Developing a roadmap for the adoption of clean fuel and vehicle standards in Southern and Western Africa

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AMMA	African Monsoon Multidisciplinary Analyses
ARA	African Refiners Association
BC	Black carbon
CCAC	Climate and Clean Air Coalition
CO	Carbon monoxide
ECOWAS	Economic Community of West African States
GDP	Gross domestic product
HDDI	Heavy-duty diesel vehicles and engines initiative
HDV	Heavy-duty vehicle
HFT	Heavy-freight truck
IARC	International Agency for Research on Cancer
ICCT	International Council on Clean Transportation
IEA	International Energy Agency
IHME	Institute for Health Metrics and Evaluation
IMF	International Monetary Fund
LCV	Light commercial vehicle
LDV	Light-duty vehicle
LT	Light truck
NO_x	Nitrogen oxide
PC	Passenger car
$PM_{2.5}$	Particulate matter, diameter 2.5 μm or less
ppm	Parts per million
PPP	Purchasing-power-parity
SADC	Southern African Development Community
SLCP	Short-lived climate pollutant
SSA	Sub-Saharan Africa
UNEP	United Nations Environment Programme
WHO	World Health Organization

Executive Summary

Road transportation is one of the leading sources of outdoor air pollution in Southern and Western Africa, where emissions from light- and heavy-duty vehicles, minibuses, buses, and two-and three-wheelers continue to negatively affect public health, making motor vehicles a central area for rapid policy response. Vehicles emit a cocktail of pollutants, among which fine particles are responsible for strokes, ischaemic heart disease, acute lower respiratory disease, chronic obstructive pulmonary disease, and lung cancer (World Health Organization [WHO], 2014a). Vehicles are the largest source of nitrogen oxides (NO_x), a pollutant that leads to ozone formation, which is a key factor in chronic respiratory diseases (e.g., asthma). Additionally, pollutants from vehicles harm agricultural productivity and lead to lost work days, school absence days, and decreased productivity for outdoor workers. In 2013, 3.1 million early deaths were caused by exposure to particulate matter ($PM_{2.5}$) and ozone globally, including approximately 90,000 early deaths in Southern Africa and 129,000 early deaths in Western Africa (Institute for Health Metrics and Evaluation [IHME], 2016). Diesel vehicles, predominant in both regions, are an important source of black carbon (BC), a component of $PM_{2.5}$ and a powerful climate pollutant. In 2012, the International Agency for Research on Cancer (IARC) declared diesel exhaust carcinogenic to humans (IARC, 2014).

Cities, in particular, have become pollution hotspots. Rapid urbanization and motorization result in significant vehicles emissions and exposure of a larger number of people. Although most cities still lack air-quality-monitoring systems, areas that are monitored reveal levels of air pollution that exceed the maximum guidelines set by the WHO. In large cities of sub-Saharan Africa, road transportation can be a significant source of $PM_{2.5}$ and ozone air pollution. Although comprehensive studies are scarce, vehicle emissions have been identified to rank among the top contributors to urban outdoor air pollution (Doumbia et al., 2012; Liousse, Assamoi, Criqui, Granier, & Rosset, 2014; Thambiran & Diab, 2011)—especially emissions from freight transportation (Thambiran & Diab, 2011), imported secondhand vehicles (Ngo et al., 2015; UNEP, n.d.), two-wheelers (Liousse et al., 2014), and old diesel vehicles (Scovronick, 2015), most of which are predominantly powered with low-quality, high-sulfur diesel fuels (Ngo et al., 2015; UNEP, n.d.).

To control the transportation-related air pollution, decades of experience in the developed and developing world have shown that a combination of clean fuel and vehicle policies are the solution. In particular, Southern and Western Africa need to limit the level of sulfur in diesel fuel to 50 ppm or adopt even more stringent fuel standards, and implement Euro 4 and IV or more stringent vehicle emissions standards. Countries in both regions have engaged in a regional framework agreement to reduce diesel sulfur content to 50 ppm and gasoline sulfur content to 150 ppm by 2020, and to implement clean vehicles policies. Weak fuel standards, particularly in the Western Africa region, have opened the door for illegitimate practices and regulatory arbitrage from foreign fuel traders. A highly publicized report by Public Eye, a Switzerlandbased global justice organization, brought international focus on Swiss commodity trading companies taking advantage of weak fuels standards in West Africa, where they sell gasoline and diesel fuels that have been blended with cheap blendstocks to maximize their profits (Public Eye, 2016). The exported fuels contain high levels of sulfur, aromatics, and benzene; are harmful to public health; and do not match the specifications of the countries where they are produced, but yet they remain within the standards of the receiving countries (Public Eye, 2016). In December 2016, five West African countries decided that all imported diesel fuels should meet a 50-ppm maximum sulfur content by July 1, 2017, with refineries in the West African sub-region having a waiver to implement upgrades to comply with the 50-ppm limits on diesel fuels by 2020 (UNEP/CCAC, 2016a). This agreement comes on the heels of Ghana's commitment to implement 50-ppm fuels (UNEP/CCAC, 2016b) and is a direct result of the work of the Climate and Clean Air Coalition's (CCAC's) Heavy-Duty Diesel Vehicles and Engines Initiative (HDDI). Since 2013, the CCAC has been working with countries and governments in low- and middle-income and emerging economies to reduce the emissions of short-lived climate pollutants (SLCPs). In the road transportation sector, the HDDI aims to reduce emissions of BC, an SLCP, through the adoption of clean fuel and vehicle regulations and supporting policies from the on-road diesel fleet (CCAC-HDDI, n.d.). The HDDI is co-led by the U.S. Environmental Protection Agency, Environment and Climate Change Canada, and the Swiss government. The implementing partners are the United Nations Environment Programme (UNEP) and the International Council on Clean Transportation (ICCT). In 2016, the HDDI launched the Global Sulfur Strategy, with the goal to ensure that all countries achieve 50-ppm diesel fuels by 2025 and that most countries achieve 10-ppm diesel sulfur fuels by 2030 (ICCT/UNEP, 2016).

This study focuses on the HDDI efforts in Southern and Western Africa to reduce vehicles' contribution to outdoor air pollution, and the health and climate impacts of vehicles' emissions. Despite countries' commitments and political will, several bottlenecks have slowed progress. At the same time, opportunities exist for those countries to achieve comprehensive clean fuel and vehicle policies. The goal of this report is to provide a roadmap to support the implementation of clean fuel and vehicle policies in Southern and Western Africa. This roadmap will pave the way for countries to:

» Identify current institutional, economic, and policy barriers that have limited countries' progress. With current regional commitments across the two regions, this report identifies factors that will likely impact the implementation of the regional agreements and proposes ways to address these obstacles.

» Take advantage of the political momentum to implement short-term actions and refine some of the policies to respond to long-term clean transportation goals, including clean air, fuel economy, compliance, and enforcement.

» Assess the social costs and the health and climate co-benefits associated with a regional transition to clean fuels and vehicles.

Indeed, a baseline study of fuel sulfur content indicates that diesel sulfur levels in Southern and Western Africa are still very high (Figure 1).

