The Economics of Plastic Use and Cleanup Priorities for West African Coastal Countries

ECONOMICS

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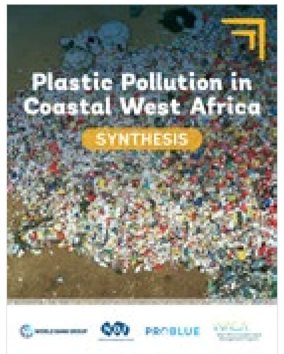
ABOUT THIS REPORT

This report aims to help decision-makers better understand the economics of marine plastic-waste generation and its cleanup, with a focus on West African coastal countries.

It was carried out under the remit of the West Africa Coastal Areas Management Program (WACA), which addresses coastal degradation—including from plastic pollution—in 17 West and Central coastal African countries and island states spanning from Mauritania to Gabon.

This report is part of a series that includes: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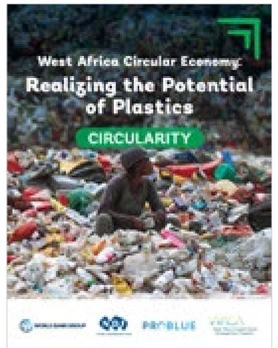
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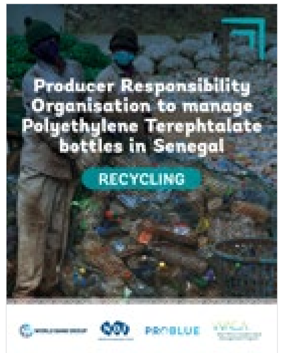
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RECYCLING

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WACA Plastic E-book

WACA Plastic E-book

KEY MESSAGES

The Africa region is currently the second-largest source of ocean plastic pollution from rivers, with a share of 7.8 percent. By 2060, Africa could become the world's largest contributor of mismanaged plastic waste.

In 14 out of 17 West African coastal countries, more than 80 percent of plastic is mismanaged, increasing the risk of plastic waste entering the oceans. There is an urgent need to improve plastic waste management systems in the region.

The overall economic cost of marine plastics to society is estimated at between US$10,000 and US$33,000 per ton of plastic. These costs are concentrated in four sectors: fisheries and aquaculture; marine-linked tourism; value of waterfront property; and biodiversity and ecosystems sectors. More research is needed to determine the costs of plastic pollution for other sectors.

Econometric analysis indicates that import taxes on polyethylene sheets could play a role in reducing marine pollution by driving down single-use plastics waste.

However, given that single-use plastics are widely used for safe drinking water, the potential public health impacts of such measures will need to be carefully considered. Similar consideration needs to be given to the distributional effects of such import taxes.

Cleanup efforts before seasonal rains in pollution hotspots should be better targeted to optimize the volumes of plastic pollution that is prevented from reaching oceans.

There is no one-size-fits-all solution. West African coastal countries do not have sufficient data for estimating country- and sector-specific costs. In this context, **location-specific analyses are needed to determine the most cost-effective policy mix for plastic waste remediation,** with the most practical policy solutions likely entailing some combination of quantity- and price-based approaches balanced by highly targeted cleanup strategies.

Public awareness, stakeholder participation in policy and strategy design, and access to environmentally friendly alternatives will be key to effective waste management.

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ABBREVIATIONS & DEFINITIONS

DHS	Demographic health survey
ECOWAS	Economic Community of West African States
GDP	Gross domestic product
MIS	Malaria indicator survey
NDF	Nordic Development Fund
SUP	Single-use plastic
TPS	Thin polyethylene sheet
UNEP	United Nations Environment Programme
WACA	West Africa Coastal Areas Management Program
WACA countries/region	The 17 coastal and island states covered by the WACA program: Benin, Cabo Verde, Cameroon, Côte d'Ivoire, Equatoria Guinea, Gabon, The Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mauritania, Nigeria, São Tomé and Príncipe, Senegal, Sierra Leone, and Togo

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EXECUTIVE SUMMARY

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Rapidly growing, unregulated plastic litter has created a multitude of environmental and economic problems worldwide.

The rapid rise in global plastic production, which had reached 368 million metric tons by 2019, is expected to double over the next two decades (Geyer, Jambeck, and Law 2017). Durability, one of the main attributes accounting for plastic's popularity, also poses serious hazards for the unregulated disposal of plastic waste.

With an estimated lifetime of centuries, plastic waste has become a major stressor in marine ecosystems (Díaz-Mendoza et al. 2020; Gallo et al. 2018; Jeftic et al. 2009; UNEP 2005). Plastic ocean debris, first observed in the 1960s, now affects all of the world's oceans. Recent studies estimate the ocean entry of plastic waste at between 4.8 million and 20 million metric tons annually (Jambeck et al. 2015; UNEP 2014). Each year, thousands of fish, seabirds, sea turtles, and other marine mammals die as a result of ingesting or becoming entangled in plastic debris.

In West Africa, the use of plastic products has proliferated with urbanization, and their unregulated disposal has created a host of terrestrial and marine-related environmental problems. The Africa region is currently the second-largest source of ocean plastic pollution from rivers, with a share of 7.8 percent (Lebreton et al. 2017; Ritchie and Roser 2018). Three African rivers figure among the world's top 20 plastic pollution sources: the Cross River (Nigeria and Cameroon); the Imo River (Nigeria); and the Kwa Ibo River (Nigeria) (Lebreton et al. 2017). Projections for 2025 indicate that mismanaged plastic waste from the Africa region will likely comprise 10.6 percent of the global total (Jambeck et al. 2015). With urbanization continuing in an unabated fashion, Africa could become the largest contributor towards global mismanaged plastic waste by 2060 (Lebreton and Andrady 2019).

A survey of current literature reveals that, in 14 out of 17 West African coastal countries, the share of mismanaged plastic waste in proportion to the total exceeds 80 percent.[1] All coastal countries need to have well-functioning plastic-waste management infrastructure, policies, and practices in place to lower the risk of plastic waste generated in coastal areas entering the oceans via wind, tidal transport, and/or transport to coastlines by inland waterways (Jambeck et al. 2015; Ritchie and Roser 2018). Clearly, West African coastal countries are in urgent need of improved plastic waste management systems.

While the reduction of mismanaged plastic waste has been recognized as an important development objective, several key factors have hindered cost-effective remediation. For example, information on the true economic cost of plastics is scarce. This cost is difficult to estimate, as persistent post-use environmental damage is hard to monetize. Also, the pros and cons of various market-based policy instruments for remediation are lacking. In addition, the spatial distribution and timing of plastic-waste generation is poorly understood. This issue is especially key because it can affect the relative importance of policy instruments.

This study aims to help decision-makers better understand the economics of marine plastic-waste generation and its cleanup, with a focus on West African coastal countries. To aid the policy process to reduce marine plastic pollution, it addresses the following key questions:

- What is the economic cost to society of marine plastic waste?
- How does this cost compare with the pollution mitigation cost, using various incentive-based, command-and-control approaches for pollution prevention and the cost of plastic waste removal through cleaning, recycling, and safe disposal?
- Would general economic measures (for example, tariffs on imported polyethylene) significantly reduce pollution from single-use plastics?
- Are there trade-offs between plastic pollution prevention and any other social objectives related to policymaking? How should cost-effective cleanups be implemented?

The study takes a location- and season-specific approach, using detailed information for Accra (Ghana) and Lagos (Nigeria) from household surveys, geographic and weather data, and measures of marine plastic pollution.

Using a holistic approach, the economic cost of marine plastics to society is estimated at between US$10,000 and US$33,000 per ton of plastic. Sector-specific damages of between US$2,000 to nearly US$7,000 have been determined for four sectors. The study's literature review shows that two main approaches are currently being used to estimate the external cost of plastics in the marine environment: damage to overall marine ecosystem services and aggregation of sector-specific costs. Using the first (holistic) approach, the annual damage cost estimate appears to be between US$10,000 and US$33,000 per ton of plastic (Barrett et al.; Conservancy 2015; Costanza et al. 2014; Jang et al. 2015).

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[1] The figures are for 2010, which is the latest year for which the available data permit cross-comparison.

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Using the second (partial) approach, the aggregate cost estimate for the four sectors where damage from the presence of plastic is clearly visible—fisheries and aquaculture; marine-linked tourism; value of waterfront property; and biodiversity and ecosystems—ranges from more than US$2,000 to nearly US$7,000 per ton of plastic waste. These estimates are important elements of the social cost of plastics and will be useful for future location-specific cost-benefit analyses for public and private interventions for waste management.

The costs of reducing plastic pollution, using three main approaches, fall within the range of the estimated external costs. A study of global experience reveals three main approaches for reducing plastic pollution: (i) incentives; (ii) command and control; and (iii) removal of plastic waste through cleaning, recycling, and safe disposal. Incentive-based approaches include levying production excise taxes or import duties on raw materials or taxing plastic products at the point of sale. Command-and-control approaches minimize the external costs generated by plastic products by banning their use through regulation and enforcement. In principle, both incentive-based and command-and-control approaches can reduce the use of many plastic products; however, complete elimination may not be feasible for some, in which case the removal of plastic waste through cleaning, recycling, or safe disposal will be beneficial. These three approaches are not mutually exclusive. Rather, they can be tailored to a particular country's local economic and political conditions to achieve the most cost-effective mix.

Taxes and bans can reduce marine pollution from single-use plastic (SUP) waste, but targeted enforcement may prove difficult if producers, sellers, and consumers are widely dispersed. In West African coastal countries, SUP sachets, bags, and other containers are fabricated from thin polythene sheet (TPS), virtually all of which is imported. One appealing policy would directly target bulk imports of polyethylene; however, evaluating this policy also requires understanding the expected response of TPS imports to the imposition of tariffs.

The results of this study's econometric analysis of TPS import demand for seven West African coastal countries indicate a high degree of income and price responsiveness. This study addressed the responsiveness question by analyzing TPS imports and their prices over time for Benin, Cameroon, Côte d'Ivoire, Ghana, Guinea, Nigeria, and Senegal. It found that, for each 1 percent increase in national income, TPS imports increased by about 1 percent. For each 1 percent increase in TPS price, TPS imports decreased by about 1 percent. These results have two major policy implications. First, without putting countermeasures in place, TPS imports and the waste generated by SUP containers will likely keep pace with national income growth. Second, TPS price increases on the world market have produced rapid, proportionate reductions in West Africa import demand. Since producers are indifferent to the sources of price change, the same will be true for price increases from import duties. Thus, a TPS tariff could be a potent weapon in the struggle to reduce SUP pollution. However, policy makers should consider the distributional implications of this option since the poor could be disproportionately impacted.

An econometric analysis was conducted for Ghana and Nigeria to assess the public health risks from policies to reduce waste from the use of SUP drinking-water containers. Using Demographic and Health Survey data for these two countries, the analysis tested whether child morbidity and mortality are lower in households that use SUP drinking-water containers, after controlling for income, education, and other socioeconomic factors widely cited in the literature. The respective results showed notable declines in the median predicted rate of child mortality (42 percent and 20 percent) and incidence of diarrhea (21 percent and 10 percent) for all children (0–5 years of age) attributable to SUP container use across and within years. This means that general measures to reduce plastic use might also increase childhood illness and death. ***These findings suggest the need to offset reduction and prevention policies with compensatory measures that promote other sources of clean drinking water, particularly for poor households.***

The study developed an illustrative cleanup strategy for marine plastic pollution in Accra and Lagos. Its focus was SUP drinking-water containers, given the potentially adverse public-health effects of banning or severely restricting their use. A hotspot targeting strategy was developed for the two cities, using a methodology that combined georeferenced household survey data on plastic use, measures of seasonal variation in marine plastic pollution from satellite imagery, and a model of plastic waste transport to the ocean using information on topography, seasonal rainfall, drainage to rivers, and river transport to the ocean. The results provide clear evidence of the accumulation of SUP container waste in hotspots during low-rainfall periods, followed by rapid river transport through flooding and runoff with the return of heavier rainfall.

More local case studies on sector-specific losses from plastic wastes are needed in West African countries. At present, West African coastal countries do not have sufficient data for estimating country- and sector-specific costs. Better data on waste plastic externalities can play a key role in assessing the benefits and costs of policy options for plastic waste remediation.

Location-specific analyses are needed to determine the most cost-effective policy mix for plastic waste remediation in each country. West African coastal countries require urgent intervention because mismanaged plastic waste in the marine environment will continue to increase at high rates (Lebreton and Andrady 2019). However, there is no one-size-fits-all solution. As options for plastic waste management improve, the most practical policy solutions will likely entail some combination of quantity- and price-based approaches balanced by cleanup strategies. Determining the most cost-effective policy mix for each country should involve location-specific analyses.

Effective waste management requires awareness raising, stakeholder participation in policy and strategy design, and promoting the development of environmentally friendly alternatives. Successful global experience indicates that effective outcomes require broad-based awareness raising about plastic pollution, including regular public consultations; stakeholder engagement in designing mitigation policies and strategies; and the development of reasonably priced, environmentally friendly alternatives planned well in advance of implementing plastic reduction policies. West African countries can improve their waste management performance by learning from successful global experience.

Import taxes on polyethylene sheets can play a key role in reducing SUP waste, but understanding the distributional implications for the poor is critical. Taxation of the imported polyethylene that comprises most of the production feedstock for SUP in West Africa is a potentially effective, price-based policy with relatively low administrative costs. Plastic demand exhibits a very elastic response to changes in the price of imported polyethylene. Import taxes have a potentially major cost advantage over directly targeted measures since the former can be administered at relatively few entry points while the latter require a widely distributed cadre of enforcement agents. Since a tariff may have a disproportionate impact on the poor, policy makers should consider potential distributional implications before implementing a tariff on polyethylene.

Economic measures must avoid adverse health impacts. While the case for public intervention to reduce plastic waste seems clear, attention must also be paid to potential conflicts with public-health outcomes. Thus, measures to reduce the use of plastic sachets and bottles should be accompanied by programs designed to improve health outcomes for children, particularly in poor households. As an alternative, subsidies could be provided for use of biodegradable drinking-water containers, which are more costly to produce.

Cleanup measures should be better targeted. Priority should be given to areas with a high incidence of plastic waste disposal near rivers, particularly more elevated areas with steeper slopes. Cleanup resources should be concentrated in marine plastic hotspot areas before the onset of the first-semester rainy season.

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1.

INTRODUCTION

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Plastic use has expanded rapidly since World War II.[2] In recent years, global plastic production has been increasing at an average rate of more than 8 percent per year.[3] By 2019, annual production had reached 368 million metric tons, and this figure is expected to double over the next two decades (Geyer, Jambeck, and Law 2017).[4] The main attributes that account for plastic's popularity are its low cost, convenience, and durability; however, the durability feature also poses serious hazards (for example, environmental, public health, economic, and aesthetic) for the unregulated disposal of plastic waste that is not incinerated, stored in landfills, or recycled.[5]

Plastics, which have an estimated lifetime of hundreds of years, have become major stressors in marine ecosystems (Díaz-Mendoza et al. 2020; Gallo et al. 2018; Jeftic et al. 2009; UNEP 2005). Plastic ocean debris, first observed in the 1960s,[6] affects all of the world's oceans; recent studies estimate ocean entry at between 4.8 million and 20 million metric tons annually (Jambeck et al. 2015; UNEP 2014).[7] In the marine environment, plastic slowly degrades into microplastics over time, accumulates on shorelines, sinks to the seabed, or floats on the sea surface.[8] Each year, thousands of fish, sea birds, sea turtles, and other marine mammals die as a result of ingesting or becoming entangled in plastic debris.

Plastic waste generated in coastal areas is at high risk of entering the oceans via wind, tidal transport, and/or transport to coastlines by inland waterways (Jambeck et al. 2015; Ritchie and Roser 2018). However, management determines this risk, highlighting the need for all coastal countries to implement well-functioning plastic waste-management infrastructure, policies, and practices.

Much of the world's mismanaged plastic waste enters rivers and water systems before ending up in the ocean.[9] The Africa region is currently the second-largest source of ocean plastic pollution from rivers, with a share of 7.8 percent (Lebreton et al. 2017; Ritchie and Roser 2018).[10]

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[2] The term *plastic* originally meant "pliable" or "easily shaped".

[3] https://www.statista.com/statistics/282732/global-production-of-plastics-since-1950/. Accessed February 2021.

[4] In 2020, global production decreased by 0.3 percent, owing to the impact of Covid-19 on the industry.

[5] Prior to 1980, virtually all plastic was discarded, with negligible incineration and recycling. After 1980 (for incineration) and 1990 (for recycling), the combined rate for incineration and recycling rates increased by about 0.7 percent per year (Geyer, Jambeck, and Law 2017). In 2015, an estimated 55 percent of global plastic waste was discarded, 25 percent was incinerated, and 20 percent recycled (Ritchie and Roser 2018).

[6] https://www.sciencehistory.org/the-history-and-future-of-plastics Accessed August 2021.

[7] Plastic accounts for between 61 and 87 percent of marine litter (Barboza et al. 2019; Galgani *et al.* 2019).

[8] Over two-thirds of marine plastic litter ends up on the seabed. Half of the remaining third washes up on beaches, while the other half (i.e. sixth of total) floats near the surface (Gallo *et al.* 2018).

[9] Plastic that ends up in the ocean also results from the disposal of solid waste, dumping of wastewater, direct littering, vehicular transport, and/or transport by wind and stormwater.

[10] The largest share has its origin in Asia, which accounts for 86 percent of the global total.


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Nigeria is Africa's largest generator of plastic waste, and among the top producers of the substance worldwide. Three African rivers figure among the world's top 20 plastic pollution sources: (i) the Cross River (Nigeria and Cameroon); (ii) the Imo River (Nigeria); and (iii) the Kwa Ibo River (Nigeria) (Lebreton et al. 2017). Projections for 2025 indicate that mismanaged plastic waste from the Africa region will likely comprise 10.6 percent of the global total (Jambeck et al. 2015). With the rate at which urbanization is taking place, Africa could become the largest contributor to global mismanaged plastic waste by 2060 (Lebreton and Andrady 2019).

A survey of the current literature revealed that the status of plastic waste in 17 West African coastal countries in 2010, the latest year for which the available data permitted cross-comparison (Table 1). Although the majority of these countries have instituted SUP reduction policies by banning certain products, their share of mismanaged waste in proportion to the total still exceeds 80 percent in 14 of them.[11] Clearly, these countries need an urgent improvement in their plastic waste-management systems (Box 1).

