
L1.			(0,0095567)***	0,0221941				
LSPE					0,5671986***	0,5543557***		
L1.					(0,0041755)	(0,0075733)		
LPIBh	0,5986657***	0,0888021			0,0379152***	0,0503476***	0,5321089***	0,8394583**
	(0,1214427)	(0,1429487)			(0,0088507)	(0,0093484)	(0,1325624)	(0,4243546)
LSPE	0,6575218***	1,014623***	0,1771895***	0,1608656***			-,0267397	-0,1009303
	(0,1954767)	(0,2148005)	(0,0144569)	(0,0174257)			(0,2405569)	(0,2278683)
Limport_waste			0,0038758**	0,0042233**	0,0025655	0,0023922		
			(0,0019107)	(0,0020023)	(0,0020091)	(0,0038149)		
Lexport_waste			0,0353096***	0,0327116***	0,0082079***	0,0086592***		
			(0,0023549)	0,0033584	(0,0007611)	(0,0015123)		
Lopen				0,0519733**				
				(0,0215714)				
LTurb		2,162589***		0,1272208*	-0,0422595	-0,1017443***		-1,222118
		(0,5605184)		(0,0657688)	(0,030849)	(0,0363821)		(0,895973)
L,ConCorrup		0,9906763		0,0221066		0,1507659***		0,1375469
		(0,6308257)		(0,0408612)		(0,0293797)		(0,3725289)
L,InfQual		-0,1000073		0,0204491		-,1474757***		0,0661076
		(0,3246171)		(0,0399565)		(0,019881)		(0,5619811)
Const	3,31399***	-0,0101283	0,5029445***	-0,0287553	0,3021029***	0,3981923***	2,581914***	4,870776
	(0,59119930	(1,222563)	(,0550433)	(0,2330075)	(0,0539648)	(0,1141714)	(0,338534)	(1,547721)
Nombre d'observation	570	570	570	570	570	570	570	570
Wald chi 2	386,87	277,51	24854,78	23309,95 (0,0000)	62881,15	15381,64	1722,15	1586,72
(Prob)	(0,0000)	(0,0000)	(0,0000)		(0,0000)	(0,0000)	(0,0000)	(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 its international waste trade dimension and in a complex African regional context. Complex, because of the non-existence of waste treatment infrastructures and the illegal nature of the waste trade. From the COMTRADE, WDI and UNEP data, we obtain two types of results: a first result that allows us to assess the state of the waste trade in SSA countries and a second that allows us to qualify the character of the waste trade in sub-Saharan Africa. The descriptive analysis offers the following relevant results: (i)Over the period 2000-2020, SSA traded a total of about 59 million tons of waste worth $29 billion or about 1.5% of international waste trade. (ii) There is an upward trend in imports in both value and volume terms. In terms of value, waste imports increased from $54.8 million in 2000 to $337.1 million in 2020. In volume, the increase is more moderate. It increases 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. (iii) In general, the composition of waste flows in SSA does not differ fundamentally from that of international flows. Four (04) of the identified categories alone account for over 85% of the volume imported in 2020. These are ferrous metals (52.8%), paper (21.4%), plastics (6.4%) and non-ferrous metals (4.4%). All products with high recovery potential. (iv) In sub-Saharan Africa, the leading player in the waste trade in SSA is South Africa with 28 million tons of waste traded over 20 years. Its alone accounts for 50% and 76% of sub-Saharan Africa's waste imports and exports respectively. (v) The weight of waste trade is still low in SSA countries. The five countries with the highest ratio are Eswatini (0.132%), Zambia (0.092%), Lesotho (0.043%), Uganda (0.042%) and Seychelles (0.035%). The low ratio of imports to GDP can be explained by the inability of SSA countries to integrate and benefit from the circular economy, particularly because of the lack of infrastructure needed to recycle recoverable waste. Also, on the light of our results, the low rate of participation in the international waste trade by African countries does not allow us to conclude on the hypothesis that Africa is a haven for waste, in particular because of the large flows that escape official controls.

Using a simultaneous equation model, the econometric analysis offers the following important results: (i) The determinants of waste imports in SSA are related to the coupled weakness of income and environmental regulation. (ii) Waste trade flows reflect a form of circular economy because of the positive impact on per capita income, but the effect is still marginal, indicating the relatively low integration of SSA countries in this trade. (iii) Environmental policies need to be strengthened in conjunction with anti-corruption policies if positive effects on growth are to be expected.

In short, for the countries of sub-Saharan Africa to be better integrated into the circular economy and to remove the obstacles to sustainable development, they must act on three fronts at the same time: (i) Develop/construct or even invest massively in infrastructures adapted to the treatment of imported waste; (ii) Take advantage of the circular economy to create quality jobs and make the transition from informal workers in the waste sector to a formal situation.

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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
```