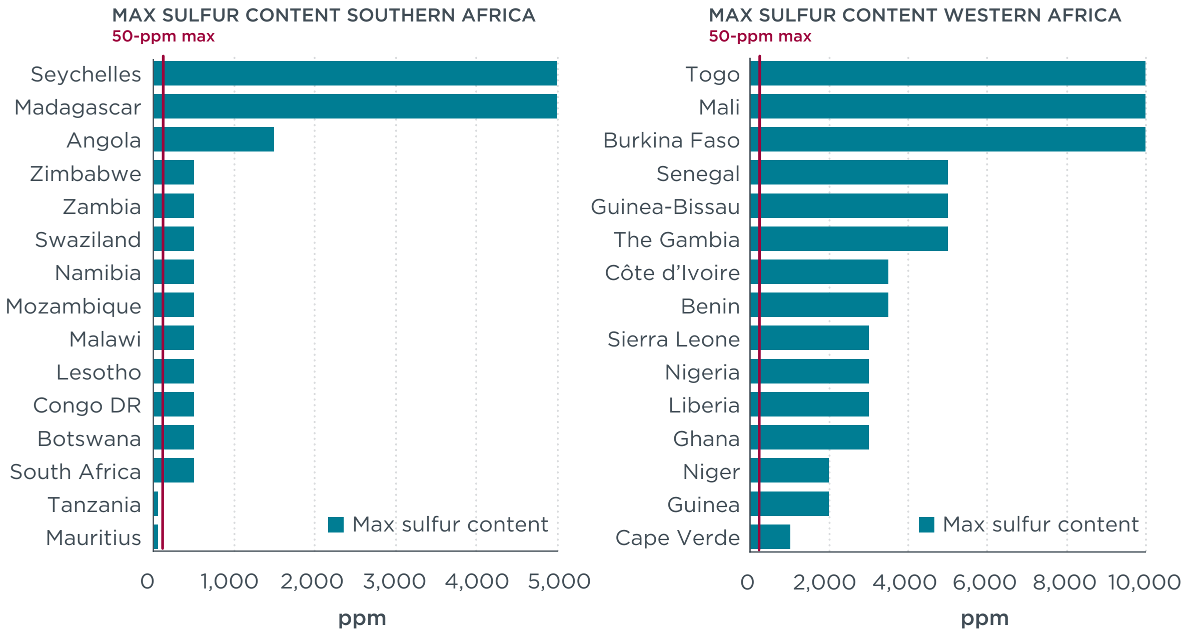

Figure 1. Diesel sulfur content in Southern and Western Africa in 2014.

In summary, this study finds that:

- The governments' goal of 2020 for achieving 50-ppm fuels is achievable for most countries in both regions, with all countries reaching this milestone by 2025. Most countries in the region should be able to reach 10-ppm sulfur fuels by 2030.
- In addition to limiting diesel sulfur levels, all countries in Southern and Western Africa should harmonize with the AFRI-4 specifications in full, including limits on gasoline sulfur content, benzene, and aromatics.
- The African Refinery Association has an opportunity to provide a timeline for AFRI-6 standards that aim to achieve 10-ppm diesel sulfur content, to align with the goal of the Global Sulfur Strategy and enable countries to meet Euro 5/V and 6/VI vehicle emissions standards.
- Two factors will likely impact the implementation of regional commitments: common fuel quality specifications and harmonized implementation timelines for importing and refining countries. The regional bodies, the Southern African Development Community (SADC) and the Economic Community of West African States (ECOWAS), are the best-suited venues for a harmonized transition, but also for discussions about countries facing obstacles—whether financial, institutional, or economic—to ensure that no country is left behind.
- In countries where multiple fuel grades will be sold, there should be establishment of labeling of low- and ultra-low-sulfur grades to inform consumers.
- All countries should limit vehicle imports to Euro 4/IV when AFRI-4 fuels become available, and to Euro 6/VI when AFRI-6 10-ppm fuels become available. For all vehicles in the fleet (older and newer), strong inspection and maintenance programs are needed.
- Looking forward, and for policymakers to benefit from data-driven policy guidance, all countries should collect and report data on imported vehicles, including emission and fuel economy certification levels and data on costs and origin of both imported and refined fuels.

- The implementation of clean fuel and vehicle policies goes hand in hand with stronger compliance and enforcement; regulators should conduct regular fuel-quality testing of imported fuels at the point of entry and fuels sold at retail stations, enforce minimum financial penalties for noncompliance with fuel specifications at retail services, and make fuel-quality testing and enforcement data (i.e., penalties collected) publicly available.
- Decision makers should take cost-effectiveness into consideration, in addition to energy security, when determining whether to upgrade refineries or switch to imports.

The implementation of clean fuels and vehicles policies will generate substantial health and climate benefits by reducing the emissions of $PM_{2.5}$, NO_X, and BC, particularly from diesel buses, minibuses, and trucks in urban areas. Figure 2 illustrates the potential emissions reduction in $PM_{2.5}$ in Nigeria when the country moves from a baseline sulfur level of 3,000 ppm to 50 ppm in 2017. In 2025, the country additionally implements a combination of 10-ppm sulfur limits on diesel fuels and a 5-year age limit on all imported vehicles. Imports after 2025 are almost all Euro V/VI. The 10-ppm ultra-low-sulfur fuels allow Euro V/VI buses and vehicles to function properly. The largest reductions occur when the contribution of cleaner vehicles grows in the overall fleet. In 2050, almost all vehicles emit at Euro V/VI levels, which virtually eliminates $PM_{2.5}$ from the vehicle fleet. Although not estimated in the study, the health benefits from such a transition are expected to be significant.

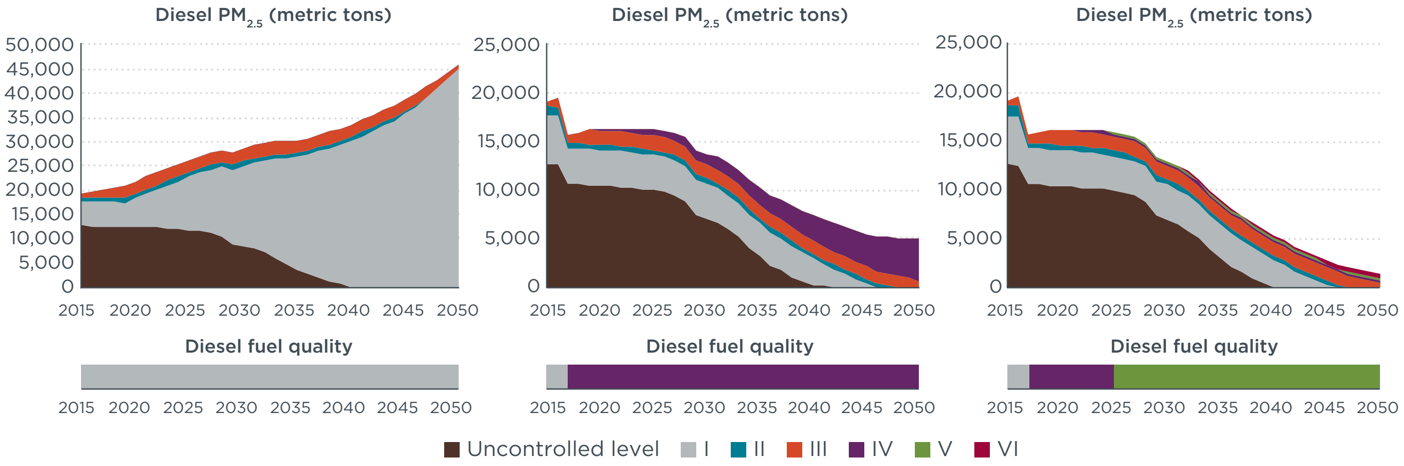

Figure 2. Potential emissions-reduction benefits in Nigeria.