Table 1: *Plastic waste in countries of West Africa Coastal Areas Management Program (WACA), 2010*

Country	Total plastic waste generation (metric tons)	Per capita plastic waste (kg/person/day)	Share of mismanaged plastic (%)	Relative share of plastic waste (% of global total)
Nigeria	5,961,750	0.1	81	2.67
Côte d'Ivoire	766,988	0.1	82	0.61
Senegal	485,586	0.1	82	0.8
Ghana	357,877	0.04	81	0.29
Cameroon	335,305	0.05	81	0.09
Benin	144,382	0.04	83	0.14
Togo	135,294	0.06	84	0.11
Liberia	121,050	0.08	84	0.18
Guinea	118,196	0.03	84	0.06
Sierra Leone	96,655	0.04	84	0.11
Mauritania	59,287	0.05	82	0.04
Equatorial Guinea	49,990	0.14	30	0.02
Gabon	32,329	0.05	34	0.02
Guinea-Bissau	30,666	0.05	83	0.06
Gambia	29,646	0.05	84	0.06
Cape Verde	11,919	0.07	74	0.03
São Tome and Principe	6,571	0.1	81	0.02

BOX 1

Classification of plastic waste generation for WACA countries

The 17 West African coastal countries can be separated into low, medium, and high categories for plastic waste intensity across three dimensions: plastic waste per thousand people; plastic waste per square kilometer; and plastic waste per US$100,000 purchasing power parity-adjusted GDP per capita. Each of these indicators has been assigned a percentile category [low 0–33; medium 34–66; or high 67–100]. A composite category is determined from a country's scores in at least two dimensions.

Table 2 *Annual plastic waste intensity by dimension*

Country	Plastic waste (t) /1,000 people	Plastic waste (t) /km2	Plastic waste (t)/US$100,000 PPP-adjusted GDP	Category
Côte d'Ivoire	29.08	2.38	5.3	High
Liberia	23.93	1.21	6.77	High
Nigeria	28.92	6.45	4.74	High
São Tome and Principe	29.98	6.56	2.97	High
Senegal	29.00	2.47	5.83	High
Togo	16.34	2.39	7.65	High
Benin	11.91	1.26	4.3	Medium
Cape Verde	21.44	2.96	1.41	Medium
Equatorial Guinea	35.63	1.78	1.02	Medium
Gambia	12.27	2.55	5.02	Medium
Guinea-Bissau	15.58	0.85	5.26	Medium
Mauritania	12.75	0.06	3.98	Medium
Sierra Leone	12.12	1.35	7.77	Medium
Cameroon	12.63	0.7	2.51	Low
Gabon	14.53	0.12	0.54	Low
Ghana	11.52	1.5	1.35	Low
Guinea	9.00	0.48	2.92	Low

Source: Calculations based on data from Jambeck *et al.* 2015.

PROJECTIONS FOR 2025 INDICATE THAT MISMANAGED PLASTIC WASTE FROM THE AFRICA REGION WILL LIKELY

COMPRISE 10.6 PERCENT

OF THE GLOBAL TOTAL.

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[11] Most plastic waste in these countries results from domestic use, and the disposal of plastic bags, grocery bags, water sachets, straws, and beverage/water bottles.

The rapid expansion of unregulated plastic disposal has created a multitude of local problems. Waste plastics clog drainage systems; contribute to widespread flooding and waterborne diseases during the rainy season; degrade sites with potential value for tourism; and contaminate both terrestrial and coastal marine ecosystems. Marginalized communities and those living near plastic waste sites are disproportionately affected, constituting an environmental injustice (UNEP 2021). Plentiful photographic evidence documents the problem (Figure 1). Well-functioning plastic waste-management systems that can address the plastics pollution problem from both a global and a local perspective offer a strong win-win potential.

While the reduction of mismanaged plastic waste has been recognized as an important development objective, cost-effective remediation has been hindered by the scarcity of information on the true economic cost of plastics. This cost is difficult to estimate, as persistent post-use environmental damage is hard to monetize. In addition to incorporating post-use environmental impacts, policy making for remediation requires weighing the pros and cons of various market-based policy instruments – as well as understanding the spatial distribution and timing of plastic-waste generation. The latter issue especially is key, because it can affect the relative importance of the policy instruments. For example, locally targeted prevention and collection may be cost-effective in cases where the generation of plastic waste is highly concentrated – such as in particular areas and seasons. In other cases, a more uniform pattern may shift the advantage toward general measures, such as taxation and quantity restrictions.

Figure 1: *Plastics in a tributary of the Odaw river (Ghana), May 2015*

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This analysis, with its focus on the coastal countries of West Africa (Figure 2), aims to help decision-makers better understand the factors that should be considered when developing cost-effective policies for reducing plastic waste in the marine environment. It begins by estimating the economic cost of the externalities generated by plastic waste in the marine environment, including damage estimates for ecosystems and related sectors (Section 2). Such uncompensated external costs are compared with those of the three main approaches currently used to reduce plastic pollution (Section 3). Because of the current lack of data in the countries of interest, global examples have been used to estimate cost.

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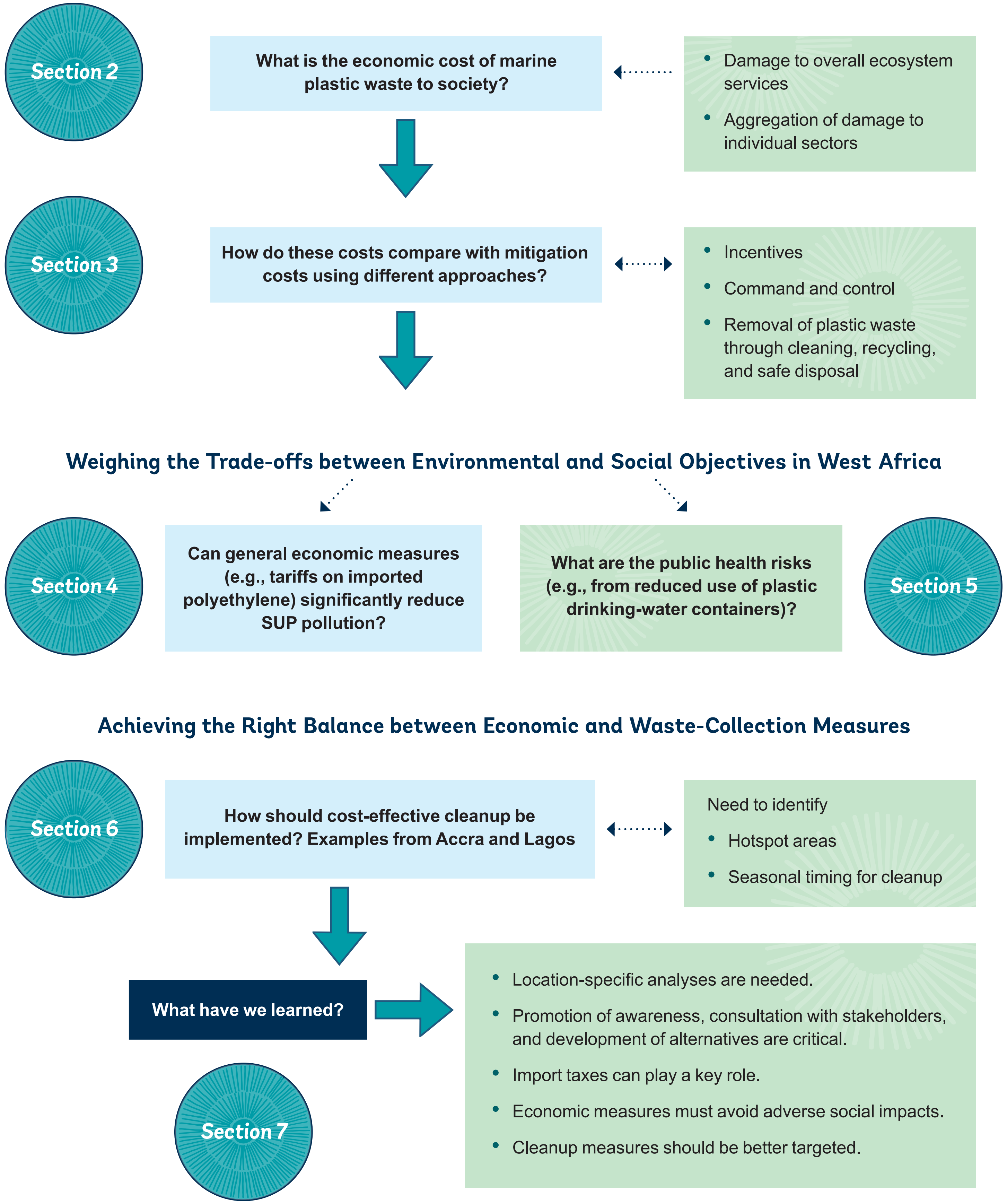
Figure 2. *Decision-making process for setting policies to reduce marine plastic pollution*



Section 2

What is the economic cost of marine plastic waste to society?

- Damage to overall ecosystem services
- Aggregation of damage to individual sectors

Section 3

How do these costs compare with mitigation costs using different approaches?

- Incentives
- Command and control
- Removal of plastic waste through cleaning, recycling, and safe disposal

Weighing the Trade-offs between Environmental and Social Objectives in West Africa

Section 4

Can general economic measures (e.g., tariffs on imported polyethylene) significantly reduce SUP pollution?

What are the public health risks (e.g., from reduced use of plastic drinking-water containers)?

Section 5

Achieving the Right Balance between Economic and Waste-Collection Measures

Section 6

How should cost-effective cleanup be implemented? Examples from Accra and Lagos

Need to identify

- Hotspot areas
- Seasonal timing for cleanup

What have we learned?

Section 7

- Location-specific analyses are needed.
- Promotion of awareness, consultation with stakeholders, and development of alternatives are critical.
- Import taxes can play a key role.
- Economic measures must avoid adverse social impacts.
- Cleanup measures should be better targeted.

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The analysis then turns to the material source of the plastics pollution problem in West Africa: imported thin polyethylene sheets (TPSes) used mainly to manufacture SUP sachets, bags, and other containers (Section 4).[12] The potential efficacy of import duties has been estimated, to reduce SUP by raising the TPS price. This estimation covered 10 countries for which relevant data could be accessed: Benin, Cameroon, Côte d'Ivoire, Gambia, Ghana, Guinea, Nigeria, Senegal, Sierra Leone, and Togo. The study found that such general economic measures would clearly have environmental benefits; however, conflicts with other social objectives may also arise. For example, because SUP containers are a major source of clean drinking water in West Africa, their reduced use would likely have adverse public-health outcomes for children from poor families—including increased sickness and death from waterborne diseases. The potential severity of this problem has been estimated from household surveys for Accra (Ghana) and Lagos (Nigeria), since these river systems have been identified as major sources of marine plastic pollution in the region (Section 5).[13]

Even if waste generation is significantly reduced through import duties on TPS, or quantity restrictions on polyethylene use, appropriately targeted cleanup programs will remain important. Because plastic-waste cleanup requires significant resources, guidance is required on cost-effective implementation. This study takes a location- and season-specific approach, using detailed information from household surveys, geographic and weather data, and measures of marine plastic pollution for Accra (Ghana) and Lagos (Nigeria) (Section 6). Based on its findings, the study offers decision makers lessons on achieving the most cost-effective policy solutions (Section 7). It is expected that this study's results will contribute to the development of evidence-based strategies for improved plastic-waste management and pollution prevention in the countries of interest.

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[12] In virtually all cases, SUP containers (plastic bottles, bags, and packaging) are fabricated from imported polyethylene with the exception of Nigeria, which has some domestic production; however, that country is also West Africa's largest importer of polyethylene.

[13] Lebreton et al. (2017) estimate annual plastic emissions from the Odaw River in Accra, and the river systems that discharge waste into Lagos Harbor, at 2.3 million kg and 6.1 million kg, respectively.

2.

The economic cost of marine plastic waste to society

Plastic products are popular because they are inexpensive, but their market price does not reflect their true environmental cost. As in other sectors, plastics production generates air and water pollution. But, unlike many other products, plastics persist in the environment and generate external costs for long periods before they disintegrate and are assimilated. Thus, the true cost of plastic equals its production cost, plus the costs of production externalities and post-use externalities.

The post-use environmental externalities of plastic are the focus of this analysis. Although its impact may differ according to product category,[14] plastics are treated as a generic product and average effects are considered. External costs are created in different environments, as plastics undergo life-cycle states after use. These include plastic litter accumulation near points of use, clogged drains, accumulation in landfills, contamination of inland water bodies (rivers and streams) (Van Emmerik and Schwarz 2019), and water transport to the marine environment. In this analysis, the focus of the post-use externality cost estimation is the marine environment, which provides a very conservative and lower-bound estimate of the true economic cost of plastics.

A survey of the literature finds that two broad approaches are currently used to estimate the external cost of plastics in the marine environment. The first approach estimates average cost across all marine dimensions, while the second estimates separate costs for the most critical dimensions and aggregates them to an estimated total cost.

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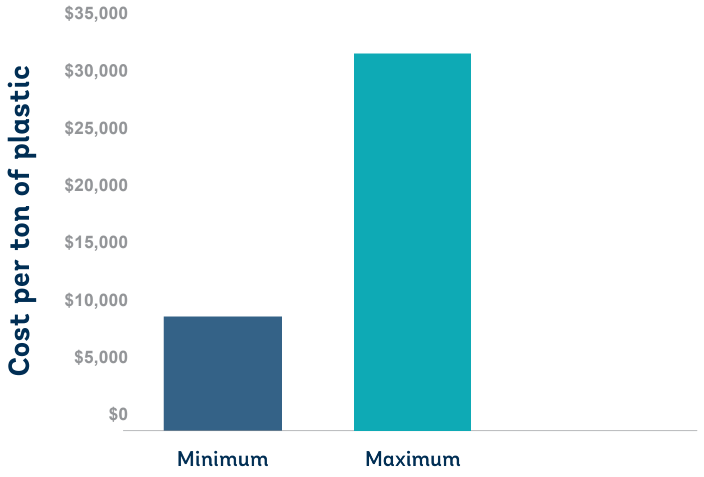
[14] See Plastic in the Ocean Statistics 2020–2021 (https://www.condorferries.co.uk/plastic-in-the-ocean-statistics).

Damage to overall marine ecosystem services

Several recent studies have estimated the cost of plastic litter in marine environments, as a reduction of social benefits from marine ecosystems that are treated as natural capital[15] (Buonocore et al. 2020).[16] On a global scale, a 2011 study estimated the annual social value of marine ecosystem services at approximately US$49.7 trillion (Costanza et al. 2014). A reduction of 1–5 percent in marine ecosystem service delivery, related to plastic litter, has been estimated by Beaumont et al. (2019). However, using a recent estimate of microplastics on the sea floor provided by Barrett et al. (2020), that is nearly twice an earlier estimate, a more realistic reduction in marine ecosystem service delivery would be 3–5 percent. Given the estimate of Costanza et al. (2014), this translates to an annual loss of US$1,500–$2,500 billion in social benefits.

Various studies have estimated the 2011 stock of plastics in the marine environment at 75–150 million tons (Conservancy 2015; Jang et al. 2015). Combining these numbers with the annual loss estimate, puts the annual cost in the range of US$10,000–$33,000 per ton of plastic.

Figure 3: *Damage cost estimates from plastics for marine ecosystem services*

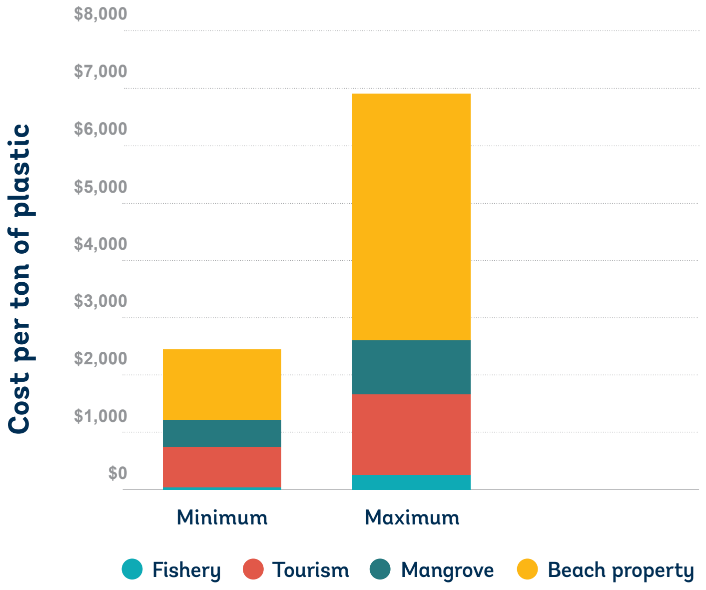


Aggregation of sector-specific costs

It is difficult to monetize the externality costs of plastic by sector. The largest direct effects of plastic waste may be the public-health impacts from consumption of microplastics in marine food products, but results to date are inconclusive. Nearly total absence of reliable secondary data on the quantitative impacts of microplastics prevented the inclusion of the externalities of microplastics in the analysis. Indirect health-cost factors include medical care for marine debris–related accidents or illnesses; water in waste plastic containers where mosquitos breed; air pollution from the incineration of plastic waste; mortality risks for households situated near garbage dumps, that are rendered unstable and prone to collapse due to plastic waste; and life-threatening floods from drainage channel blockage caused by plastic waste. Most of these indirect cost factors are location-specific, and therefore difficult to value in the global context. Although estimation of the health externalities of plastics is critical, a comprehensive estimation of these health effects on mortality and morbidity was not feasible because the "risk ratios" are not yet available in peer-reviewed literature.

However, losses are clearly visible in certain other sectors. The aggregate cost estimate for the four sectors highlighted below, ranges from more than US$2,000 to nearly US$7,000 per ton of plastic waste (Figure 4).[17]

Figure 4: *Damage cost estimates in four sectors due to the presence of plastic*



Fisheries and aquaculture

Plastic litter can impact fisheries by lowering fish yields, damaging fishing gear (for example, nets and boat propellers), and lowering the market prices of products that are considered contaminated by plastics and their associated chemicals. Among these, the price-reducing impact is the most difficult to evaluate.