Introduction and regional context

In July 2009, countries in Western Africa signed a regional framework agreement with the goal to adopt a maximum sulfur content of 50 ppm in diesel and 150 ppm in gasoline by 2020 (UNEP, 2009; U.S. EPA, 2012). Similarly, in Southern Africa, nations have planned to move to 50-ppm low-sulfur diesel and 150-ppm gasoline fuels by 2020 (UNEP, 2008), as part of their efforts to improve air quality through clean fuels and vehicles policies in sub-Saharan Africa. In both regions, efforts have been made to transition, with multiple fuel grades, including some 50-ppm low-sulfur diesel, already available in Botswana, the Democratic Republic of Congo (DRC), Malawi, Mauritius, Namibia, South Africa, and Tanzania for the Southern Africa region. Western Africa, although lagging behind, has recently made an important step, with five countries deciding to import low-sulfur fuels by July 2017, with a waiver for refineries to produce 50-ppm fuels by 2020 (UNEP/CCAC, 2016a). But despite efforts across the two regions, several hurdles have slowed progress, with sulfur content in a number of countries still among the highest in the world.

This report reviews the progress to date of countries in these two regions and assesses the barriers they face and opportunities they can leverage to reach their clean fuels and vehicles goals. This work is expected to inform the development of regional and national roadmaps for the adoption and implementation of clean fuels and vehicles standards, specifically 50-ppm and 10-ppm sulfur fuels and Euro 4 and IV or more stringent emission levels for vehicles. The study is one component of a larger initiative supported by the Climate and Clean Air Coalition (CCAC) to reduce short-lived climate pollutants (SLCPs) from diesel engines globally. Diesel engines are the primary transportation-related source of black carbon (BC), a powerful SLCP. Since 2013, the CCAC Heavy-Duty Diesel Vehicles and Engines Initiative (HDDI) has been working with countries and governments in low- and middle-income and emerging economies to support uptake of diesel BC emissions-control strategies. The initiative is co-led by the U.S. Environmental Protection Agency, Environment and Climate Change Canada, and the Swiss government. The implementing partners are the United Nations Environment Programme (UNEP) and the International Council on Clean Transportation (ICCT). The study seeks to provide governments, regulators, policymakers, and other stakeholders with answers to some critical questions as they establish their regional and national roadmaps for cleaner fuels and vehicles given the current context. Some of those questions are: Why is it important to implement clean fuels and vehicles strategies to protect public health and the environment? What are the barriers to and opportunities involved in adopting these standards? What are the policy options and possible implementation timelines? What are the potential emissions-reduction benefits?

To answer this last question, the ICCT has developed a Southern and Western Africa Fleet Model, which is a simulation tool specific to both regions that estimates future vehicle emissions based on fuel sulfur standards, vehicle emissions standards, regulations on imported secondhand vehicles, and the timeline associated with the implementation of those standards. As countries have specific realities, the model provides flexibility to use countries' specific data when those data are available.

In this study, Western Africa and Southern Africa are defined as being members of the Economic Community of West African States (ECOWAS) and the Southern African Development Community (SADC), as shown in Figure 3.

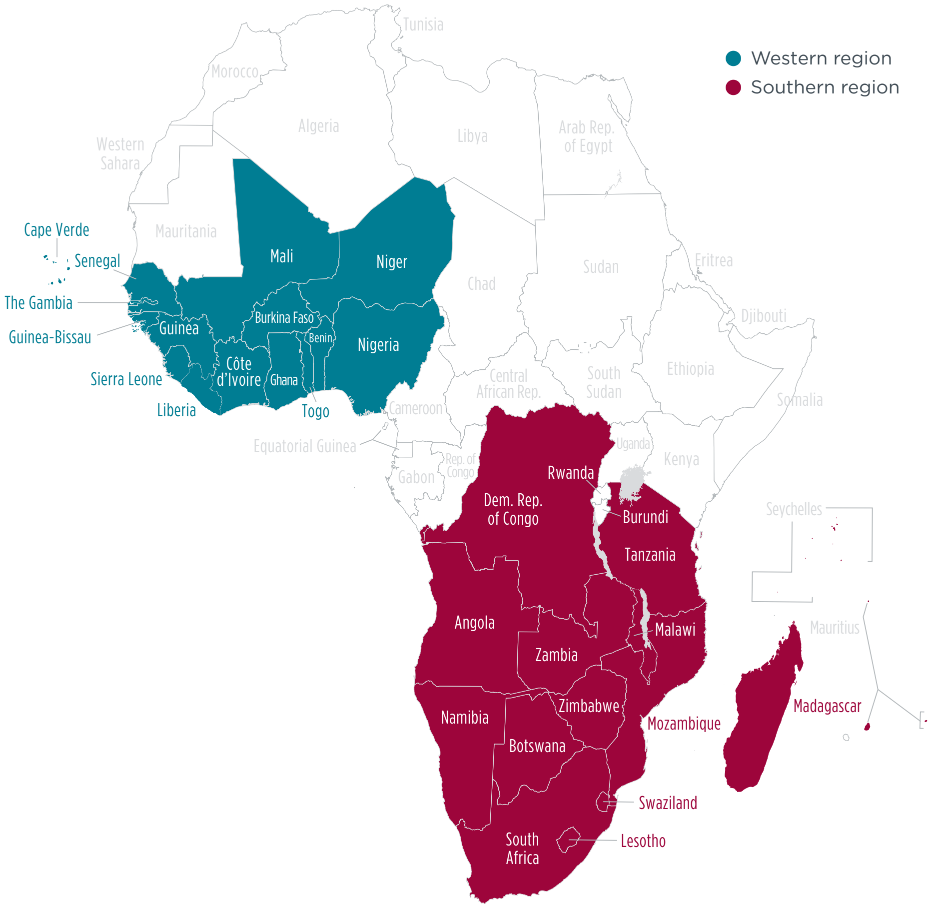

Figure 3. Map of regions and countries represented in this study.
Source: CITAC/ICCT (2016)

The African continent is large and diverse, equivalent in size to the United States, China, India, and Europe combined (OECD/IEA, 2014), with growing economies and populations that are increasingly urban and motorized. Africa, as a whole, accounts for 16% of the world's population, with 1.2 billion people as of mid-2015 (UN World Population Prospects, 2015). The African population is expected to double, from its 2015 level, to reach 2.4 billion by 2050 (UN World Population Prospects, 2015). In terms of urbanization, according to the World Urbanization Prospects (2014), Africa will be the fastest urbanizing region from 2020 to 2050.

The gross domestic product (GDP) for African countries combined was projected to grow by 4.5% in 2015 and 5% in 2016, after slightly slower growth in 2013 (3.5%) and 2014 (3.9%; African Economic Outlook, 2015). In many African countries, growth has been driven by domestic demand (private consumption and public infrastructure investments), whereas the export values of goods have been reduced due to low export prices and lower demand from advanced and emerging economies (African Economic Outlook, 2015). In 2014, Western Africa, despite the outbreak of the Ebola epidemic, achieved high economic growth (6%). Côte d'Ivoire led the region with a real GDP growth of 8.3%, whereas Nigeria, the largest West African economy, recorded a growth of 6.3% following a diversification toward non-oil sectors. In Southern Africa, growth fell below 3%, with South Africa's economy growing by 1.5%, as a result of weakened demand from trading partners, lower prices for raw materials, labor unrest, and electricity shortages. Agriculture holds the largest share of the economy and accounts for approximately 20% of the sub-Saharan GDP (compared with 6% worldwide) and approximately 65% employment (OECD/IEA, 2014). Appendix A provides the projected GDP growth in 2015 and population per country (African Economic Outlook, 2015). In terms of trade, Europe remains Africa's largest trading partner, but when comparing single countries' trade with Africa, since 2009, China has become Africa's biggest trading partner (African Economic Outlook, 2015).

Fuel consumption in the Southern Africa region recorded a compound annual demand growth of 3.9% since 2000, whereas the Western Africa region recorded a growth of 4.6% during the same time. The top three largest oil products consumers in the Southern Africa region are South Africa, Angola, and Tanzania by total consumption. However, by demand growth in 2014, Zambia led the region in 2014 (+11.1%), followed by Tanzania (+6.5%), and Angola (+5.9%; CITAC/ICCT, 2016). In Western Africa, the top three consumers of oil products are Nigeria, Ghana, and Senegal. However, demand growth for oil products in the region was highest in Côte d'Ivoire (7.8%), followed by Mali (3.6%) and Nigeria (3.5%).

Some studies have analyzed the causal relationship between energy consumption and economic growth (Alam & Paramati, 2015). Although consumption of oil products should be regarded as just one component of a country's energy use, along with other disaggregated components such as coal and natural gas (Alam & Paramati, 2015), Côte d'Ivoire, Tanzania, and Zambia, which are among the top performers for GDP growth, are also among the top oil consumers in terms of demand growth in their respective regions. Furthermore, analysts argue that the growing economies of sub-Saharan Africa will drive fast growth in demand for oil products (CITAC/ICCT, 2016).

Tables 1 and 2 indicate the oil products demand growth in key countries of both regions, and Figures 4 and 5 provides the overall consumption of the largest oil products consumers. Most refined products consumed in both regions are diesel and gasoline. Diesel is the most dominant fuel in the Southern Africa region, representing 59% of total diesel and gasoline consumption. In contrast, in the Western Africa region, gasoline is the most dominant fuel, with a share of 66%. The regional data for Southern and Western Africa are skewed by large markets. In the Southern Africa region, South Africa accounts for 59% of the region's consumption, with its domestic consumption dominated by diesel, whereas in Western Africa, consumption in Nigeria amounts to 65% of the region's total, with its consumption dominated by gasoline. Looking across the countries in both regions, diesel is the dominant fuel, except in Nigeria, where gasoline consumption exceeds the entire diesel consumption of the rest of the region, partly accentuated by subsidies on gasoline price, which were removed recently.

Table 1. Fuel demand growth for key countries in Southern Africa in 2014.

South Africa	+ 5.6%
Zambia	+11.1%
Angola	+5.9%
Tanzania	+6.5%

Figure 4. Largest oil products consumers in Southern Africa (million metric tons) in 2014.

Table 2. Oil products demand growth in key countries in Western Africa in 2014.

Nigeria	+3.5% (down from 9.6%)
Senegal	+3.0%
Côte d’Ivoire	+7.8%
Mali	+3.6%
Ghana	-1.3%

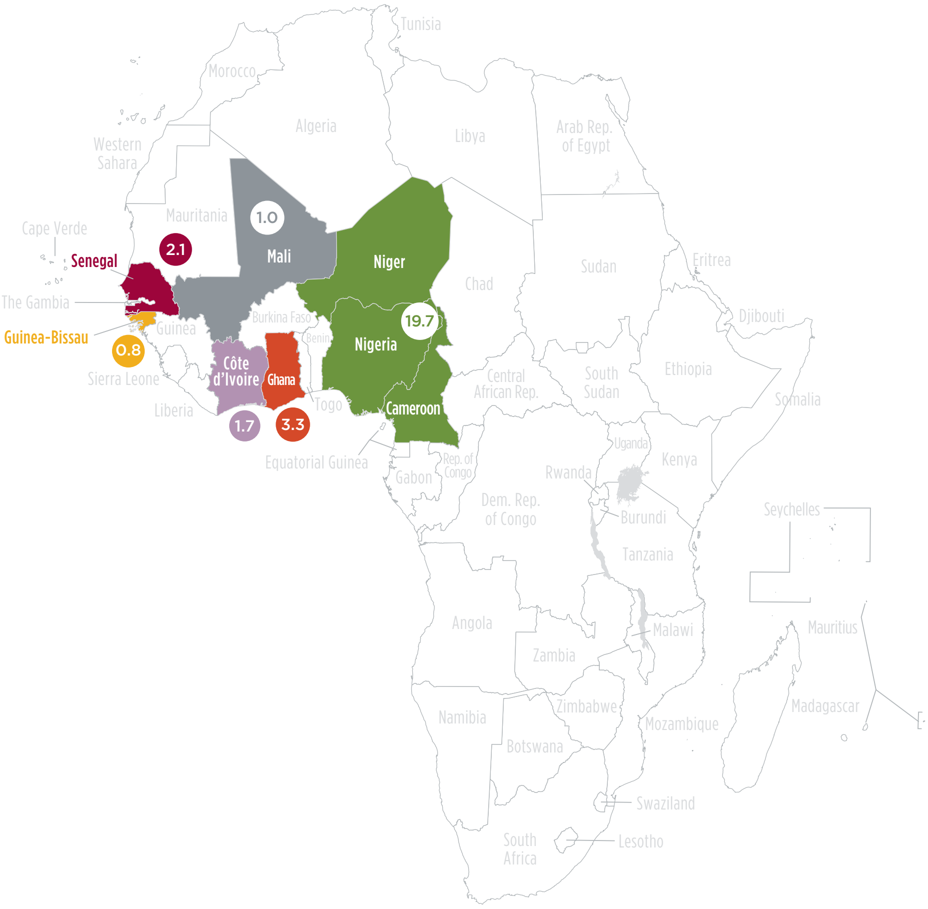

Figure 5. Largest oil products consumers in Western Africa (million metric tons) in 2014.

It is difficult to estimate vehicle population and flows in sub-Saharan Africa. Difficulties in accessing data and a lack of reliability and consistency in the registration systems across countries are key barriers (Black & McLennan, 2015). Vehicle data are not readily available in most countries' published statistics. Some trade statistics specify vehicle flows in monetary values, not in number of vehicles imported or exported. When those data are accessible, there may be large discrepancies between datasets from different sources. For example, according to Black and McLennan (2015), Wards Auto estimates the total registration in Nigeria in 2013 to be 1.4 million, which is an underestimate of their own over-5 million estimate. Similarly, PWC estimates the motorization rate in Nigeria at 81 passenger cars per 1,000 inhabitants (PWC, 2015), whereas OICA estimates motorization rates both in 2011 and 2012 to be 20 cars per 1,000 inhabitants (OICA, 2013). Some registration systems lack important attributes such as vehicle model or model year—important elements to assess vehicle emissions and fuel consumption. A number of censuses estimate total vehicles on road in countries with cumulative vehicle registration, not taking into account vehicle retirement from the fleet.

Vehicle ownership in Africa is low—below the world average—with only South Africa, Botswana, Mauritius, and Namibia exceeding 50 cars per 1,000 people, as shown in Figure 6 (OECD/IEA, 2014). But, by many accounts, vehicle ownership is growing fast, with OICA citing an increase of 31% over an unspecified time frame (OICA, 2016).