Global fish output was US$159 billion in 2019, of which marine output was estimated at US$112 billion.[18] Various studies in different locations have estimated that the reduction in fish yield and damage to fishing gear caused by marine plastic litter costs the fishing industry 1–5 percent of output value. Based on these estimates, the annual cost of plastic litter for world fisheries is in a range of US$1.12–$5.6 billion. Using the estimated marine plastic stock of 75–150 million tons, this translates to an annual cost of US$56–$279 per ton of plastic litter. It should be noted that these estimates are conservative, because they do not include market-price reductions from perceived contamination.

Marine-linked tourism

Plastic pollution of beaches and offshore waters can significantly reduce beach tourist visits and revenue. In response, the Global Tourism Plastics Initiative has been formed to reduce pollution, by promoting the elimination of unnecessary plastic items and the development of reusable, recyclable, and/or compostable plastics.

Total leisure-tourism revenue in 2018 was US$840 billion, of which about US$280 billion was linked to marine tourism.[19] Various studies indicate that beach litter can lower tourism revenue by as much as 40 percent, depending on the extent of the littering involved (Jang et al. 2014). A conservative assumption of 5–10 percent loss in revenue from littering produces economic losses in the range of US$14–$28 billion per year. It is estimated that shorelines are littered by nearly 20 million tons of marine plastic annually, yielding an external tourism cost in the range US$695–$1,390 per ton of plastic.

Value of waterfront property

Studies on the impact of plastic pollution on property values are rare, but numerous studies find that real estate prices can be reduced by as much as 25 percent by nearby air or water pollution (Liu et al. 2018).[20] In light of these findings, it seems reasonable to assume a 10 percent reduction in the value of a beachfront property for each ton of plastic beach litter found around that location. Beachfront property values vary greatly by country and locale. In the United States, for example, median beach house values range between US$250,255 and $885,086 across a range of locations (2020 figures).[21] Assuming a 10 percent valuation loss for plastic beach litter, a 30-year use period, and a 3 percent interest rate, the annual loss range could be US$1.314–$4,647. Converting this loss at purchasing power parity for 37 large countries yields an average global annual loss in the range of US$1,207–$4,269.

Biodiversity and ecosystems

When plastic litter contaminates marine ecosystems, organisms can suffocate and die from its ingestion. In addition, plastic litter can reduce the growth rates of seagrass, coral, and mangroves. Information scarcity in this context hinders comprehensive valuation, but existing data is sufficient to permit external cost estimates for mangrove ecosystems.

Plastic litter damages mangrove stands, mainly by preventing germination and growth of their seedlings. One recent study found a negative correlation between the density of plastic debris in mangrove areas, and that of seedlings and trees, as well as the mean diameter and height of trees. Global studies indicate that each hectare of mangroves provides an average of 17 tons of woody material per year. Wood loss from plastic litter can vary between 10 and 50 percent, depending on litter density (Manullang 2020). With a conservatively estimated loss rate of 10–20 percent, the annual loss in woody material per hectare could range from 1.7–3.4 tons.

Losses can also be imputed from numerous studies that have ascribed value to mangroves as sources of timber and firewood, flood protection, prevention of shoreline erosion, carbon sequestration, water purification, fish spawning, and other biodiversity-related benefits. The estimates vary widely, with a median value of about US$1,200 per ha (Salem and Mercer 2012). Assuming 147,186 km^2 in global coastal mangrove coverage[22] and a range of 37.5–75 million tons of plastic litter trapped in neighboring shoreline, the yield is 2.5–5.1 tons of plastic litter per hectare of mangroves. The associated external cost could therefore reach US$473–US$946 per ton of plastic litter.

It should be noted that these two approaches to computing the total economic costs of marine plastics to society are not fully comparable. The first approach provides a holistic estimate of overall costs in the marine environment. In contrast, the second approach only includes a few sector-specific costs for which data is available, and the aggregation of these sector-specific costs only provide a partial estimate of the overall costs. Nevertheless, it is expected that these partial estimates will still prove useful for critical sector-level analysis. Estimates presented in this section are important elements of the social cost of plastics and will be useful for future location-specific cost-benefit analyses for public and private interventions for waste management.

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[15] Defined as the world's stocks of natural assets.

[16] Most of these studies are regional, and very few attempt a global-level evaluation.

[17] These widely varying sectoral and global estimates can provide benchmark-cost estimates for the 17 coastal countries of West Africa, and can be replaced by country-specific estimates where appropriate supporting data becomes available.

[18] Details are available at http://www.fao.org/fishery/statistics/global-production/en.

[19] See https://www.statista.com/topics/962/global-tourism/#:~:text=Globally%2C%20travel%20and%20tourism's%20direct,at%20580.7%20billion%20U.S.%20dollars.

[20] Also see https://courses.lsa.umich.edu/healthy-oceans/group-1/group-1-sub-1/plastic-pollution-and-its-economic-damage/.

[21] See https://www.vacasa.com/top-markets/2021-best-place-to-buy-a-beach-house.

[22] https://www.mangrovealliance.org/30-years-of-global-forest-data/#:~:text=%E2%80%9CMore%20than%2040%20percent%20of,and%202020%20(Table%2031).

3.

How the economic costs compare with those of the main approaches to pollution mitigation

The above section shows that even conservative methods yield significant external cost estimates for plastic waste in the marine environment, and action is clearly warranted in the majority of cases. A study of global experience reveals three main approaches to reducing plastic pollution, all of whose costs fall within the range of the estimated external costs for plastic waste. These approaches, which are described below, are not mutually exclusive. Rather, they can be tailored to a particular country's local economic and political conditions, so as to achieve the most cost-effective mix.

Incentives

Demand-side policy instruments can reduce plastic waste by adding external costs to the market prices of plastic products. One common practice is levying production excise taxes or import duties on raw materials, such as polyethylene. Another incentive-based approach taxes plastic products at the point of sale. Section 2 showed that the external cost of plastic waste in the global marine environment was in the range of US$10,000–$33,000 per ton. The tax or duty imposed on the production of plastic, or the extra price charged on its sale, should be commensurate with this level of external cost.

The case of SUP bags is analyzed for illustration. Since each kilogram of plastic yields, on average, 180 SUP bags, internalizing the external damage of US$10,000–$33,000 per ton of plastic would add US$0.06–0.18 to the price of each bag. Adding this to the average retail cost of US$0.03 per plastic bag would result in a final bag price of US$0.09–0.21.[23] Numerous studies have examined the impact of a higher price on demand for SUP bags. One study in Ireland revealed a use reduction of nearly 100 percent at a per-bag price of US$0.15 (Convery, McDonnell, and Ferreira 2007). A number of other studies found major reductions with charges of US$0.05 or more (Dikgang et al. 2012; Homonoff 2018). These findings suggest that internalizing all the costs associated with a plastic bag (its manufacturing costs and negative environmental externalities) would probably reduce its use to zero.

However, several caveats should be noted. Firstly, such economic incentive schemes can entail significant operating costs. If such schemes are carefully designed, experience shows that operating costs can be reduced to as low as 3 percent of revenues (Convery, McDonnell, and Ferreira 2007). Secondly, the convenience of many plastic products may perpetuate their use, even when charges are significant. This could be particularly true when consumers are unaware of the environmental-change component. Thirdly, price effects may erode over time as incomes change and preferences shift.

Command and control

A second approach for minimizing the external costs generated by specific plastic products is to ban their use, through direct regulations prohibiting their use and by imposing high enough penalties to enforce the ban. While successful bans will eliminate the cost of external waste for such products, they may also force consumers to forgo the associated conveniences or pay higher prices for biodegradable substitutes.

The production cost of biodegradable paper bags is US$0.04–0.05 per unit, compared to the US$0.01 manufacturing cost.[24] Using these values, replacing SUP bags with paper bags would involve an extra cost of US$0.05 per bag. Because each kilogram of plastic yields 180 plastic bags on average, this replacement would translate into an extra cost of US$9,000 per ton of plastic. Since this cost is less than the external damage cost of US$10,000–$33,000 per ton of plastic, using paper bags as an alternative to support the ban would enhance its social benefit.

The use of reusable bags instead of plastic bags also involves extra cost, as it is often inconvenient to carry and reuse bags. Also, reusable bags may pose health hazards.[25] Although the costs of inconvenience and health hazards are difficult to estimate directly, it is possible to obtain an indirect valuation of these costs from studies that have estimated the costs of plastic bans using willingness-to-pay (WTP) analyses of consumer surveys. These studies report WTP values in the range of US$0.03–0.08 for a plastic bag alternative, depending on the location and nature of the population surveyed (Convery, McDonnell, and Ferreira 2007). Based on these WTP values and converting to tons using average bags per ton in production yields, reusable bag costs appear to have a range of US$5,760–$14,220 per ton of plastic—which is lower than the external damage estimate (US$10,000–$33,000 per ton of plastic). Thus, in view of the high external damage caused by plastics, eliminating their use through legislative bans and switching to paper or reusable bags should enhance overall social welfare.

One should also note that plastic bans may face significant implementation difficulties. These include direct implementation costs, opposition from the plastics industry, job losses in that sector, and diversion of demand to untaxed parallel markets that can only be suppressed with high enforcement costs.

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[23] Manufacturing a plastic bag costs about US$0.01, and it retails for about US$0.03 at the consumer level.

[24] https://www.bmt.com/what-is-the-real-cost-of-paper-vs-plastic/

[25] For example, reusable grocery bags can transmit bacteria and viruses to other shoppers and store employees.

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Removal of plastic waste through cleaning, recycling, and safe disposal

In principle, both incentive-based and command-and-control approaches can significantly reduce the use of many plastic products; however, for some types of plastic products, complete elimination may not be a feasible option. Thus, the removal of specific plastic products before they enter the waste stream will be beneficial for protecting the marine environment. Plastic-waste removal includes collection for recycling from users, targeted removal of plastic litter from identified natural traps, and reuse or safe disposal. The costs at each step vary widely with the volume of plastic waste and its spatial dispersion. This approach is cost-effective, if its cost is less than the external cost of plastic waste.

Numerous cost studies for rivers and lakes have analyzed plastic bag and bottle waste, since this accounts for the bulk of plastic litter. They show that removal and recycling costs can range between US$0.01 and US$0.08 per unit of plastic product (Burnett 2013; Taylor and Villas-Boas 2016). Incorporating average product weight yields a cost range of US$1,920–$14,220 per ton of plastic for plastic bags, and one-third to one-half of those estimates for plastic bottles, which are heavier. With increased efficiency of removal and recycling operations, these costs should decrease over time. Since they are much less than the external damage estimate (US$10,000–$33,000 per ton of plastic), removal of plastic litter should also lead to enhanced social welfare.

4.

How general economic measures could significantly reduce plastic pollution

Marine pollution from plastics can be reduced significantly by reducing single-use plastic waste. As noted above, direct economic measures (taxation at points of production, or sale, or product bans) can be used to reduce marine pollution from SUP waste. However, targeted policies imply their targeted enforcement, which can be difficult to achieve when producers, sellers, and consumers are widely dispersed.[26]

In West African coastal countries, all SUP sachets, bags, and other containers are fabricated from thin polythene sheets (TPSes), virtually all of which are imported.[27] One appealing policy would directly target bulk imports of polyethylene, the essential feedstock for SUP containers, at relatively few ports of entry. Tariffs are already familiar in all West African coastal countries, and implementation could be limited to relatively few port areas and a small, more-easily-monitored cadre of agents. However, evaluating this policy option also requires understanding the expected response of imports of TPS to the imposition of tariffs. The responsiveness question could be addressed by analyzing polyethylene imports and their prices over time.

Figure 5 displays the TPS imports trend over the 1995-2019 period for 10 countries in the region.[28] Steady growth is evident, with substantial interim fluctuations. As shown, import prices for TPS have varied more than fourfold since 1996, and the growth of TPS imports has been accompanied by wide price fluctuations (Figure 6).

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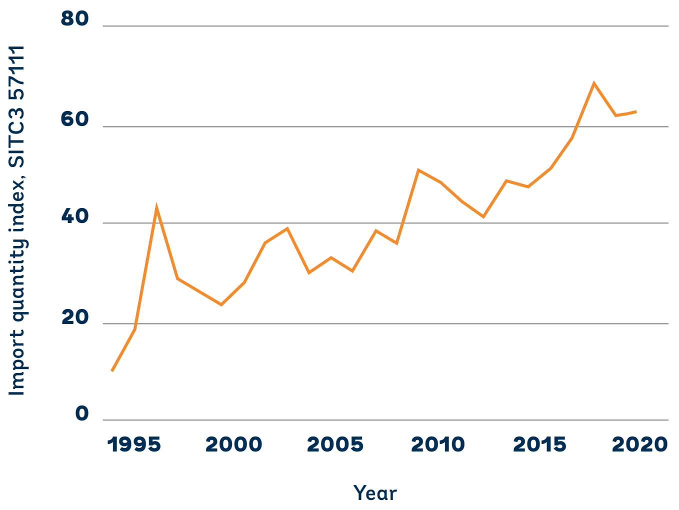
[26] Small-scale producers that are widely dispersed can command large output shares for products. If both sales outlets and consuming households are widely dispersed, targeted quantity or price policies will require a large cadre of low-wage agents – who are both disciplined and incorruptible. In practice, meeting such conditions has generally proven difficult.

[27] The UN Comtrade database, under code 57111, classifies TPS as "polyethylene sheets, with a specific gravity of less than 0.94."

[28] Since 1995, West Africa has sourced TPS mainly from four supplier regions ¬– the European Union (principally France and Belgium), East Asia (Republic of Korea and China), the United States, and the Middle East (Saudi Arabia and Qatar). Over time, the supplier shares of the European Union and East Asia have declined, while the shares of the United States and the Middle East have increased.

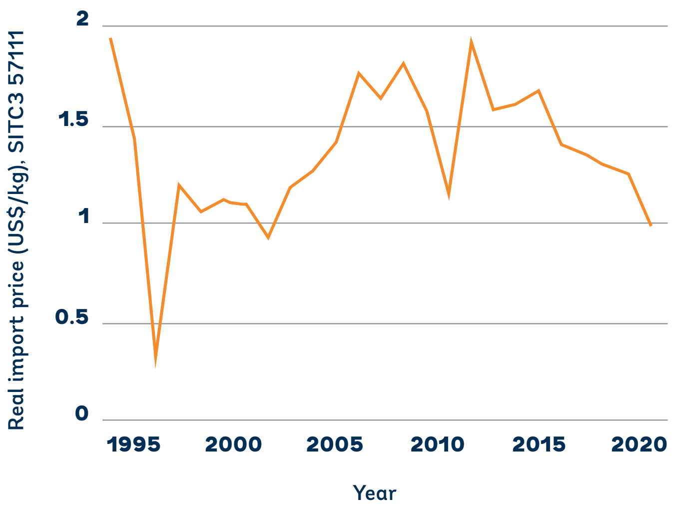
Figure 5. *TPS imports by 10 West African countries, 1995–2019*



Note: The 10 countries are Benin, Cameroon, Côte d'Ivoire, Gambia, Ghana, Guinea, Nigeria, Senegal, Sierra Leone, and Togo. The Comtrade database has no TPS import entries for Liberia.

Source: Comtrade.

Figure 6. *Imported TPS price for West Africa, 1995–2019*



Source: Comtrade.

This study performed an econometric analysis of TPS import demand for seven countries: Benin, Cameroon, Côte d'Ivoire, Ghana, Guinea, Nigeria, and Senegal (Appendix A).[29] The results indicate a high degree of income and price responsiveness: Each 1 percent increase in national income increases TPS imports by about 1 percent, and each 1 percent increase in TPS price reduces imports by about 1 percent. From a policy perspective, these results have two major implications. Firstly, because the real TPS price exhibits no trend over time, TPS imports and the waste generated by SUP containers should keep pace with national income growth without putting countermeasures in place (Table 2). For Ghana, the region's fastest-growing economy, this would mean nearly doubling the amount of SUP waste over the coming decade.

Second, the evidence shows that price increases on the world market have produced rapid, proportionate reductions in West African TPS import demand. Since producers are indifferent to the sources of price change, the same thing will be true for price increases from import duties. Thus, a TPS tariff could be a potent weapon in the struggle to reduce SUP pollution. However, a tariff may have a disproportionate impact on the poor, and policy makers should consider the distributional implications if they choose this option.

Table 2: *Real GDP growth in West Africa, 2005–19*

Country	Growth rate (%)
Ghana	6.5
Togo	5.2
Côte d'Ivoire	5.2
Senegal	4.5
Nigeria	4.4
Benin	4.3
Cameroon	4.2
Guinea	4.1
Gambia	2.8
Sierra Leone	-0.9

Source: World Development Indicators.

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[29] Data problems prevented the inclusion of Gambia, Liberia, Sierra Leone, and Togo.

5.

The public health risks: The case of plastic water containers in Ghana and Nigeria

Import duties and other measures to reduce plastic waste have clear environmental benefits, but decision-makers must also take other social objectives into consideration. For example, SUP containers (water sachets and bottles) are a major source of clean drinking water in West Africa. Thus, reducing the use of these containers may increase sickness and death from waterborne diseases. If so, public health may suffer significantly from the use of general price- or quantity-based instruments that limit plastic consumption and waste.