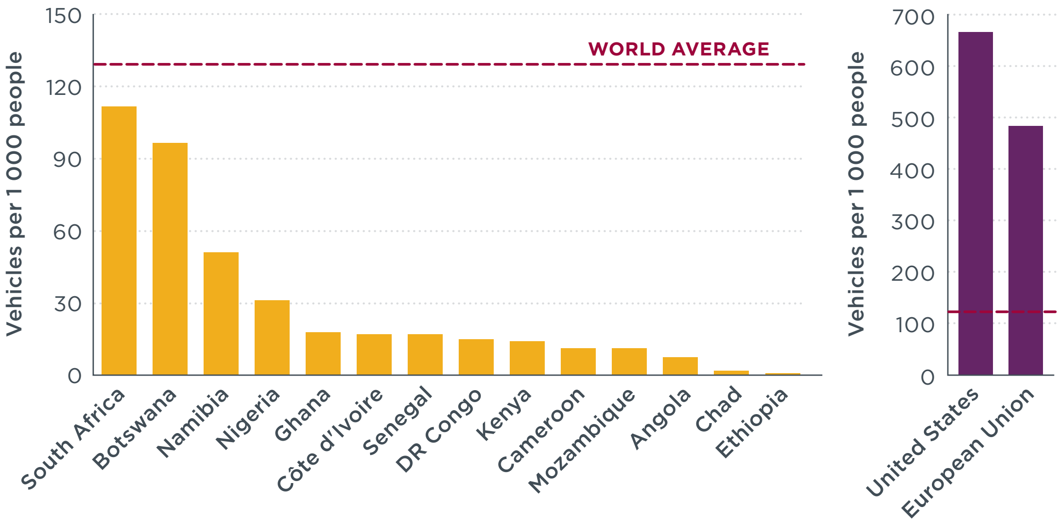

Figure 6. Car ownership in selected countries of sub-Saharan Africa in 2012.
Source: OECD/IEA (2014)

In general, sub-Saharan Africa relies primarily on imports to meet its demand for vehicles, whether new or secondhand. Vehicle production in the region is very limited. According to the 2015 OICA Vehicle Production Statistics, only South Africa has a significant vehicle manufacturing industry in the sub-Saharan region; the other manufacturers are in countries in North Africa (Algeria, Egypt, Morocco, and Tunisia; OICA, 2016). Outside of South Africa and specific countries in Northern Africa, assembly activity is minimal, involving mostly final assembly of partly assembled vehicles (Black & McLennan, 2015). Local companies, along with Chinese, European, Indian, Japanese, Korean, North American, and Singaporean manufacturers, conduct assembly operations that cover light- and heavy-duty vehicles, minibuses, buses, motorcycles, and tractors.

South Africa has assembly operations for trucks with very low local content, and for light commercial vehicles. In Nigeria, assembly operations are mainly for light commercial vehicles. In Kenya, assembly operations are for light- and heavy-duty vehicles, buses, and motorcycles. Botswana assembles some buses and tractors. Ethiopia has begun an ambitious vehicle-assembly activity program, including small assembly operations for electric vehicles and a state-owned firm that assembles a broad range of vehicles for commercial and military purposes (Black & McLennan, 2015; UNEP/CCAC, 2016d).

In 2012, Africa imported approximately 2.2 million cars and motorbikes, supplied directly or indirectly by the European Union (EU), Japan, and the United States (Black & McLennan, 2015; OECD/IEA, 2014; UN COMSTAT, 2014). A large share of the imports consists of secondhand vehicles, except in South Africa, where such imports are strictly banned (Black & McLennan, 2015; OECD/IEA, 2014). In Nigeria, for example, 75% of cars sold in 2014 were used cars, and less than 1% of the cars on Nigeria's roads are new (PWC, 2015). Western Africa imports primarily originate from the EU, with a smaller share from the United States. The region imports arrive through the ports of Cotonou (Benin), Lomé (Togo), Lagos (Nigeria; Black & McLennan, 2015), and Tema (Ghana; UNEP/CCAC, 2016c). In the Southern Africa region, countries import vehicles primarily from Japan and, to some extent, from the Middle East, and vehicles are imported through the port of Durban (South Africa) and through trade corridors starting in East African ports (Black & McLennan, 2015; Brooks, 2012; Lester, 2015).

Black and McLennan (2015) compiled the top 10 sub-Saharan African importers of used and new passenger vehicles from the EU, Japan, and the United States, as shown in Tables 3 and 4. Note that not all of the imported vehicles stay in the country; many are sold in neighboring countries. For example, most of the imports through Lomé (Togo) and Cotonou (Benin) are sold in Niger, Mali, Burkina Faso, and Nigeria. It is estimated that 85% of Benin's imports and 75% of Togo's imports are sold in Nigeria. There is likely an illegal flow of smuggled vehicles in the region, which is not taken into account in those estimates (Assamoi & Liousse, 2010; Beuving, 2004; Black & McLennan, 2015; Golub, 2012).

Table 3. Top 10 sub-Saharan Africa importers of used passenger vehicles from the EU, U.S., and Japan in 2013.*

Country	Number of Passenger Cars Imported	Percentage of top 10 imports
Benin	303,395	37%
Nigeria	223,608	27%
Ghana	69,247	8%
Kenya	57,036	7%
South Africa	50,422	6%
Tanzania	28,173	3%
Guinea	27,585	3%
Cameroon	26,848	3%
Togo	24,119	3%
Uganda	20,527	2%

*Countries in italics are not in the region covered by this report.
Source: Black & McLennan (2015); compilation based on the Eurostat Comext Database, Japanese Customs and Tariff Bureau, and U.S. International Trade Commission.

Table 4. Top 10 sub-Saharan Africa importers of new passenger vehicles from the EU, U.S., and Japan in 2013.*

Country	Number of Passenger Cars Imported	Percentage of top 10 imports
South Africa	169,361	77%
Nigeria	19,671	9%
Benin	8,014	4%
Angola	7,683	3%
Ghana	5,997	3%
Mauritius	2,628	1%
Senegal	2,136	1%
Kenya	2,036	1%
Côte d'Ivoire	2,009	1%
Gabon	1,644	1%

*Countries in italics are not in the region covered by this report.
Source: Black & McLennan (2015); compilation based on the Eurostat Comext Database, Japanese Customs and Tariff Bureau, and U.S. International Trade Commission.

Given the prevalence of imported secondhand vehicles in most sub-Saharan African countries, the vehicle technology included for emission control is strongly linked to those in the vehicles' country of origin, albeit with a time lag. Factors that may impact vehicle performance once they arrive include the extent to which the emissions-control systems have been tampered with or removed during the import process, the lack of fuel required for emission-control technologies to function properly, and poor maintenance. In most countries, regulations on imported secondhand vehicles are weak or non-existent. When those regulations exist, they are mostly in the form of age-based or mileage-based restrictions. For new vehicles, only South Africa and Nigeria have vehicle emissions standards. South Africa in 2006 adopted the Euro 2 for light-duty vehicles (LDVs) and Euro II for heavy-duty vehicles (HDVs), with available matching fuels. Nigeria has adopted Euro 3 vehicle standards for LDVs, but matching fuel is not available to date.

The number of vehicles in sub-Saharan Africa is expected to grow significantly over the next 2 decades. Demand for private vehicles is highly income elastic, and, as the middle class in Africa continues to grow, demand for private vehicles will continue to grow (Black & McLennan, 2015). The International Energy Agency (IEA), in one of its 2040 scenarios, estimates that the population of LDVs will triple by 2040 to more than 50 million vehicles, and the population of commercial vehicles and buses will increase from 8 million in 2012 to 25 million in 2040 (OECD/IEA, 2014). Growth in some markets will be even stronger. South Africa is already a rapidly growing market. By 2030, Nigeria's GDP per capita is projected to exceed $5,000, the level at which LDV ownership accelerates rapidly (Chamon, Mauro, & Okawa, 2014; IMF, 2005; OECD/IEA, 2014).

With rapid urbanization and motorization in cities of sub-Saharan Africa, it is urgent to implement transportation policies that will protect public health. The potential for significant growth in vehicle population in sub-Saharan Africa puts a sharper focus on vehicles' contribution to air pollution and its health burden, as well as highlights the need to mitigate these impacts through clean fuels and vehicles policies.

Section 1 of this report provides an overview of the air quality and health impacts of road transportation in the sub-Saharan African context. A more detailed description of those impacts, along with benefits of clean fuels and vehicles are provided in Appendix B. Section 2 provides a comprehensive picture of fuel in both regions. It analyzes fuel flows, fuel sulfur content, current and projected fuel consumption, and refinery operations in each region. Similarly, Section 3 provides a picture of vehicle flows and stocks and regulations in both markets. Section 4 outlines major barriers to the adoption of clean fuels and clean vehicles, along with opportunities to overcome those barriers. Section 5 presents results from a modeling exercise to assess the benefits of recommended policies within specified timelines in Nigeria; Section 5 also acknowledges the limitations of the study and suggests next steps to be considered by stakeholders. Finally, Section 6 closes with the policy recommendations.

SECTION 1

Air quality, transportation, and health impacts in sub-Saharan Africa, and the case for low-sulfur fuels and clean vehicles

Outdoor air pollution is one of the leading contributors to the global burden of disease. In 2013, 3.1 million early deaths were caused by exposure to particulate matter ($PM_{2.5}$) and ozone (IHME, 2016; Vos et al., 2015). Air pollution from $PM_{2.5}$ emissions has been identified as responsible for strokes, ischaemic heart disease, acute lower respiratory disease, chronic obstructive pulmonary disease, and lung cancer (Scovronick, 2015; WHO, 2014a). Ground-level ozone (O_3), better known as *smog*, is a key factor in chronic respiratory diseases, such as asthma. Additionally, these pollutants harm agricultural productivity and lead to lost work days, school absence days, and decreased productivity for outdoor workers. Road transportation (e.g., via light- and heavy-duty vehicles, buses and minibuses, and two- and three-wheelers) is an important source of $PM_{2.5}$ and one of the largest sources of nitrogen oxides (NO_X)—a pollutant that leads to ozone formation. Additionally, on average, exposure to vehicle emissions likely greater than those from other sources because vehicle exhaust pipes are closer to the ground and therefore to a region's inhabitants (OECD/IEA, 2016). A sharper focus should be put on diesel vehicles; uncontrolled diesel engines typically emit more NO_x, and $PM_{2.5}$ than do gasoline engines (Bond et al., 2013). In 2012, the International Agency for Research on Cancer (IARC) declared diesel exhaust carcinogenic to humans (IARC, 2014; Scovronick, 2015; U.S. EPA , 2012). Diesel engines are also an important source of BC emissions, a component of $PM_{2.5}$ and an SLCP. With a short lifetime in the atmosphere (up to 10 days) and the second strongest warming potential, BC penetrates deeply into the lungs, is associated with all-cause and cardiopulmonary mortality, and negatively impacts climate and weather (Scovronick, 2015).

Sub-Saharan Africa is increasingly relying on motor vehicles for the transportation of persons and goods (Thambiran & Diab, 2011). Quantifying the significance of vehicle emissions to air pollution mortality and morbidity in Southern and Western Africa is a challenge. Air quality is poorly monitored, and there has been very limited research detailing the contribution of road transportation. Detailed data on individual countries' air pollution levels are scarce, and many cities still lack air-quality-monitoring systems (WHO, 2014b). These factors make it difficult to assess the overall level of air pollution and to quantify the related disease burden. Even when the burden of disease is quantified, identifying the sources responsible and the impact of each source could be difficult, because the level of toxicity of pollutants may vary across sources (Lelieveld, Evans, Fnais, Giannadaki, & Pozzer, 2015).

Despite the need for further research, the seemingly low contribution of vehicle emissions to air pollution when considered nationwide, and the existence of other urgent issues that rank high on countries' policy agendas (e.g., poverty eradication, access to education, and healthcare), at least four factors make the adoption of clean fuels and vehicles standards a serious area for quick policy action: (a) African economies are projected to grow substantially; (b) large cities in Southern and Western Africa have been increasingly concerned with high levels of air pollution, including from vehicles; (c) buses, minibuses, and informal buses are ideal targets that will achieve substantial emissions reductions in the near-term; and (d) cost-effective solutions exist for cleaning up fuels and vehicles in Africa that will generate not only benefits, but also co-benefits in terms of the climate, air quality, and social benefits. These factors are discussed in more detail in the following sections.

1. African economies are expected to have a medium-term growth under specified conditions (African Economic Outlook, 2015). According to the World Bank, economic growth is associated with increased motorization, for passengers and freight transportation (Global Road Safety Facility, The World Bank; Institute for Health Metrics and Evaluation, 2014), which would result in an imbalance between the projected economic growth and the emissions from an increasing fleet of motor vehicles on the current trajectory. Transportation is a crucial driver of economic growth and poverty reduction (World Bank, 2013). Some countries in the region, including South Africa and Nigeria, in addition to economic growth, will also record growth in GDP per capita, further contributing to their vehicle ownership being even stronger. Studies by the International Monetary Fund (IMF) indicate a strong association between GDP per capita and vehicle ownership: vehicle ownership starts to grow quickly when countries reach an income of about $2,500 per capita in purchasing-power-parity (PPP) terms. Rapid growth continues until per-capita income reaches about $10,000. Saturation level is at about 850 vehicles per 1,000 people (IMF, 2005). South Africa is already a rapidly growing market. By 2030, Nigeria's per-capita GDP is projected to exceed $5,000, the level at which passenger vehicle ownership accelerates rapidly (Chamon et al., 2014; IMF, 2005; OECD/IEA, 2014). Therefore, African governments have the opportunity to couple their economic growth with sustainable transport choices—particularly clean fuels and vehicles policies—that will contribute to meeting their Sustainable Development Goals.

2. Large cities in Southern and Western Africa have been increasingly concerned with high levels of air pollution, including from vehicles. The Global Burden of Disease, an effort to quantify the burden from several diseases, including those linked to $PM_{2.5}$ and ozone, shows in its 2013 update that exposure to $PM_{2.5}$ and ozone has caused thousands of deaths across Southern and Western Africa. In Southern Africa, both $PM_{2.5}$ and ozone pollution led to approximately 90,000 deaths in 2013. In the same year, ozone pollution was responsible for approximately 4,000 deaths in Western Africa, with one fourth of the disease burden in Nigeria. $PM_{2.5}$ was responsible for approximately 125,000 premature deaths in Western Africa. Overall, Nigeria ranked 12th in the global burden of disease, recording increased premature deaths from ozone (IHME, 2016). Figures 7 and 8 illustrate the disease burden from $PM_{2.5}$ and ozone in both regions.