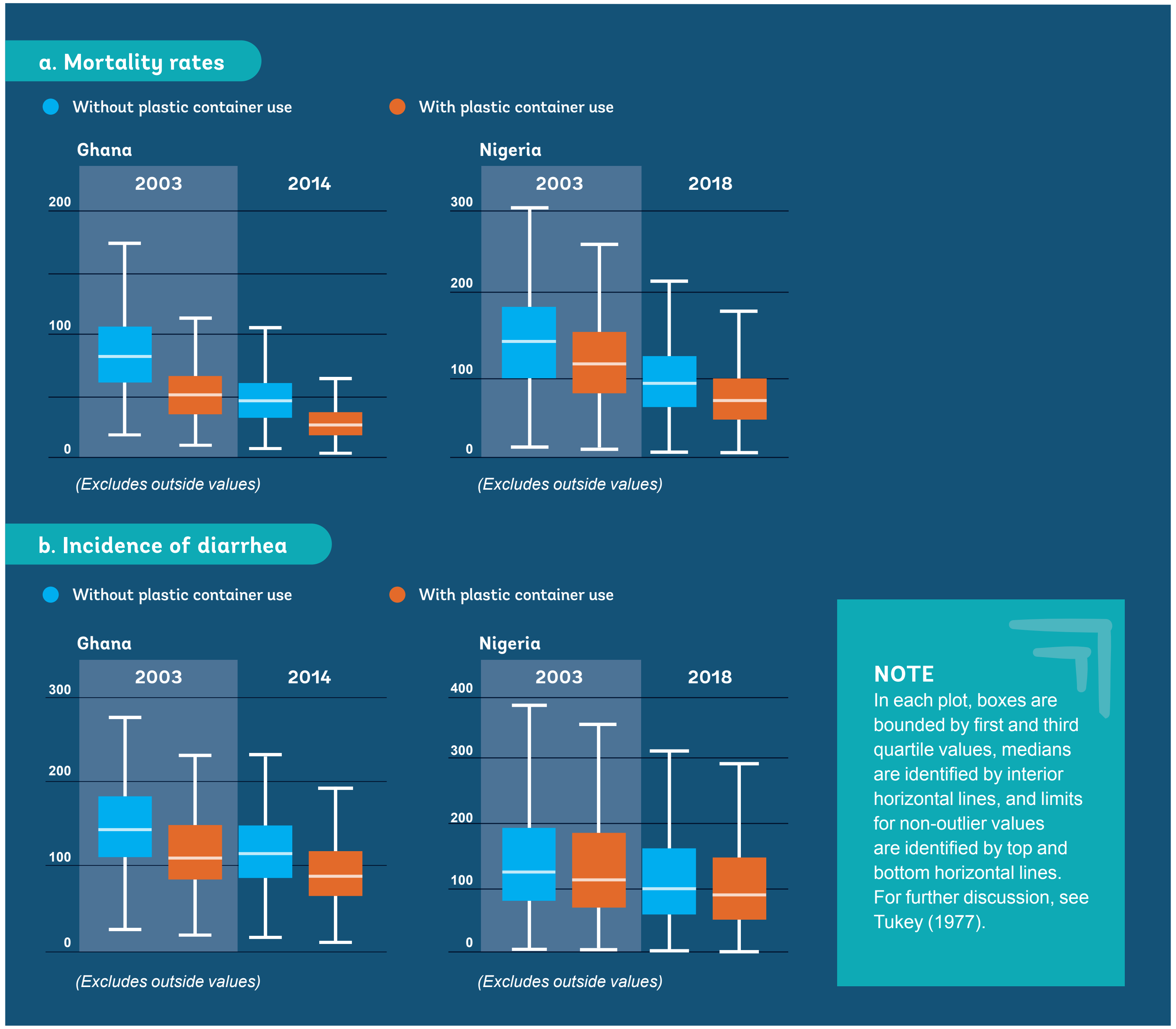
Since this is a potentially critical policy question, an econometric analysis was conducted in two countries – Ghana and Nigeria – to test the child-health impact of plastic container use. A database was constructed from demographic health surveys (DHSes) in Ghana (2003, 2008, 2014) and Nigeria (2003, 2008, 2013, 2018), which reported caretaker responses for 12,500 and 99,500 children, respectively. For each child, caretakers reported mortality status; recent incidence of diarrhea; gender; age in months (age at death for mortality); years of mother's education; real household income; and the primary source of their drinking water, including plastic drinking containers (sachets and/or bottles).

The econometric analysis tested whether child morbidity and mortality were lower in households that used plastic containers for drinking water, all else being equal. After controlling for income, education, and other socioeconomic factors, the analysis found significantly lower mortality rates and incidence of diarrhea for children in households that used plastic water containers (Appendix B). To explore the implications, the econometric results were used to predict mortality rates and diarrhea incidences for all children (0–5 years of age) in the sample, with and without use of plastic water containers.

Figure 7 and Table 3 summarize the strong effects revealed by the analysis.

The box plots in Figure 7 display the distributions of predicted child mortality (Figure 7a) and diarrhea (Figure 7b), scaled to rates per 1,000 children. The figures display similar patterns—that is, notable declines attributable to plastic water container use for comparable measures, both across and within years.

Figure 7: *Child health impacts of plastic water container use in two countries*



NOTE

In each plot, boxes are bounded by first and third quartile values, medians are identified by interior horizontal lines, and limits for non-outlier values are identified by top and bottom horizontal lines. For further discussion, see Tukey (1977).

Table 3: *Child-health impacts with and without plastic water container use in Ghana and Nigeria*

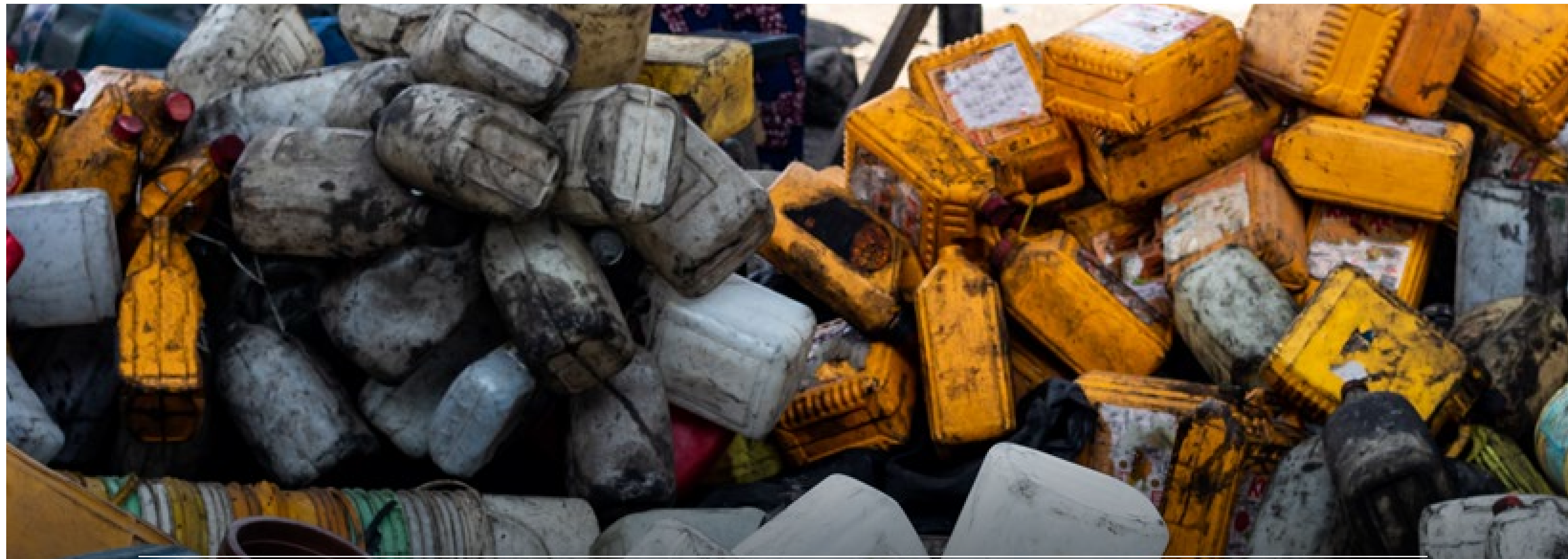
Country	Mortality rate (per 1,000)				Incidence of diarrhea (per 1,000)			
	With	Without	With	Without	With	Without	With	Without
	2003		2014		2003		2014	
Ghana	50	81	26	45	116	145	92	117
	2003		2018		2003		2018	
Nigeria	113	137	72	90	113	124	89	99

Source: Demographic and Health Surveys.

Table 3 summarizes the median values in Figure 7. The most recent results for Ghana (2014) show that with plastic water container use, the median predicted child mortality rate fell by 42 percent (from 45 to 26). The equivalent result for Nigeria in 2018 was a 20 percent decline (from 90 to 72). For the median predicted child incidence of diarrhea in the most recent years under analysis (2014 and 2018), the two countries' respective rates declined by 21 percent and 10 percent when households sourced drinking water from plastic containers. Clearly, these are not small effects.

The econometric results align with the widespread belief among West Africans that water in plastic containers is cleaner and safer, than water from other sources.[30] However, the benefits of cleaner water may be underestimated if the sample data includes contaminated containers. Some contamination has been revealed by sample-based analysis of water sachets in Accra (Kwakye-Nuako et al. 2007) and Lagos (Omolade and Gbadamosi 2017). The larger estimated benefits for Ghana, shown in Table 3, suggest that the issue of water contamination may be greater in Nigeria.

In summary, the message from these results seems clear and highly-relevant for formulating plastic-waste reduction policies in both Ghana and Nigeria: Analyses of large samples, drawn over extended periods from high-quality household surveys, provide strong evidence that use of plastic sachets and bottles for drinking water significantly reduces mortality and incidence of diarrhea among children—after controlling for the other determinants of child morbidity and mortality that are widely cited in the literature. Therefore, reducing the use of plastic drinking-water containers may significantly increase childhood illness and death.[31] This suggests that policy makers who opt for reducing SUP containers should also consider countervailing health policies, such as targeted measures to compensate for the potential impacts on child health—particularly in poorer households. In light of these results, assessing potential conflicts with public-health objectives, using DHS data from other countries, is clearly a domain for additional research.



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[30] These results do not indicate that plastic water containers are cleaner and safer in all cases. Actual quality in specific cases may be problematic, in the absence of consistent public testing and certification.

[31] Although these estimates may fully or partially reflect the influence of unobserved variables that are correlated with plastic container use, the results are cautionary, given the size of the estimated impacts on and stakes for public health.

6.

How to implement cost-effective cleanups: Examples from Accra and Lagos

Discussion in the previous sections shows that effective strategies for reducing plastic-waste pollution in the marine environment need to balance pollution prevention, with cost-effective cleanup measures. Scarce cleanup resources should target "hotspots"—that is, those areas with a particularly high incidence of plastic-waste disposal.[32] In the context of marine pollution, the most critical inland points are those near rivers that carry plastic waste to the ocean.[33] This section develops an illustrative cleanup strategy for marine plastic pollution in Accra and Lagos. The focus, in this case, is plastic drinking-water containers, since the previous section shows that bans or severe use restrictions may be inadvisable because of their potentially adverse public-health effects. The results suggest that targeted policies may have a temporal, as well as a spatial, component.

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[32] At the outset, it will be noted that modeling leakages and quantification of location-specific environmental impacts (soil, groundwater etc.) were not possible as high-resolution geocoded data required for such analyses are not yet available in the countries of interest.

[33] Estimates indicate that approximately 80 percent of the world's ocean plastics enter the ocean via rivers and coastlines (Li, Tse, and Fok 2016).

Incorporating plastic disposal hotspots

Knowing with precision where plaster litter accumulates is critical for cost-effective cleanups. In the absence of geocoded data by type of litter, this study estimated location-specific waste accumulation by combining population maps with three components of the relationship between income and plastic container use: (i) the effect of overall income growth on demand; (ii) the diffusion of demand for plastic sachets, which entered the market in the late 1990s;[34] and (iii) the spatial distribution of plastic-container use, which reflects the spatial distribution of household income.

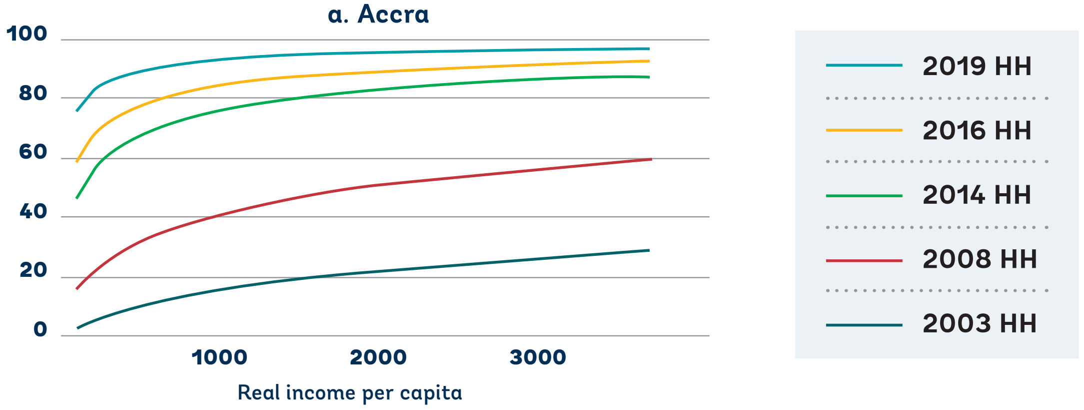
Household income and population data

Real income per capita since 2000 has approximately doubled in Ghana and Nigeria. Since plastic containers are normal goods,[35] one would expect income growth to have increased the demand for plastic-water containers – all else being equal. This analysis of the Accra and Lagos metropolitan areas, during the 2003–19 period, used household survey data on plastic container use and household economic status from multiple rounds of demographic health surveys (DHSes) and malaria indicator surveys (MISes).[36] The findings indicate that household income has a large effect on plastic-container use in both areas. In addition, a highly significant time trend in both cities indicates that plastic container use has spread rapidly across income groups over time.

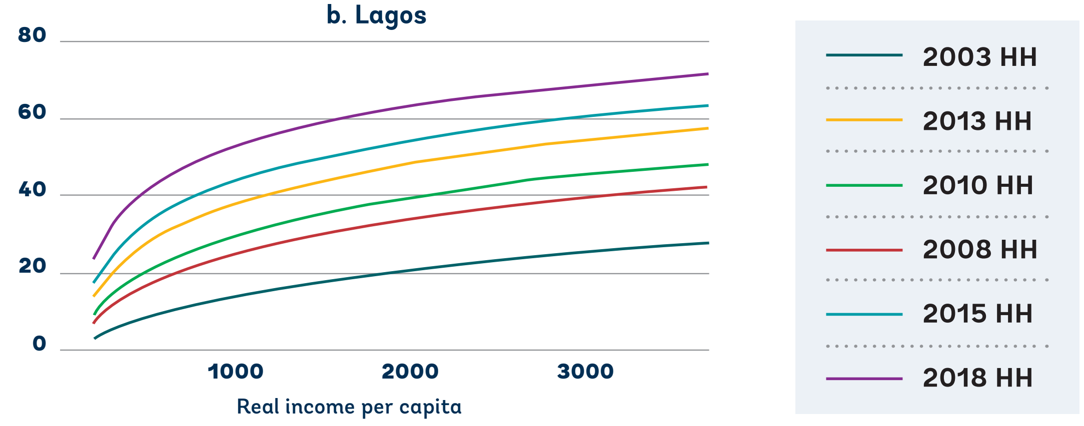
Figure 8 illustrates the implications of results from the econometric analysis (Appendix C). In both Accra and Lagos, the intensity of plastic container use over the 2003–19 period exhibited major increases. In Accra, use by the poorest households increased from less than 10 percent to nearly 80 percent, with use by the richest households increasing from about 30 percent to nearly 100 percent (Figure 8a). Diffusion to the poorest households was less pronounced in Lagos than in Accra; even so, incidence of use among the richest households increased from less than 30 percent to about 70 percent (Figure 8b). The econometric results thus highlight the importance of residential income data, to identify areas with a higher incidence of plastic-container use and disposal in Accra and Lagos. If households are strongly clustered by income, then plastic-waste hotspots will occur in higher-income areas.

Figure 8. *Incidence of plastic container use, by household income per capita, 2003–19*

a. Accra



b. Lagos



Source: DHS and MIS surveys.

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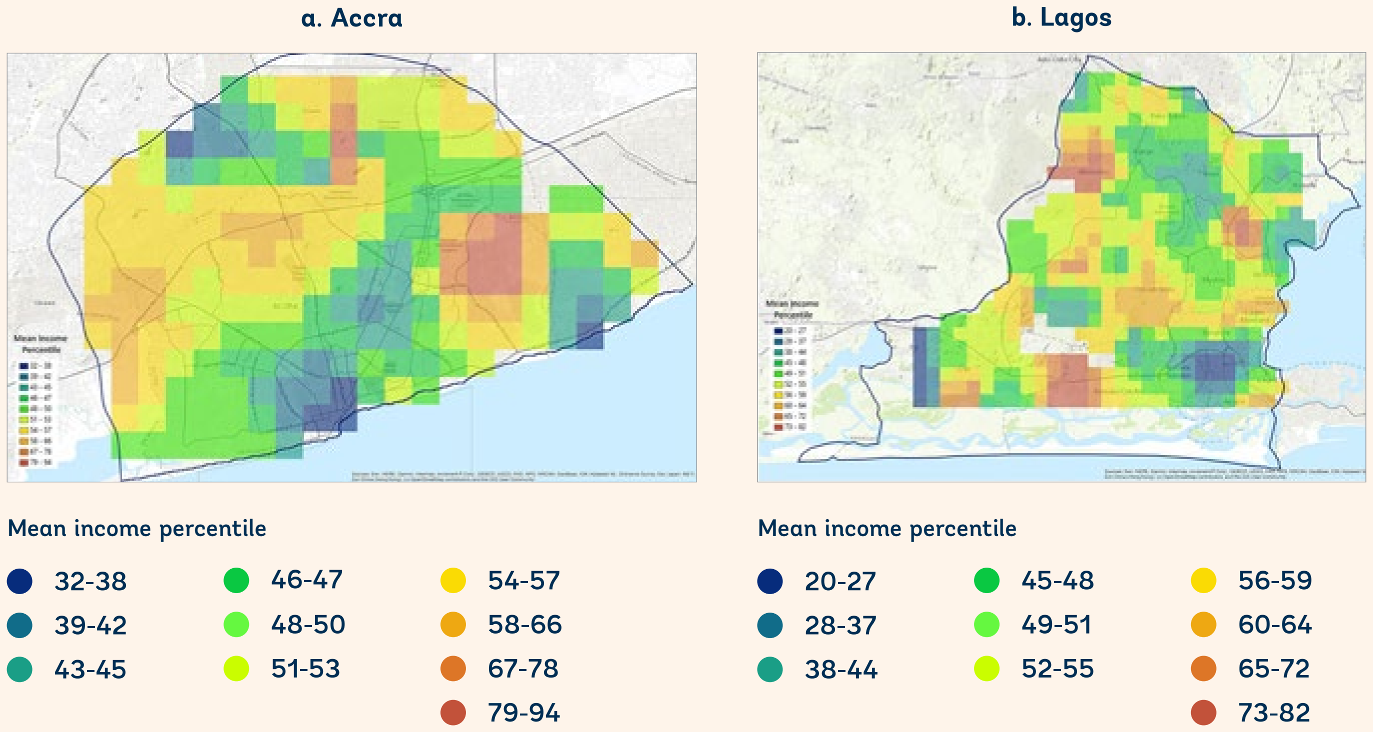
[34] Sachets account for the bulk of plastic drinking-water containers used in Ghana and Nigeria. Sachets first appeared on the market in the late 1990s, when entrepreneurs in West African cities began using new Chinese machinery that heat-sealed water in plastic sleeves (Stoler *et al.* 2012).