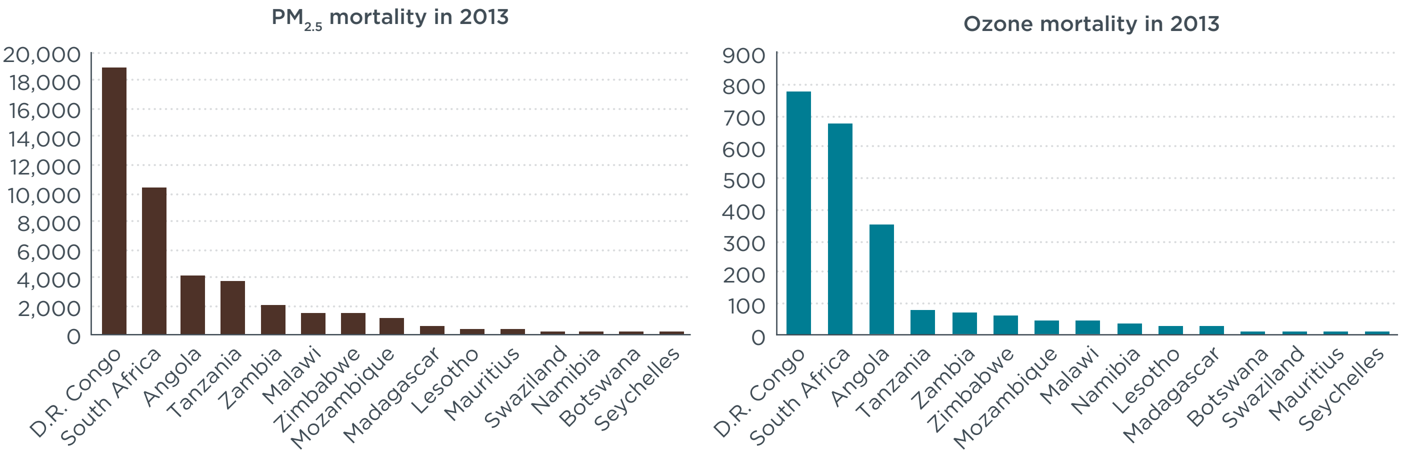

Figure 7. $PM_{2.5}$ and ozone mortality in Southern Africa in 2013.
Source: IHME (2016)

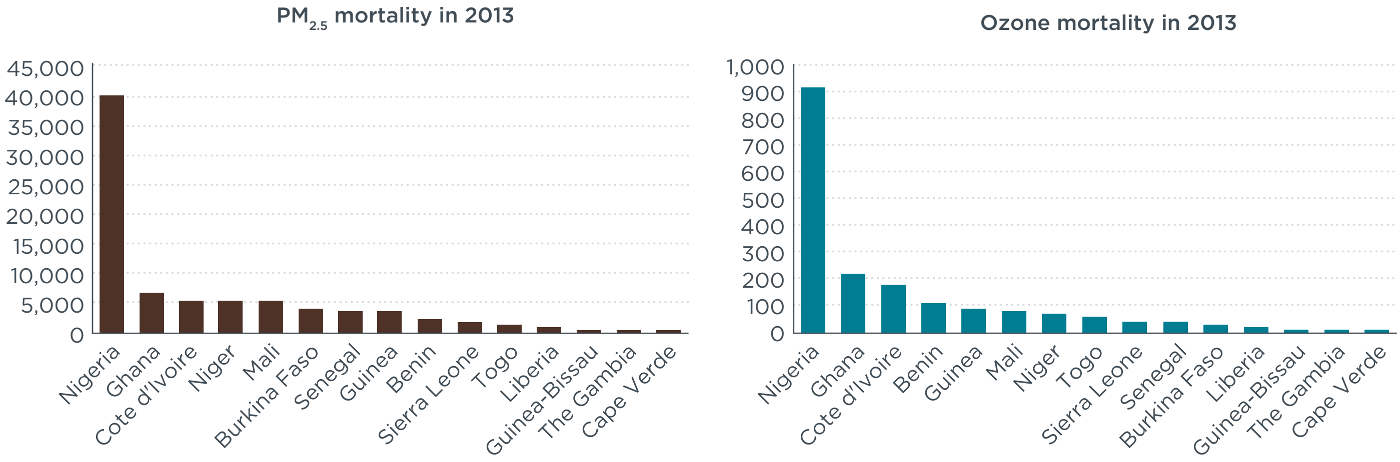

Figure 8. $PM_{2.5}$ and ozone mortality in Western Africa in 2013.
Source: IHME (2016)

At the city level, the situation is alarming. Almost all African cities reporting on the WHO air-pollution-monitoring system fail to meet the maximum admitted levels of $PM_{2.5}$ annual mean of 10 µg/m^3 (Scovronick, 2015). Although Nigeria's ozone air pollution is linked to sources including the oil and gas industry in the Delta Niger, as a result of flaring, illegal oil refining, gas leakage, and venting, in the Megacity of Lagos, ozone pollution is comparable to the levels in India and China (Marais et al., 2014). Therefore, the contribution of high-sulfur diesel fuels used for vehicles and diesel-powered backup generators needs closer examination. Figure 9 compares air pollution levels in cities of Southern and Western African with the WHO air quality guidelines for $PM_{2.5}$.

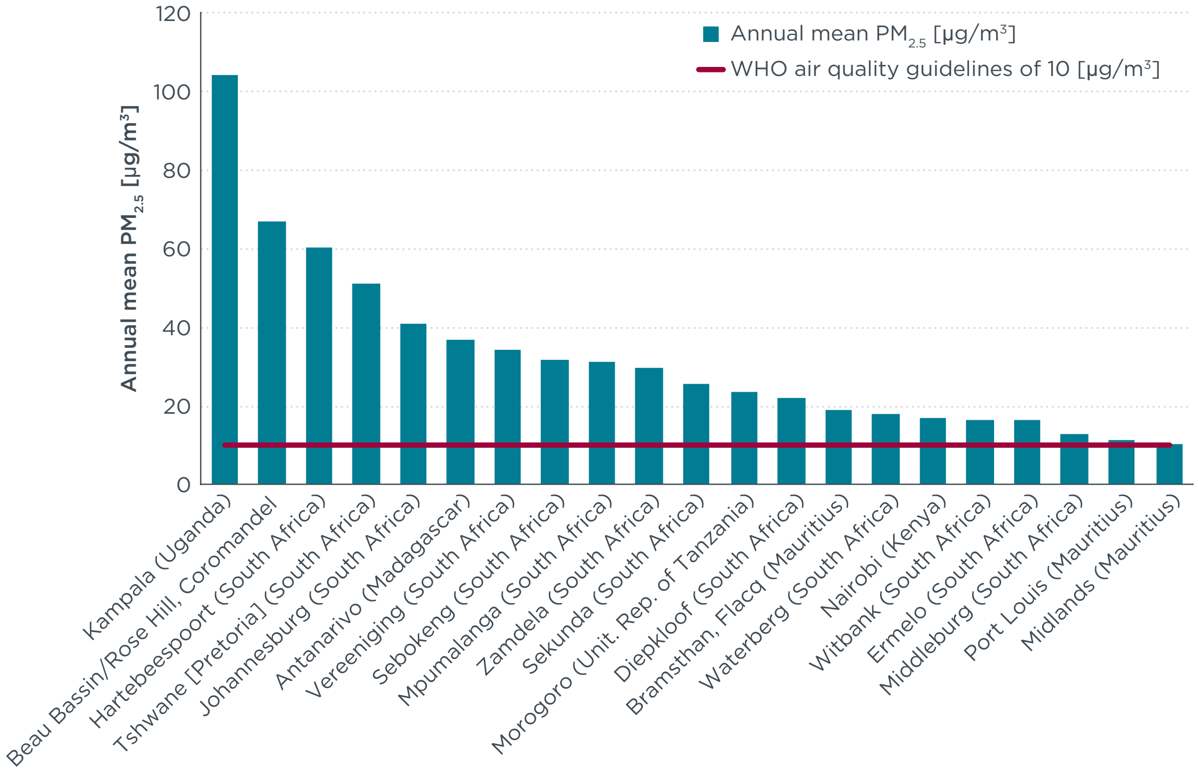

Figure 9. Annual mean of $PM_{2.5}$ in cities of Southern and Western Africa compared with the WHO air quality guidelines for $PM_{2.5}$.
Source: WHO (2014b)