[35] Normal goods are those for which demand rises with an increase in consumer income.

[36] This analysis is based on five surveys conducted in Accra (DHS 2003, 2008, 2014; MIS 2016, 2019) and six surveys conducted in Lagos (DHS 2003, 2008, 2013, 2018; MIS 2010, 2015).

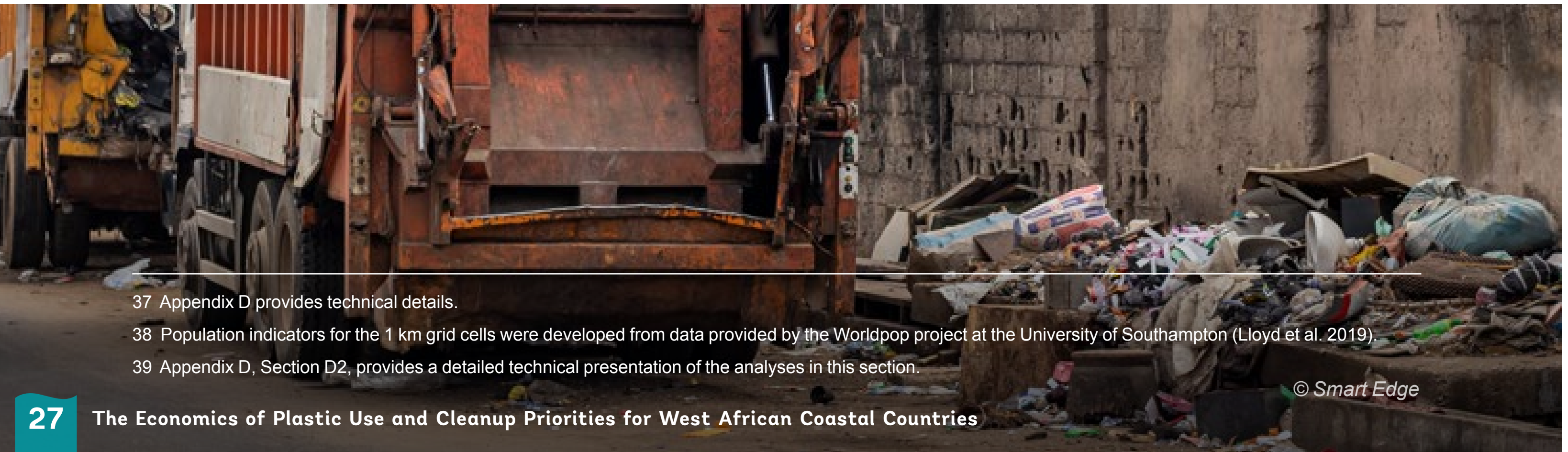
Residential clustering in Accra and Lagos was tested by dividing the metropolitan areas into square cells, that each measure 1 km on their sides. Household survey data from the past two decades were then used to compute mean income percentiles for each cell. Figure 9 shows that cell percentiles vary from 32 to 94 in Accra, and from 20 to 82 in Lagos; clusters of high-income (brown) areas and low-income (blue) areas are clearly visible on the maps (Figures 9a and 9b). For both cities, residential clustering by income has remained roughly stable over a long period.[37]

Figure 9: *Maps showing residential income clustering*



Disposal trends

Identification of hotspots also require information on the number of households and the population figures involved, as total waste load depends on total use. Figure 10 combines income and population data into estimates of plastic container use and disposal trends over the 2003–19 period.[38] Areas with the least and greatest disposal are shown in blue and brown, respectively. Three clear patterns are evident from the maps. The first one reflects the previously mentioned dominance of changes in plastic-use intensity over time. Starting with uniformly low use in 2003, the maps display the rapid onset of widespread plastic-container use after 2010. The second pattern shows the spatial variation in population density, which is reflected in the spatial gradations of plastic use. The third pattern relates to population clustering by income, which differs markedly between the two cities. In Accra, the overall pattern is roughly concentric, with aggregate plastic use declining from the area of highest population density (Figure 10a). A small exception is posed by a separate northeast cluster. By contrast, the pattern in Lagos is polycentric – with three visible clusters that exhibit increasing density on a roughly north-south axis (Figure 10b).[39]



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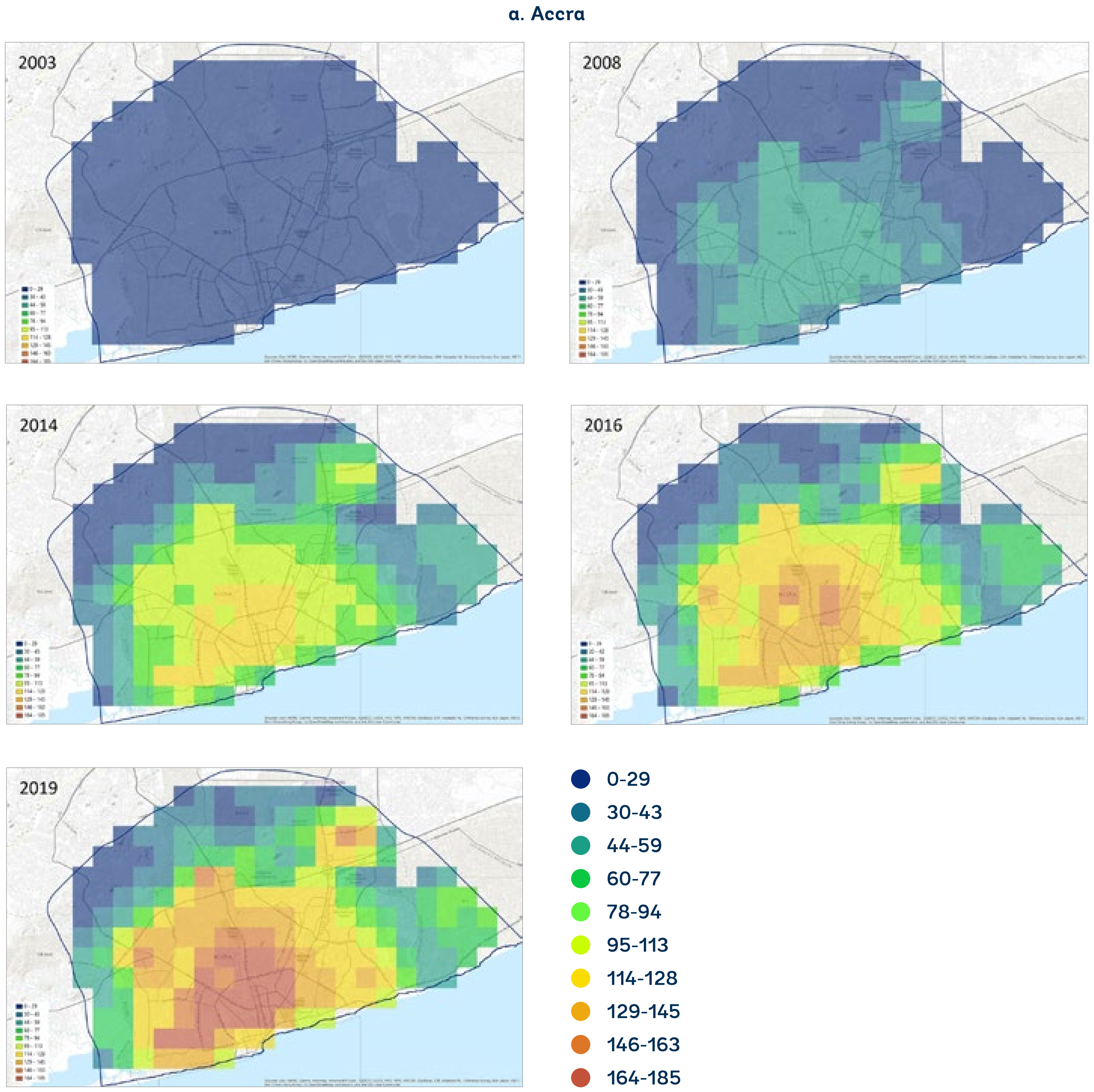
[37] Appendix D provides technical details.

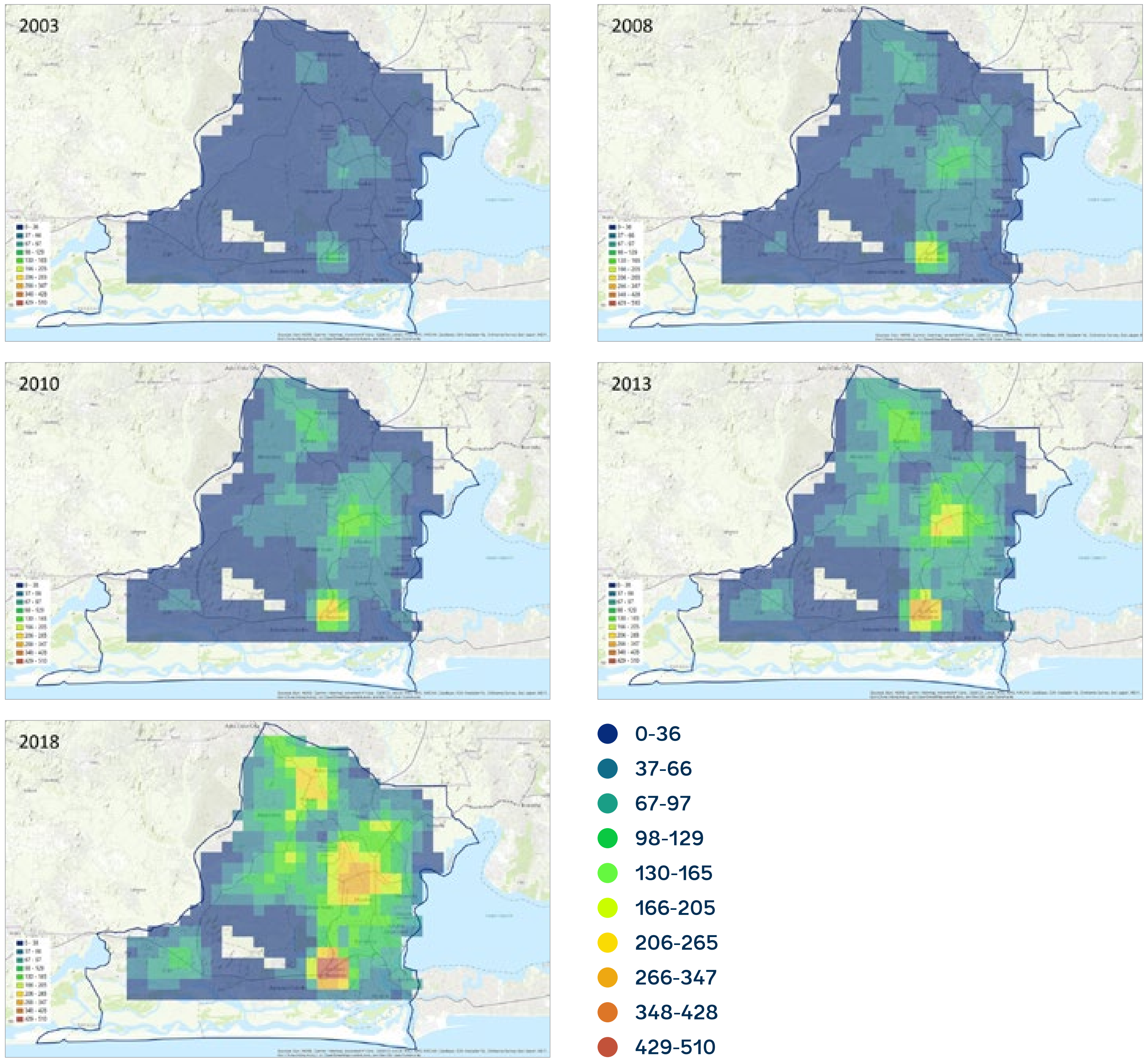
[38] Population indicators for the 1 km grid cells were developed from data provided by the Worldpop project at the University of Southampton (Lloyd et al. 2019).

[39] Appendix D, Section D2, provides a detailed technical presentation of the analyses in this section.

Figure 10: *Maps showing plastic-water container use and disposal over time*



b. Lagos



Incorporating rivers as conduits of plastic waste

The analysis presented above finds strong evidence, in both Accra and Lagos, of the spatial clustering of plastic waste. Local environmental impacts are undoubtedly significant, and a comprehensive treatment of plastic-waste deposition should consider targeted measures to address this problem. However, reducing marine-plastic pollution requires greater geographic focus. Unless plastic waste is deposited within the tideline, it cannot pollute the ocean without conduits. The main ones are rivers into which plastic waste has been directly dumped – either transported downhill by rainfall runoff, or picked up by seasonal floods (Lebreton et al. 2017).

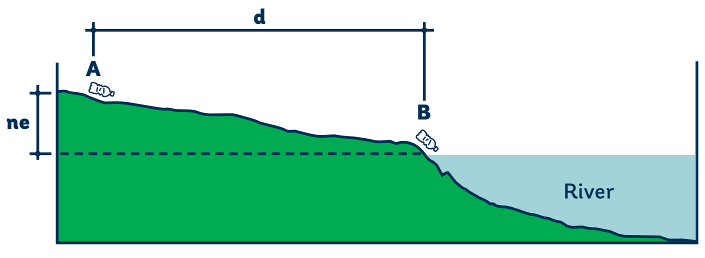
Figure 11 displays the river systems in Accra and Lagos. As shown, Accra is dominated by the Odaw system, whose basin roughly bisects the metropolitan area along a north-south axis (Figure 11a). In Lagos, the rivers are more scattered, with the Owo system in the west, the Ogun system in the northeast (which empties into the Lagos Lagoon), and numerous waterways in the south, including Badagry Creek, Ajegunle Canal, and Lagos Harbor (Figure 11b).

Figure 11: *Maps of river systems in Accra and Lagos*


a. Accra **b. Lagos**

Numerous researchers have attempted to measure the transport of plastic waste by river (Schmidt et al. 2017; van Calcar and van Emmerik 2019; van Emmerik and Schwarz 2019; Windsor et al. 2019). For this study, their analyses have been extended to a simple geophysical model for identifying spatial clusters whose plastic-waste generation has particular importance for ocean pollution. The model incorporates three sources of plastic transport by rivers: (i) direct dumping by riverside households; (ii) downhill transport by rainfall runoff; and (iii) transport by floods. In the vicinity of a river, the probability that a plastic container discarded at point A will enter the river is modeled using three variables: (i) the elevation of point A; (ii) the elevation of river point B closest to point; and (iii) the distance from point A to point B. The model's operation can be illustrated by imagining the impact of torrential rain, and its runoff, on a plastic container where it is discarded (point A). The likelihood that runoff will transport the container to the river depends, in part, on the gradient from point A to the river—which can be approximated by the difference in elevation of points A and B ("net elevation" of point A).

Figure 12: *River transport of plastic waste*



A = Point inland where plastic waste is discarded
B = River point nearest to point A
ne = Net elevation
d = Distance between points A and B

The steeper the gradient (or the greater the net elevation of point A), the more likely that the waste discarded at point A will be transported to the river during the runoff period.[40] But this effect will be attenuated by the distance from point A to the river (Figure 12).

To summarize, the likelihood of river deposition of waste discarded at point A increases with the net elevation of point A, and decreases with the distance between points A and B. What applies at a distance also applies for points near a river: The transport likelihood is greatest at locations on the riverbanks, where net elevation and distance are both zero. Points along the river's floodplain also have high likelihood during periods of heavy rainfall, since both their net elevation and distance are low. The likelihood of transport declines as distance increases, but may be relatively high if areas with a high net elevation are not too distant.[41]

At all grid cells in Accra and Lagos, the model incorporates the effects of distances from the closest river points, as well as their net elevations to display the relative likelihood that a plastic container dumped in the cell will be transported by a river. The results are presented in Figure 13 (page 31), which identifies rivers by white lines; least-likely areas for riverine waste transport in dark blue; and most-likely areas in dark brown. The spatial patterns for the two cities differ markedly, owing to their unique topographies and river systems. In Accra, the likelihood of plastic-container transport declines continuously with distance from the Odaw River and its tributaries, with modifications for areas where higher elevation has greater runoff during rain and flooding. In Lagos, areas of high transport likelihood are defined by three riverine areas, while a large swath of interior territory has a low likelihood of waste transport.

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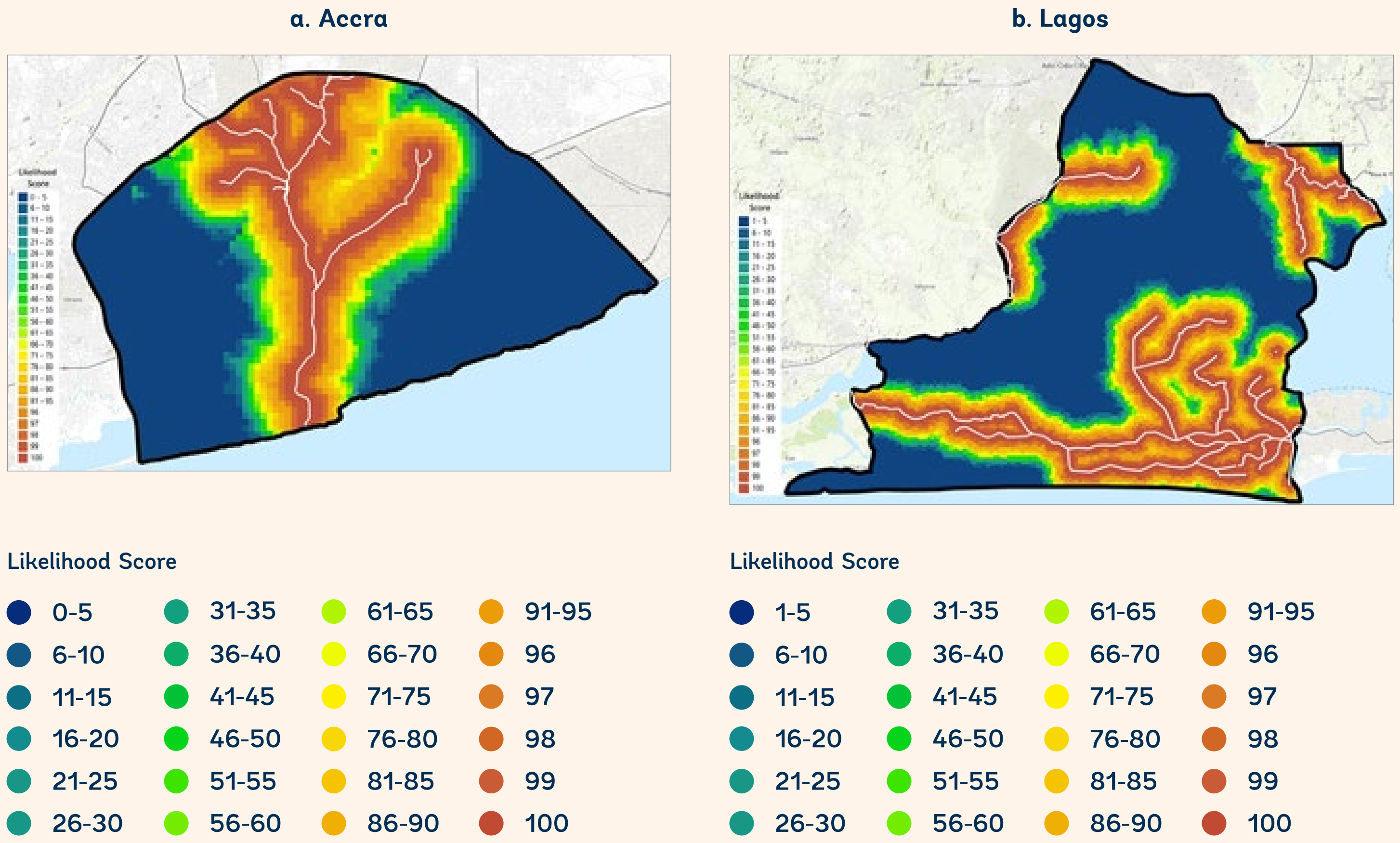
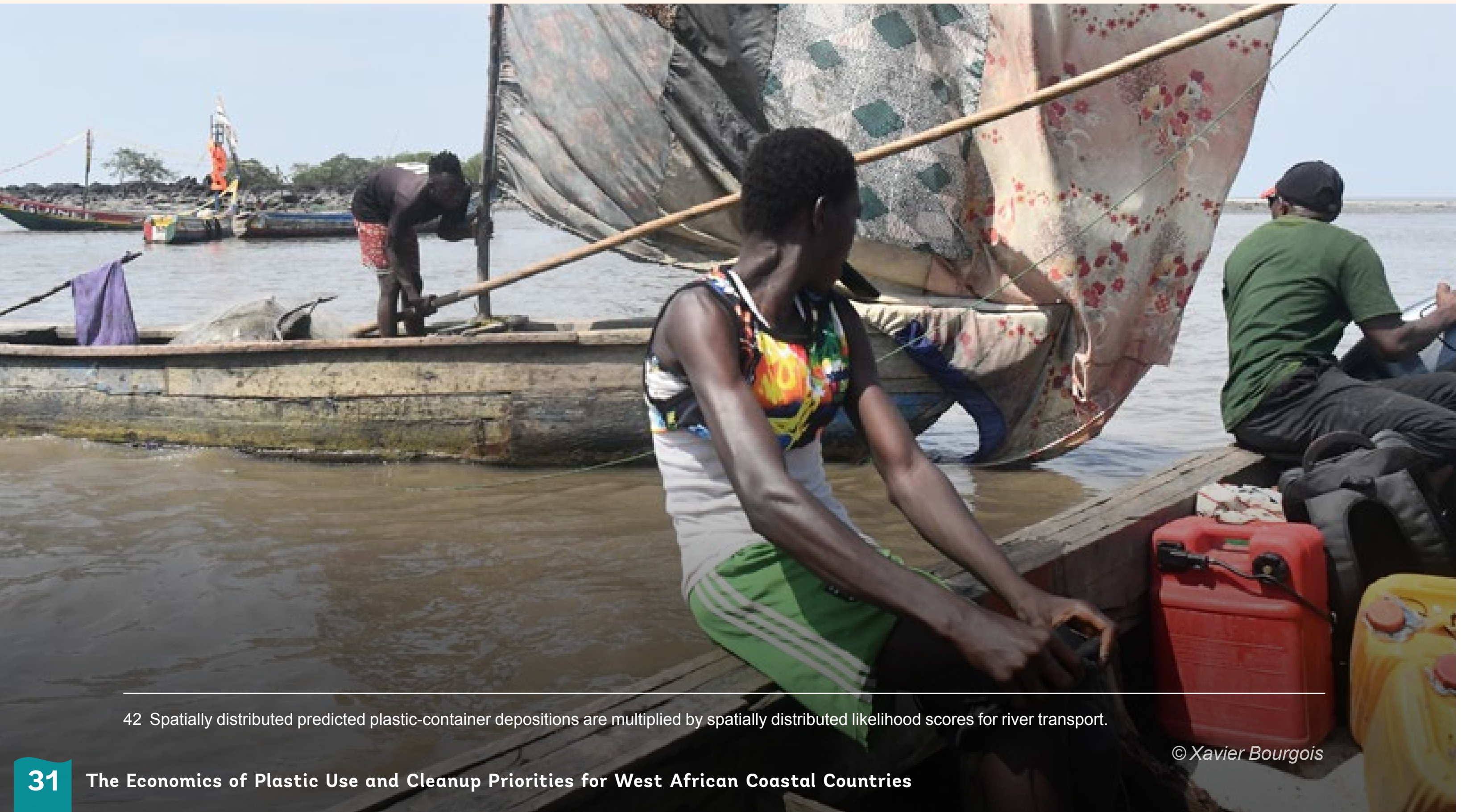
[40] Appendix E provides maps of "net elevations" (elevation of each point minus elevation of nearest river points) for Accra and Lagos.

[41] The role of terrain in plastic-waste discharge to rivers has been little explored by empirical research. Full empirical analyses would be challenging, given the need to geolocate the initial positions – and subsequent locations – of a large sample of waste plastic items over an extended period.

Figure 13: *Maps showing the likelihood of plastic waste being transported by river*





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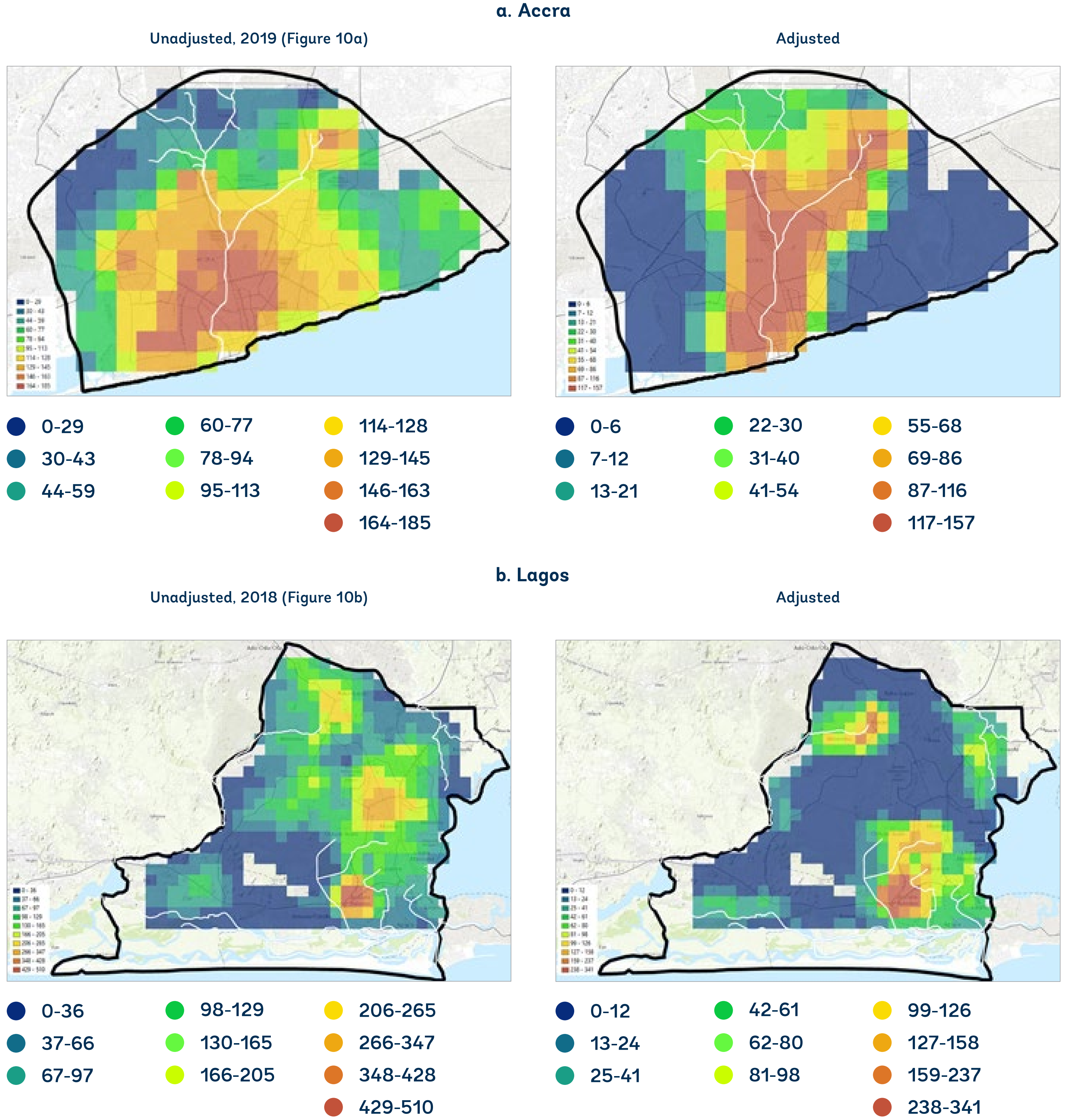
Combining hotspot data with the likelihood of river transport

Figure 14 combines the information on plastic-waste hotspots (subsection 6.1), and the likelihood of river transport (subsection 6.2), to produce marine plastic-pollution hotspots for Accra and Lagos.[42] In Figures 14a and b, the unadjusted maps on the left-hand side show predicted plastic-container waste generation (previously shown in Figures 10a and b, respectively). The maps on the right-hand side, adjust the left-hand side maps, for the likelihood that plastic-waste containers will be transported by river to the ocean. In each case, the incorporation of river transport creates a marine pollution hotspot map, which differs significantly from the general (unadjusted) hotspot map.

Figure 14. *Plastic hotspots, with and without adjustment for rive-transport likelihood*



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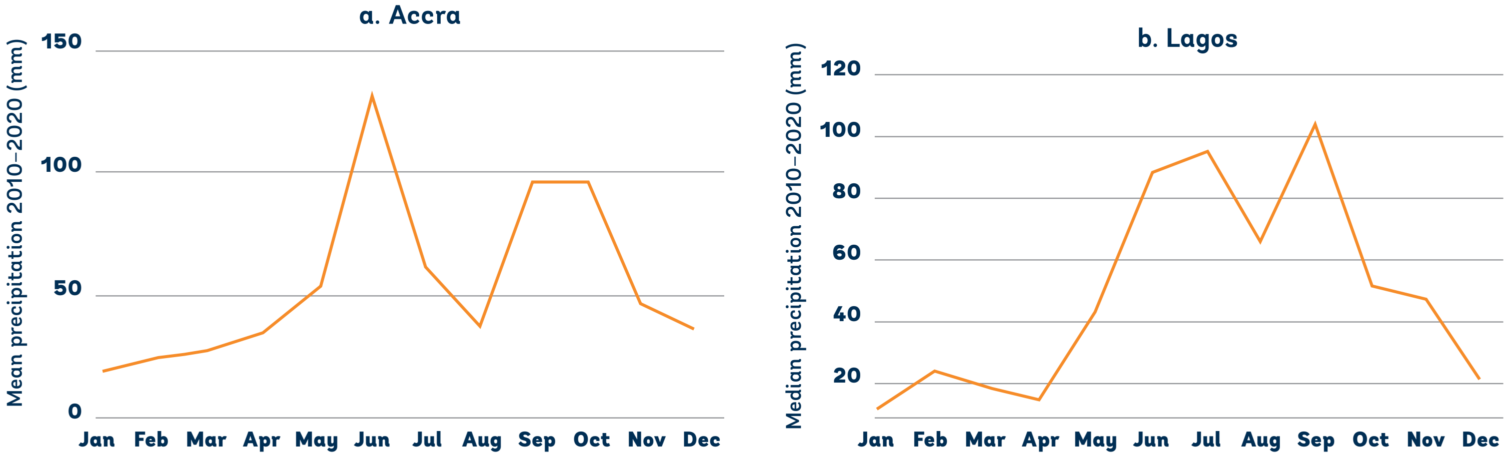
[42] Spatially distributed predicted plastic-container depositions are multiplied by spatially distributed likelihood scores for river transport.

Incorporating seasonal rainfall cycles

The river-transport model used in this study follows the recent literature in assigning an important role to rainfall, as a source of both flooding and runoff (Lebreton et al. 2017). Plastic waste disposal occurs at a steady rate, which is determined by daily or weekly plastic container use. Runoff from rainfall transports plastic container waste to rivers at some rate, even during months when the average rainfall is low. But plastic waste will tend to accumulate in the dry months if the dry-season rate of transport is below the rate of plastic waste accumulation, until the next rainy season increases transport to the nearby rivers once again. Understanding the temporal dynamics of waste transport requires an understanding of rainfall patterns, together with actual evidence of ocean pollution.

Figure 15 displays monthly rainfall patterns for the two cities. In Accra, rainfall increases from January to an annual peak in June; declines through August; increases to a lower peak in September/October; and declines during the course of December (Figure 15a). Lagos's pattern is more compact, with an increase from January to July; a decline in August; an increase to another peak in September; followed by a decline during the course of December (Figure 15b).[43]

Figure 15. *Median monthly rainfall, 2010–20*



Assessing the relationship between seasonal rainfall cycles, and the timing of riverine deposition and transport of plastic waste, requires a model of their interaction. As no such systematic study of this relationship is available in the literature, actual evidence of ocean plastic pollution in coastal waters was analyzed using satellite images. Relevant spectral images, from the European Space Agency's Sentinel-2 satellite platform, were downloaded for the period December 2019 to November 2020. Sufficiently clear images for the ocean area immediately abutting the mouth of the Odaw River were available for the Accra analysis (Figure 16), but images for Lagos were unfortunately too cloudy to perform a comparable analysis.[44]

Figure 16: *Plastic pollution measurement area for Accra*

These Accra satellite images were used to compute a floating-debris index adjusted for plastic content from the methodology of Biermann et al. (2020) (Figure 17a), and a plastics index based on the methodology of Themistocleous et al. (2020) (Figure 17b). The plotting results paint a picture quite similar to the seasonal plastic pollution cycle in the coastal waters abutting the Odaw River: a rapid increase from December to a peak early in the first-quarter rainy season, followed by a steady decline in mid-to-late summer and consistently higher levels in November.[45]

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[43] Considerable uncertainty surrounds measurement of rainfall in Accra and Lagos in any given year, because daily reports from the relevant ground stations are relatively sparse. Records for Accra could be accessed on average for 72 reporting days per year, and for Lagos for 44 reporting days, which was clearly insufficient for tracking daily or monthly precipitation in any given year. For this study, monthly median precipitation is therefore computed from World Weather Online daily data downloads.This data takes the form of recordings of daily forecasts, not actual observations, but aggregation over the ten-year period 2010-2020 provides at least an approximation to the annual pattern.

[44] Clear imagery for Accra includes two images for December 2019 and January, February, March, August and November 2020, together with three images for April 2020 and one image for May.

[45] Both the indices mentioned are based on new methodologies that have not been extensively tested, beyond their original applications in other regions.


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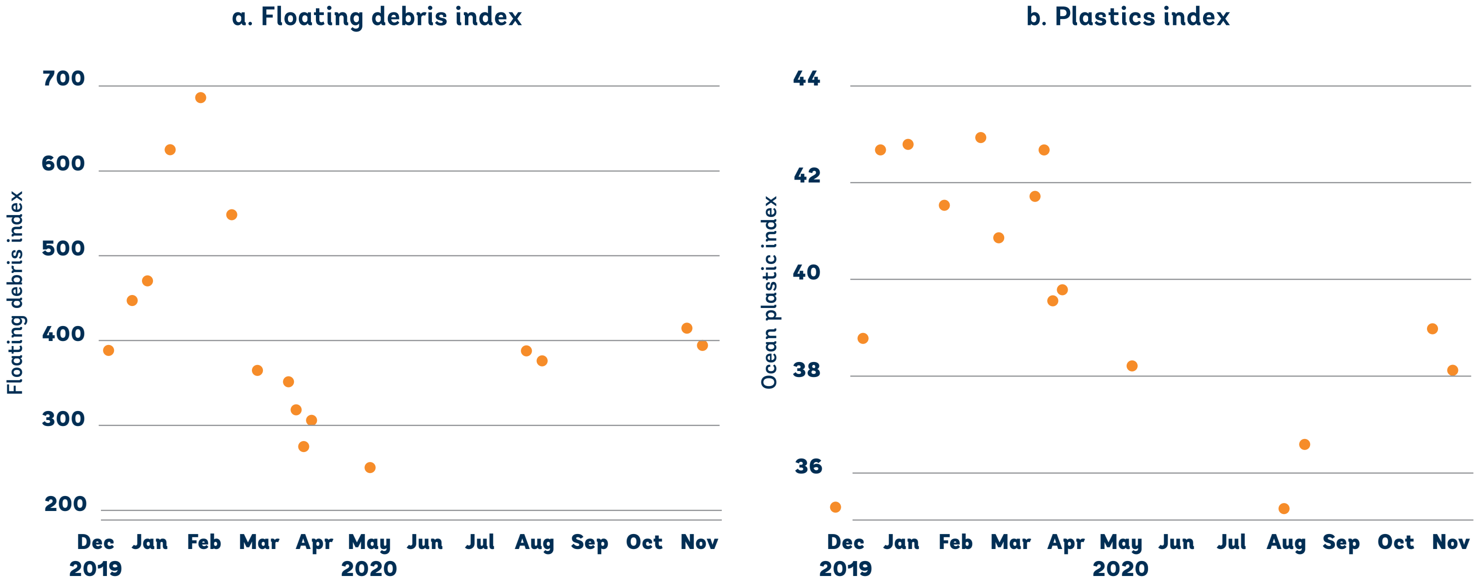
Figure 17: *Monthly plotting results for the Accra offshore area*



Source: European Space Agency.

These results provide clear evidence of the accumulation of plastic-container waste in hotspots during low-rainfall periods, followed by rapid river transport by means of flooding and runoff with the return of heavier rainfalls. The potentially important policy implication is that cleanup resources should be concentrated in marine plastic hotspot areas, before the first-quarter rainy season begins.

7.

What we have learned

Researchers estimate that 8.3 billion tons of plastic has been produced since the 1950s, with roughly 60 percent ending up in landfills or the natural environment.[46] In 2015, global production of mismanaged plastic waste totaled 60–99 million tons, and a business-as-usual scenario increases this range to 155–265 million tons annually by 2060. Without waste-management improvement, plastic waste in the oceans is predicted to increase by an order of magnitude. Mismanaged plastic waste unfortunately accumulates and persists in the oceans, with adverse consequences for marine ecosystems and potential damage to human health. The stakes for coastal countries are also high, because marine plastic litter adversely affects fisheries and aquaculture, biodiversity, coastal ecosystems, tourism, and waterfront property values.

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[46] It is estimated that approximately 80 percent of marine-plastic debris results from land-based sources (Lebreton *et al.* 2017).

More local case studies on sector-specific losses from plastic wastes are needed in West African countries.

Although it is difficult to monetize the adverse coastal impacts of marine plastic litter, the global studies cited in Section 2 indicate that even conservative estimates of externality costs are high. At the same time, global cost estimates vary widely by location. At present, West African coastal countries do not have sufficient data for the estimation of country-specific and/or sector-specific costs; and more local case studies are needed for the computation of sector-specific losses resulting from plastic waste. Better data on waste plastic externalities can play a key role in assessing the benefits and costs of policy options for plastic waste remediation.

Location-specific analyses are needed to determine the most cost-effective policy mix for plastic-waste remediation in each focus country.

West African coastal countries require urgent intervention, because mismanaged plastic waste in the marine environment will continue to increase at alarmingly high rates (Lebreton and Andrady 2019). However, there is no one-size-fits-all solution. Currently, 12 of the 26 member countries in the Economic Community of West African States (ECOWAS) have some type of SUP policy. Of those, 11 have weakly enforced plastic bans, while one (Ghana) has a price-based strategy based on excise taxes (Adam et al. 2020). As options for plastic waste management improve, the most practical policy solutions will likely entail some combination of quantity- and price-based approaches balanced with cleanup strategies, as discussed in Section 3.

Determining the most cost-effective policy mix for each country should involve a degree of location-specific analyses. In addition, practical problems, such as pressure from stakeholders and political viability, will likely be major considerations. At present, the countries of interest lack sufficient data for estimating country-specific costs – which suggests the need for more local case studies to compute sector-specific damages and losses from plastic waste. Better data on the externalities of plastic waste could also play a key role in assessing the benefits and costs of remediation policy options.

Awareness raising initiatives, stakeholder participation in policy and strategy design, and access to environmentally friendly alternatives are key to effective waste management.

Global experience indicates that both bans, and price-based strategies, can be effective methods to reduce plastic waste. However, effective waste management also requires broad-based awareness about plastic pollution and stakeholder engagement when designing mitigation policies and strategies. Regular public consultations can also help to promote awareness and create the necessary political will. Experience shows that people are more likely to accept a ban or price-based strategy if they have access to suitable, environmentally friendly alternatives that are reasonably priced. The development and promotion of alternative or reusable products require planning well in advance of implementing plastic-reduction policies. The jobs created in the alternative sectors can also mitigate the opposition that may arise from the potential loss of employment in the plastics industry.[47] Taking the extra time for advance planning and publicity can help both the plastics industry, and the general public, to adjust to a scenario with lower plastic usage. West African countries can improve their waste-management performance by learning from successful global experiences.

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[47] In practice, enforcement of plastic-use reduction policies can be difficult because the plastics industry employs thousands of people – serving as a livelihood for many families and a significant source of government revenue (Behuria 2019; Death 2016; Jambeck et al. 2018). For example, the government of Côte d'Ivoire revoked its plastic ban in 2013 because of threats and demonstrations by the plastics manufacturers' association and employees, who were provoked by the potential revenue loss of over 7,600 jobs.

Import taxes on polyethylene sheets can play a key role in reducing single-use plastic waste, but understanding the distributional implications for the poor is critical.

Taxation of the imported polyethylene, which comprises most of the production feedstock for SUP in West Africa, is a potentially effective, price-based policy option with relatively low administrative costs. Ghana's waste-reduction strategy, which employs taxation of imported plastics, provides a useful example (Adam et al. 2020). As discussed in Section 4, plastic demand exhibits a very elastic response to changes in the price of imported polyethylene. Import taxes have a potentially major cost advantage over directly targeted measures since the former can be administered at relatively few entry points, while the latter require a widely distributed cadre of enforcement agents. Taxation of imported plastic may be urgently needed because historical evidence suggests that, without countervailing policy measures, the future income growth rate in West Africa will be matched by a concomitant growth rate in plastic demand. However, a tariff may have a disproportionate impact on the poor, and policy makers should consider potential distributional implications before they implement a tariff on polyethylene.

Economic measures must avoid adverse health impacts.

While the case for public interventions to reduce plastic waste seems clear, Section 5 suggests that attention must also be paid to potential conflicts with public-health outcomes. Empirical analysis strongly suggests that clean-water consumption from plastic sachets and bottles has significantly reduced sickness and death among West African children. Thus, measures to reduce the use of plastic sachets and bottles should be accompanied by programs designed to improve health outcomes for children, particularly in poorer households. As an alternative, subsidies could be provided for the use of biodegradable drinking-water containers that are more costly to produce than traditional plastic containers.

Cleanup measures should be better targeted.

Priority should be given to areas with a high incidence of plastic-waste disposal near rivers, particularly more elevated areas with steeper slopes. Focusing on waste cleanups before the onset of the first-semester rainy season will be most effective.

Although policies to reduce plastic waste are critical, realism also dictates the need for improved waste-collection measures. For the marine environment, it is particularly important to develop collection strategies that target areas where high-waste volumes also have a high likelihood of transport to the ocean via local rivers. Where feasible, these strategies should be informed by continuous sampling to identify such areas. For more resource-constrained environments, the analysis in Section 6 shows how readily available economic, demographic, and topographical information can be combined to identify the "hotspot" areas where high-volume waste transport via rivers is most likely. This analysis also shows that the intensity of the waste-collection activity should vary with the annual rainfall cycle, since the greatest river transport of plastic waste to the ocean occurs at the beginning of the rainy season, when large volumes of waste accumulated during the dry season are flushed into rivers by the onset of heavy rains.

An additional lesson from the river-transport analysis is that policies to reduce marine-plastic waste should often be formulated for river basins, rather than operating at national or local levels. This suggestion may require the development of institutions that foster coordinated implementation of waste-management policies, across urban areas drained by the same river basin.

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Appendixes

Appendix A. The macroeconometrics of single-use plastic imports

Panel Estimation of Regional Import Demand Elasticities

Import duties are already familiar in all West African countries and relatively easy to enforce, but how effective would they be in reducing demand for single-use plastics?

The responsiveness of demand for thin polyethylene sheets (TPSes) to import duties is addressed with data from the natural experiment on TPS import prices for 10 West African countries:[48,49], Benin, Cameroon, Côte d'Ivoire, Gambia, Ghana, Guinea, Nigeria, Senegal, Sierra Leone, and Togo. As Figure 5 (page 21) shows, the import price has varied more than fourfold since 1995. All West African economies are price-takers, since they are too small to affect aggregate demand/supply relations in the global TPS market. Each country therefore faces an exogenously determined TPS price, and econometric estimation of the following import-demand model is straightforward. In the regression specification, logarithms of model variables are employed for two reasons. Firstly, logarithmic models are less susceptible to distortions from a few "outlier" observations for the dependent variables. Secondly, and equally importantly, the estimated parameters in a logarithmic model are easily interpreted because they measure the percentage change in the dependent variable that is attributable to a percentage change in an independent variable.

$$Inm_{it}= \beta_0+\beta_1\ Inq_{it}+ \beta_2\ Inp_{it}+ \varepsilon_{it}^{50} \qquad (1)$$

where, for country i in year t, m^{it} equals TPS import quantity, q_{it} equals national income, p_{it} is the TPS import price, and ε_i stands for the effect of unobserved variables—which may be random or temporally correlated.

The TPS data for each West African country has been drawn from the UN's Comtrade database.[51] TPS prices for each country are computed in two steps.[52] Firstly, total current-dollar import values are divided by import quantity. Secondly, corrections are made for interim dollar inflation, using the U.S. gross domestic product (GDP) deflator. Our measure of national income, drawn from the World Bank's World Development Indicators, is GDP measured in constant U.S. dollars (2010).

Composite income and price elasticities for the West African countries are estimated by pooling the TPS and national income data for the 1990–2019 period. The TPS data is far from complete for Gambia, Sierra Leone, and Togo, so the econometric exercise simply employs data for Senegal, Guinea, Côte d'Ivoire, Ghana, Benin, Nigeria and Cameroon. Appropriate panel regression techniques are used to estimate the econometric model, and to test for significant differences in import-price elasticities across countries.

Table 4 presents the results, which indicate large and highly significant income and price elasticities. For the composite regression reported in column (1), the estimated income and price elasticities are 1.4 and -1.0, respectively. By implication, each 1 percent increase in national income induces a 1.4 percent increase in imports of thin polyethylene sheets (TPSes), and each 1 percent increase in price induces a 1 percent decrease in imports.

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[48] The Comtrade database has no entries for TPS imports by Liberia.

[49] The import quantity index in Figure 4.1 is calculated in two steps. Firstly, import quantities in each country are normalized to the range 0–100. Then, a mean normalized quantity for the 10 countries is calculated for each year. We prefer this index to the regional total, which would give most of the weight to the three countries that account for 80 percent of TPS imports (Nigeria, Côte d'Ivoire, and Ghana). Nigeria, alone, accounted for 46 percent of regional imports during the 2015–19 period.

[50] In this model, β1 is the income elasticity of import demand. The estimated parameter is expected to have a positive sign, because it measures the percentage increase in TPS imports that will be induced by a one-percent increase in national income. B2 is the price elasticity: It is expected to have a negative sign because it measures the percentage decrease in TPS imports that will be associated with a one-percent increase in the price.

[51] https://comtrade.un.org/data.

[52] Separate import prices have been computed for each country, to allow for some difference in import composition not captured by Comtrade's five-digit data.

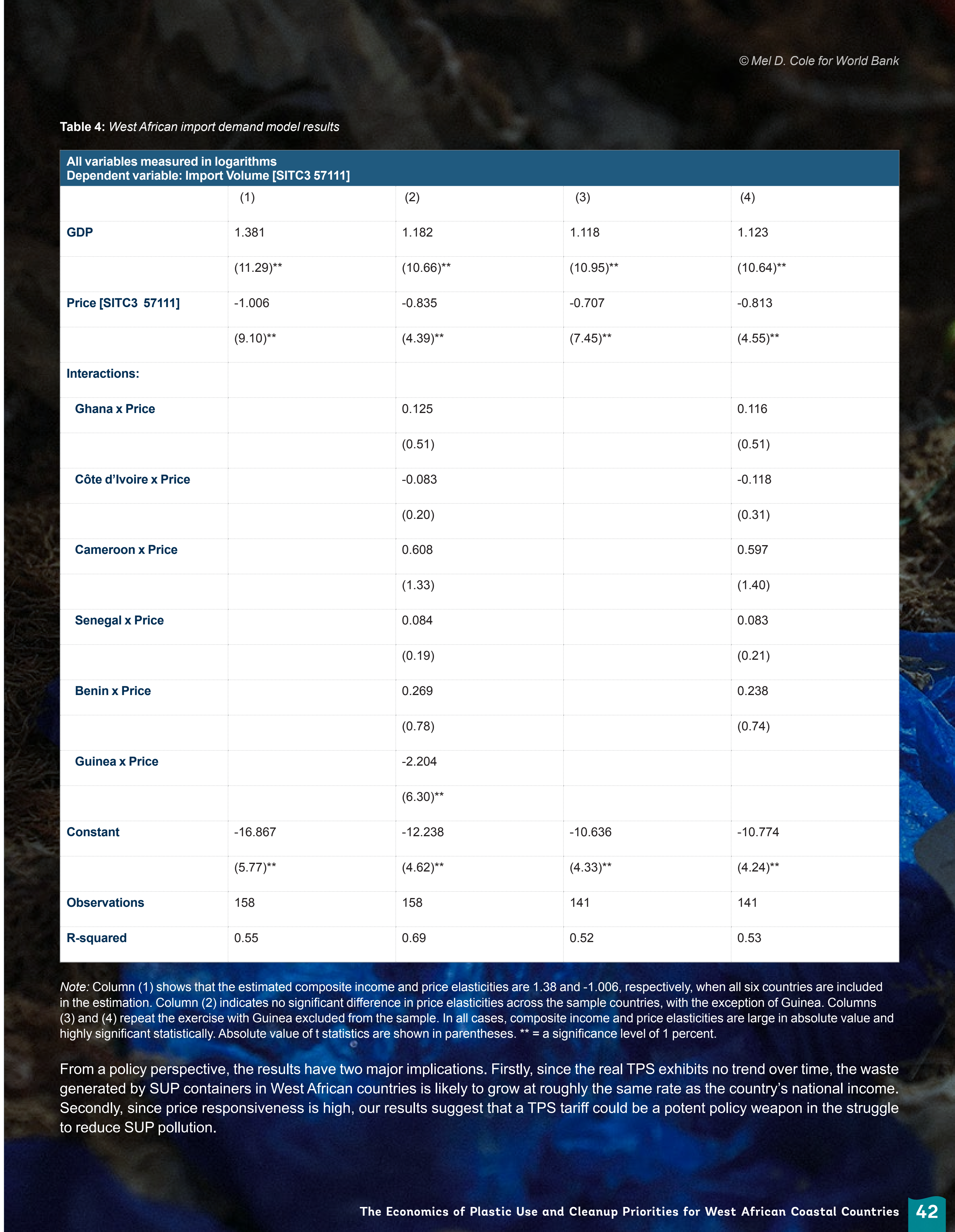

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Table 4: *West African import demand model results*

All variables measured in logarithms
Dependent variable: Import Volume [SITC3 57111]

	(1)	(2)	(3)	(4)
GDP	1.381	1.182	1.118	1.123
	(11.29)**	(10.66)**	(10.95)**	(10.64)**
Price [SITC3 57111]	-1.006	-0.835	-0.707	-0.813
	(9.10)**	(4.39)**	(7.45)**	(4.55)**
Interactions:				
Ghana x Price		0.125		0.116
		(0.51)		(0.51)
Côte d'Ivoire x Price		-0.083		-0.118
		(0.20)		(0.31)
Cameroon x Price		0.608		0.597
		(1.33)		(1.40)
Senegal x Price		0.084		0.083
		(0.19)		(0.21)
Benin x Price		0.269		0.238
		(0.78)		(0.74)
Guinea x Price		-2.204		
		(6.30)**		
Constant	-16.867	-12.238	-10.636	-10.774
	(5.77)**	(4.62)**	(4.33)**	(4.24)**
Observations	158	158	141	141
R-squared	0.55	0.69	0.52	0.53

Note: Column (1) shows that the estimated composite income and price elasticities are 1.38 and -1.006, respectively, when all six countries are included in the estimation. Column (2) indicates no significant difference in price elasticities across the sample countries, with the exception of Guinea. Columns (3) and (4) repeat the exercise with Guinea excluded from the sample. In all cases, composite income and price elasticities are large in absolute value and highly significant statistically. Absolute value of t statistics are shown in parentheses. ** = a significance level of 1 percent.

From a policy perspective, the results have two major implications. Firstly, since the real TPS exhibits no trend over time, the waste generated by SUP containers in West African countries is likely to grow at roughly the same rate as the country's national income. Secondly, since price responsiveness is high, our results suggest that a TPS tariff could be a potent policy weapon in the struggle to reduce SUP pollution.

Appendix B. The health impact of plastic container use

Does drinking water from plastic sachets and bottles reduce the probability of mortality and morbidity (incidence of diarrhea), among children living in Ghana and Nigeria?

To test the impact of plastic drinking water containers on mortality and the incidence of diarrhea in children, an econometric database was constructed from DHSes for Ghana (2003, 2008, 2014) and Nigeria (2003, 2008, 2013, 2018). The database reports caretaker responses for more than 12,500 children in Ghana and 99,500 children in Nigeria. Probit regressions were used to analyze the data. The regression-dependent variables were dichotomous measures for mortality (child has died: 1 if yes, 0 if no) and diarrhea incidence (1 if had diarrhea recently, 0 otherwise). The independent variables were child gender; years of mother's education; real household income;[53] plastic drinking-container use (1 if plastic bottles or sachets are the household's primary drinking water source, 0 otherwise); and child's age in months (age at death for mortality). Unobserved spatial and temporal factors were also controlled for, by including dummy variables for DHS years and level-1 administrative regions (12 in Ghana, 38 in Nigeria).

Table 5 presents probit-based econometric estimates that can be interpreted as the change in dependent variable probability, for a one-unit change in the independent variable.[54] For clarity, the dummy variable results for time periods and administrative regions were excluded. These are significant in all cases, suggesting that a host of temporal and local factors also have an important impact on child mortality and morbidity. Among the reported regression variables, mother's education and child's age have consistently high significance. In the results, income has a perversely positive, significant association with child mortality. Income has the expected sign for diarrhea and is significant for Nigeria. Among the four results for plastic container use, all have the expected sign (container use reduces the dependent variable probability), and three of the results are statistically significant.

Table 5: *Plastic drinking-water container use and child health in Ghana and Nigeria*

Dependent variable: Probability of child death or recent diarrhea				
	Ghana[a]		Nigeria[b]	
	(1)	(2)	(3)	(4)
Variable	Death	Diarrhea	Death	Diarrhea
Female	0.032	-0.001	0.006	0.008
	(0.89)	(0.02)	(0.52)	(0.72)
Mother's education (Years)	-0.022	-0.010	-0.033	-0.003
	(4.49)**	(2.60)**	(21.11)**	(2.17)*
Income per capita	0.712	-0.129	0.397	-0.054
($US 2010)	(8.24)**	(1.49)	(19.56)**	(2.21)*
Plastic container use	-0.250	-0.140	-0.117	-0.056
	(2.82)**	(2.03)*	(2.93)**	(1.34)
Age (months)	0.007	-0.008	0.009	-0.012
	(6.63)**	(10.00)**	(28.50)**	(34.66)**
Constant	-1.651	-0.710	-1.384	-1.276
	(23.02)**	(12.39)**	(25.62)**	(18.79)**
Observations	12,708	12,541	99,471	98,743

Note: Absolute value of t statistics are shown in parentheses. * and ** equal significance levels of 5 percent and 1 percent, respectively.

a. Data from Ghana DHS (2003, 2008, 2014).

b. Data from Nigeria DHS (2003, 2008, 2013, 2018).

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[53] The measure of household income is derived from two variables. The first is the DHS measure of relative economic status, which is a score derived from an inventory of household possessions. This is standardized for each DHS by dividing by the mean score. The second is the World Bank measure of real income per capita in the DHS years. The World Bank measure of real income per capita for the DHS years is multiplied by the standardized DHS score, to produce an estimate of relative household income per capita.

[54] Probit estimation appropriately constrains model-based probability estimates to the range [0–1].

To explore the implications of these results for both countries, the probit results in Table 5 [55] are used to predict mortality rates and diarrhea incidences for all children [0–5 years of age] in the sample (12,500 for Ghana; 99,500 for Nigeria), with and without plastic water container use, which is reported in Figure 7 (page 23) and Table 5.

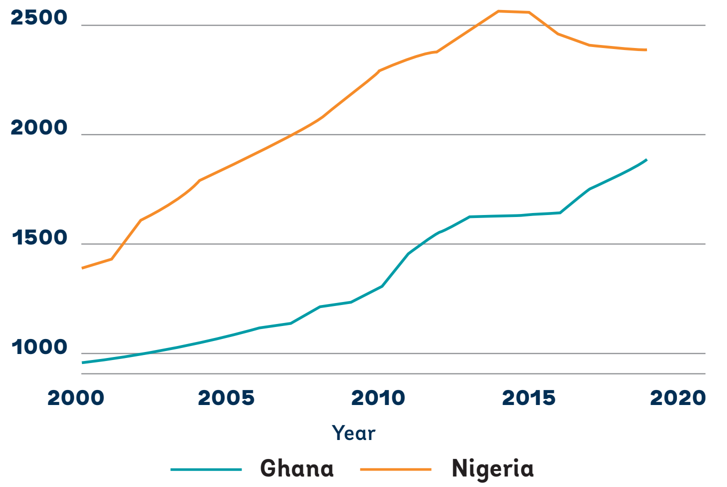
Although these estimates may fully or partially reflect the influence of unobserved variables that are correlated with plastic container use, the results are certainly cautionary given the size of the estimated impact and the stakes for public health. In both Ghana and Nigeria, reducing the use of plastic drinking-water containers may significantly increase childhood illness and death. Policy makers who opt for reducing SUP containers should also consider countervailing health measures, particularly for poorer households.

Appendix C. Household income and plastic container use

How significant is the effect of income on plastic container use across households and over time?

Real income per capita has approximately doubled in Ghana and Nigeria since 2000 (Figure 18). It is expected that this income growth has increased demand for plastic water containers, all else being equal. Plastic sachets account for the bulk of plastic water-container use in Ghana and Nigeria. They first appeared on the market in the late 1990s, when entrepreneurs in West African cities began using new Chinese machinery that heat-sealed water in plastic sleeves (Stoler et al. 2012). Given the sachets' novel status, one would expect a period of product diffusion to produce some adjustment lag in the income/consumption relationship.

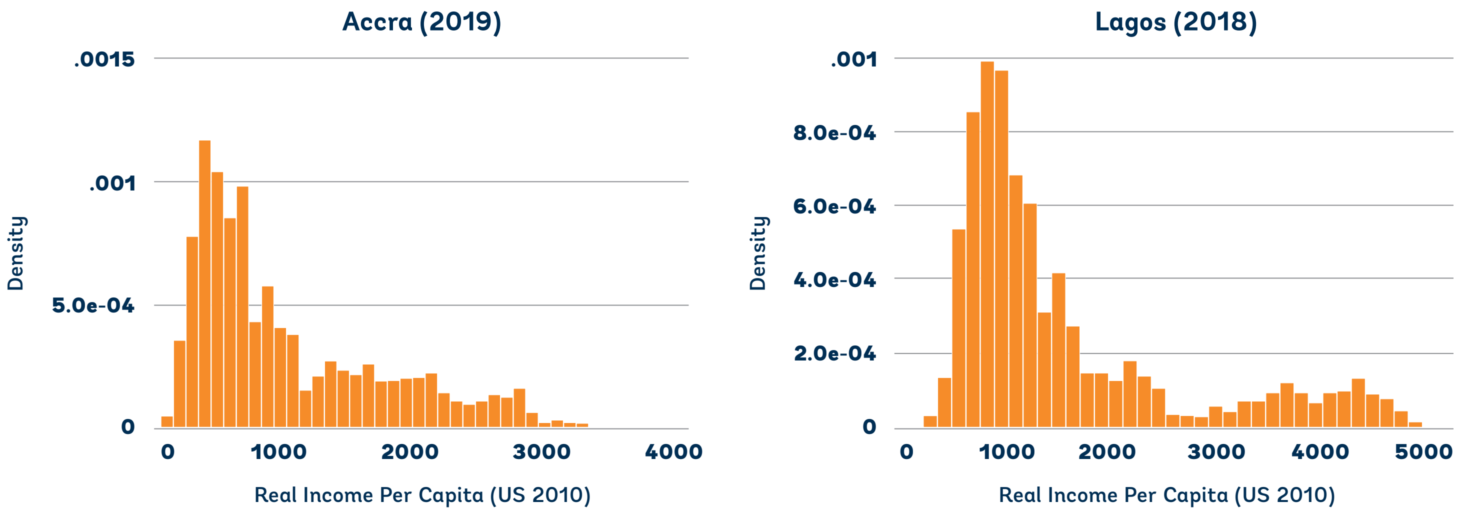
Figure 18. *Real income per capita in Ghana and Nigeria, 2000–19*



Source: World Development Indicators, Income Per Capita (Constant $US 2010).

To capture both income and diffusion effects for plastic containers at the household level, an econometric model for households surveyed by the DHS or MIS in the Accra and Lagos metro areas is estimated for the 2003–09 period. The dependent variable is a dichotomous measure (1 if plastic containers are the household's primary drinking water source, 0 otherwise). The independent variables are household income and a time trend.[56,57] A probit probability model is employed, which bounds model predictions within the range [0–1].

Figure 19. *Per capita income distribution*



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[55] The results for panel dummy variables in years and level-1 administrative units, that are excluded from Table 5, have now been incorporated.

[56] The DHS and MIS include a measure of relative economic status: a factor score derived from a principal components analysis of many dummy variables that record the presence, or absence, of household possessions. To estimate real household income per capita for each household, its factor score is transformed into a percentile [0–100]; divided by the total household members; the result is divided by its sample mean value; and that result multiplied by the World Bank estimate of real income per capita in the relevant survey year.

[57] The focus is on income/container use dynamics here because the relationship is critical for the follow-on identification of plastic-waste "hot spots" in the two cities. The research also tested the role of a demographic variable that has a potentially significant role for health-related reasons: the household percentage of children aged five or less. If drinking water in plastic containers is generally deemed safer, households with proportionately more vulnerable children might be expected to use plastic containers at higher rates. However, the econometric tests of this proposition have not revealed a vulnerable-child effect that is consistently significant for in either Accra or Lagos.

Figure 19 shows that the distribution of household income is highly skewed in both cities. In the regression specification, income is transformed to its logarithm to minimize outlier effects, and because it provides a better fit than untransformed income (which also fits very well in any case). Table 6 shows that the regression results are extremely robust. Household income has a large and highly significant, statistically identical effect on plastic container use in Accra and Lagos. The time trend is highly significant in both cities, but steeper in the case of Accra (0.158 versus 0.077).

The dynamic implications of these results are explored by estimating the probability of plastic-container use, for the full range of incomes in each DHS/MIS year. Figure 6.3 displays the results, which show the separate effects of income growth and product diffusion over the past two decades.

Table 6: *Household income and plastic container use in Accra and Lagos, 2003–19*

Dependent variable: Household uses plastic sachets or bottles as primary drinking water source (1 if yes, 0 if no)		
	Accra	Lagos
DHS/MIS Year	0.158	0.077
	(28.09)**	(17.68)**
Log (Household Real Income Per Capita)	0.356	0.355
	(9.05)**	(12.50)**
Constant	-320.780	-157.111
	(28.37)**	(18.01)**
Observations	3,094	5,137

Note: Absolute value of t statistics are shown in parentheses. * and ** equal significance levels of 5 percent and 1 percent, respectively.

Appendix D. Spatial clustering of income and plastic-waste generation

How do income and population affect the spatial distribution of plastic-waste generation?

Income Clustering

In order to assess the intertemporal stability of residential spatial clustering by income, 1 km grids are overlaid on the two cities and mean household income percentiles computed for grid squares using 3,094 households in five surveys for Accra (DHS 2003, 2008, 2014; MIS 2016, 2019), and 5,137 households in six surveys for Lagos (DHS 2003, 2008, 2013, 2018; MIS 2010, 2015). The methodology incorporates the random 2 km locational variation imposed on each urban survey cluster by DHS and MIS, to ensure respondent anonymity. Each survey cluster is treated as a high-resolution set of points, bounded by a circle with a 2 km radius that is centered on the cluster coordinates recorded by the survey. For one cluster, the mean household income percentile is assigned to all points within the circular bound. Then, all cluster circles are overlaid, and each point is assigned the mean value for all clusters represented at that point. A GIS raster has been created from these points, and resampled to the scale consistent with our 1 km grid.

If spatial clustering by income were a transient phenomenon, one would expect to see a quasi-uniform spatial distribution of mean income percentiles that have been calculated from random surveys over nearly two decades. However, the results presented in figure 6.2 are highly non-uniform. Mean percentiles across grid cells range from 32 to 94 in Accra, and from 20 to 82 in Lagos – and spatially clustered high- and low-income areas are clearly visible. The conclusion is that both Accra and Lagos have stable patterns of residential income-class separation.

Spatial Clustering of Plastic-Waste Generation

Appendix C documents the strong association between household income, and the probability of using plastic containers for drinking water. The above subsection shows that both Accra and Lagos have stable residential clustering by income stratum. It follows that the intensity of plastic-container use and plastic-waste generation would also be clustered spatially by income stratum. However, the econometric results illustrated in figure 6.1 also suggest that new-product diffusion of plastic water sachets has reduced this spatial variation over time. To explore the implications, the mean probability of plastic-container use in each grid cell and time period has been computed.[58] This captures the spatial distribution of use intensity, but aggregate use is the relevant measure for policy analysis. To proxy aggregate use, use intensity is scaled by population in each grid cell.[59]

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[58] This methodology incorporates the random 2 km locational variation imposed on each urban survey cluster by DHS and MIS, to ensure respondent anonymity. Each survey cluster is treated as a high-resolution set of points bounded by a circle, with 2 km radius centered on the cluster coordinates recorded by the survey. For one cluster, the mean probability of plastic container use is assigned to all points within the circular bound. Then, all cluster circles are overlaid and each point is assigned the mean value for all clusters represented at that point. A GIS raster has been created from these points, and then resampled to the scale consistent with our 1 km grid.

[59] To produce population indicators for the 1 km grid cells, 100 m rasters were resampled from the Worldpop project at the University of Southampton (Lloyd et al. 2019).

Tables 7 and 8 display yearly statistics for use intensity and population, with three highlights. Firstly, the statistics for household-use probabilities provide another illustration of the intertemporal pattern revealed by the econometric results in figure 6.1. In Accra and Lagos, the table registers continuous upward shifts in distribution from 2013 to 2019. At the same time, most of the variation is temporal, not cross-sectional. To cite one example, the median use probability for plastic containers increases in Accra from 16 in 2003 to 95 in 2019, and in Lagos from 20 to 63. At the same time, the ratio of maximum to minimum value—a measure of cross-sectional variation—declines steadily toward 1.0 in both cities.

Table 7: *Household use probabilities for plastic drinking water containers: Distribution statistics for 1-km grid cells*

Survey	Year	Min	P10	P25	Median	P75	P90	Max	Max/Min
					Accra				
DHS	2003	12	15	15	16	17	18	19	1.66
DHS	2008	35	41	42	44	45	46	48	1.36
DHS	2014	73	78	78	80	81	82	83	1.13
MIS	2016	83	86	87	88	88	89	90	1.09
MIS	2019	92	94	95	95	95	96	96	1.04
					Lagos				
DHS	2003	12	18	19	20	21	22	27	2.23
DHS	2008	22	29	31	32	34	35	41	1.89
MIS	2010	26	35	37	38	40	41	47	1.78
DHS	2013	35	44	46	47	49	50	56	1.63
MIS	2015	41	50	52	54	55	57	62	1.54
DHS	2018	50	60	61	63	64	65	71	1.42

Population provides a strongly contrasting case in Table 8, where most of the variation is cross-sectional – not temporal. The distributions for Accra and Lagos both shift upward over time as the urban population grows, but with less than doubling of median indicator values (56.0 to 94.8 in Accra; 68.4 to 108.6 in Lagos). At the same time, the maximum/minimum ratios vary from 8.1 to 8.9 in Accra, and from 81.5 to 146.4 in Lagos.

Table 8: *Population indicators for 1-km grid cells*

Survey	Year	Min	P10	P25	Median	P75	P90	Max	Max/Min
					Accra				
DHS	2003	12.7	21.3	31.1	56.0	80.0	96.1	110.4	8.7
DHS	2008	15.5	22.9	35.4	63.3	96.8	111.4	125.4	8.1
DHS	2014	17.7	27.8	41.4	75.0	120.6	137.6	158.2	8.9
MIS	2016	19.8	30.5	45.9	80.5	129.4	149.6	170.0	8.6
MIS	2019	21.9	31.9	52.3	94.8	137.7	167.1	195.6	8.9
					Lagos				
DHS	2003	6.1	17.8	34.8	68.4	120.7	168.0	522.6	85.7
DHS	2008	7.4	21.2	40.6	79.3	141.8	201.1	603.4	81.5
MIS	2010	7.8	22.4	42.5	85.0	151.9	217.8	650.0	83.3
DHS	2013	6.7	23.7	45.9	93.8	167.9	230.7	715.0	106.7
MIS	2015	7.1	24.9	50.4	100.7	177.2	246.5	770.0	108.5
DHS	2018	5.8	27.5	54.9	108.6	191.8	276.4	849.2	146.4

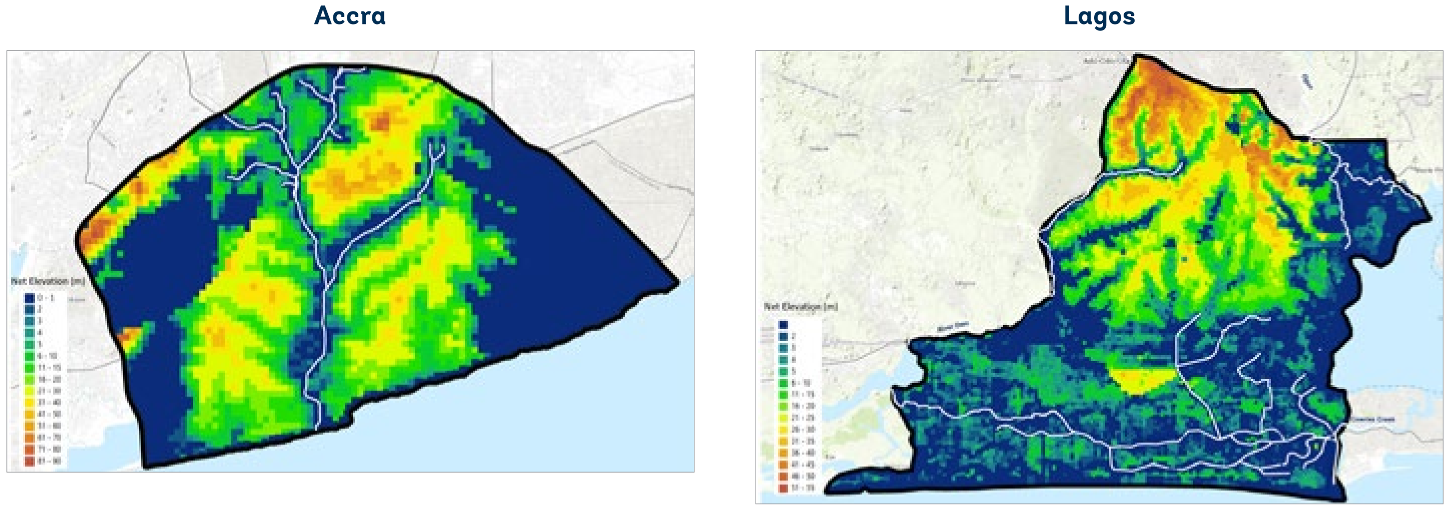
Since the aggregate index for plastic-container use is the product of use probability and the population indicator, the preceding results have two clear implications. Firstly, for any given year, the spatial variation in population greatly outweighs spatial variation in plastic-use probability when determining aggregate indicator values. Secondly, also across years, temporal variation in plastic-use probability greatly outweighs spatial-population variation when determining indicator values.

Appendix E. Rivers as conduits for plastic waste

Does proximity to urban rivers make a difference to marine-plastic pollution?

To understand the risk posed by river transport of plastic waste to oceans, the simple geophysical model developed for this study assigns each 1 km grid cell a score for its likelihood of accumulated waste transport via river. The score incorporates net elevation (elevation of a point minus the elevation of the nearest river point), and the distance from the closest river point. Figure 20 presents maps of net elevations of all 1 km grid cells for Accra and Lagos.

Figure 20: *Maps of net elevations*



Net Elevation (m)

- ● 0-1
- ● 2
- ● 3
- ● 4
- ● 5
- ● 6-10
- ● 11-15
- ● 16-20
- ● 21-30
- ● 31-40
- ● 41-50
- ● 51-60
- ● 61-70
- ● 71-80
- ● 81-90

Net Elevation (m)

- ●
- ● 2
- ● 3
- ● 4
- ● 5
- ● 6-10
- ● 11-15
- ● 16-20
- ● 21-25
- ● 26-30
- ● 31-35
- ● 36-40
- ● 41-45
- ● 46-50
- ● 51-55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