According to studies conducted across Southern and Western Africa, exposure from transportation emissions has become a major concern in cities. In Western Africa, Knippertz et al. (2015), in their study *The possible role of local air pollution in climate change in West Africa*, argue that air pollution should be rapidly targeted in West Africa, because cities are growing explosively, and emissions inventories need to be developed for key sectors such as road transport. Although part of West African air pollution is derived from natural sources, there is an alarming interplay of anthropogenic sources of air pollution, including from vehicle traffic, that have been underestimated (Knippertz et al., 2015). In Accra, Arku et al. (2014), in *Personal particulate matter exposures and locations of students in four neighborhoods in Accra, Ghana*, find that school proximity to major roads, along with materials of school surfaces and biomass use, are likely to be important determinants of students' exposure to air pollution. In their study *Air pollution and climate change co-benefit opportunities in the road transportation sector in Durban, South Africa*, Thambiran & Diab (2011) identified road transportation in Durban as a significant emitter of carbon monoxide (CO), nitrogen oxides (NO_X), and particulate matter (PM) emissions. The African Monsoon Multidisciplinary Analyses (AMMA) and the African Capitals Pollution (POLCA) programs have also pointed to road traffic as a growing source of urban air pollution. Based on observations from the AMMA program, Liousse et al. (2014) report, in *Explosive growth in African combustion emissions from 2005 to 2030*, that anthropogenic sources—mostly traffic and open burning of biomass in Western Africa—have had a significant impact on urban air quality. The related BC emissions, CO, NO_X, and SO_2 are projected to increase if no regulations are implemented (Liousse et al., 2014). The AMMA program also records a significant level of emissions from two-wheelers in Bamako and Cotonou (Liousse et al., 2014; Val et al., 2013). Similarly, the AMMA and POLCA programs measured real-time emissions of BC between 2005 and 2010 in Cotonou, Dakar, and Bamako. Results indicate that traffic contributes up to 88% versus 12% for biomass burning during certain periods, with emissions reaching higher levels during peak hours and lower levels during school vacations, reduced travel activity times, and on Sundays in Dakar (Doumbia et al., 2012). Doumbia et al. (2012) conclude that urban areas are emissions hotspots, and they identify vehicle engines among the leading sources. Outside the Southern and Western Africa regions, in their study *Occupational exposure to roadway emissions and inside informal settlements in sub-Saharan Africa: A pilot study in Nairobi, Kenya*, Ngo et al. (2015) find a higher level of exposure to pollutants for population groups leaving or working near major roads and suggest policies that target diesel vehicles, dust, and trash burning. Similarly, Kinney et al. (2011), in *Traffic Impacts on* $PM_{2.5}$ *Air Quality in Nairobi, Kenya*, conclude that "many Nairobi residents are exposed on a regular basis to elevated concentrations of fine particle air pollution, with potentially serious long-term implications for health," especially "people who spend more time on or nearby roadways such as motorists, pedestrians, traffic police, or those engaged in informal businesses along roadways."

Because of the limited available data, the impacts of vehicle emissions on air quality and public health seem to be underestimated (Global Road Safety Facility, The World Bank; Institute for Health Metrics and Evaluation, 2014).

1. Buses, minibuses, and informal buses are ideal targets that will achieve substantial emissions reductions in the near term. These vehicles are driven most of the time; have bigger engine sizes; are generally older when compared with the rest of the fleet; consume high-sulfur diesel fuels or adulterated fuel (in the hope of better profits); and are sources of harmful air pollutants, such as diesel particulate matter and BC (Kumar, Singh, Ghate, Pal, & Wilson, 2016; OECD/IEA, 2014). With cities facing rapid urbanization, there is an unprecedented demand for transportation services, which is putting pressure on governments. The lack or shortage of mobility services has led to the rise of informal public transportation in the form of buses, minibuses, or other informal buses (Kumar et al., 2016). *Informal public transportation services* refer to public transportation services that are different than the typical government-provided bus- and rail-based transportation in cities and exist mostly in the form of shared services, using vehicles with seating capacity ranging from 3 to 20 people (Cervero & Golub, 2007; Gwilliam, 2002; Kumar et al., 2016). The services are provided by private-sector entities, some of which do not comply with the government rules and regulations. These informal transportation modes are important because they complement or fill the gaps left by the government's system and respond to the increasing need for mobility by providing frequent, convenient, flexible, and affordable services (Cervero, 2000; Cervero & Golub, 2007; de la Pena & Albright, 2013; Institute of Urban Transport, 2014; Kumar et al., 2016; Shimazaki & Rahman, 1996). Yet, those transportation systems come with many externalities and deserve greater attention. In sub-Saharan Africa, older diesel vehicles are prevalent (UNEP, n.d.). About 75% of the total particle emissions from older diesel vehicles is BC (Bond, et al., 2013; Scovronick, 2015; UNEP-WMO, 2011). In Dakar, old vehicles, heavy-duty vehicles, and minibuses using low-quality diesel are important sources of traffic-related pollution

(Doumbia et al., 2012; Val, et al., 2013). Cleaning up the formal and informal public transportation sectors will not only reduce the health and climate burden from the sector, it can also catalyze efforts to improve service, efficiency, and access. Our modeling exercise in Section 6 specifically assesses the potential benefits of a strategy focused on cleaning up buses, minibuses, and trucks.

2. Cost-effective solutions exist for cleaning up fuels and vehicles in Africa that will generate not only benefits, but also co-benefits in terms of the climate, air quality, and social benefits (Thambiran & Diab, 2011). Decades of experience to reduce emissions from vehicles worldwide indicate that fuels and vehicles act as a system, and effective control of emissions require clean, low-sulfur fuels and clean vehicles. Specifically, low-sulfur fuels reduce the overall sulfate emissions, enable the effective use of vehicle emission control (as described in Appendix B), and optimize the lifetime of vehicles (UNEP/PCFV, 2014). Addressing air pollution and its health impacts are well beyond the control of individuals (WHO, 2014a) and require actions from policymakers at the city and national levels. The co-benefit approach has been successfully applied in the road transportation sector in cities such as Bogota (Thambiran & Diab, 2011; Woodcock, Banister, Edwards, Prentice, & Roberts, 2007) and Mexico City (McKinley et al., 2005; Thambiran & Diab, 2011). The approach takes into account greenhouse gas (GHG) and air quality objectives, includes the trade-off between those objectives, and allows for more effective emissions-reductions strategies. Those integrated approaches are lower in cost and less difficult to implement compared with each approach taken independently (Thambiran & Diab, 2011). Furthermore, the health benefits are realized locally and in the near term. Some transportation policies are straightforward and have the potential to produce (in some cases, immediate) benefits for health through emission reductions from existing vehicle fleets (Scovronick, 2015). Addressing the SLCP elements (including BC and ozone) contributes to mitigate near-term climate change. BC and ozone precursors are emitted along with other pollutants; therefore, policies to reduce BC and ozone will also reduce other pollutants directly or indirectly (Bond et al., 2013).

To develop clean fuels and vehicles policies and reduce transportation-related air pollution in Southern and Western Africa, it is important to understand existing fuels markets and the baseline characteristics of the vehicle fleet.

SECTION 2

Fuel flows and fuel sulfur levels in Southern and Western Africa

Accessing updated data on fuel consumption in sub-Saharan Africa is challenging, given the gaps or lack of publicly available official data for individual countries. For this report, CITAC, a consulting firm that specializes in the downstream oil sector in Africa, was contracted. This section focuses on gasoline and diesel consumption in each country, pricing, and the regional projections of fuel demand. These are important factors to establishing effective clean fuels policies, because they quantify current and future emissions of transportation-related air pollutants, define the type and anticipated effects of policy interventions, and help with understanding the price control that drives the adoption of specific fuels and affects key stakeholders, such as refiners.

I. DIESEL AND GASOLINE CONSUMPTION

Transportation energy use in Southern and Western Africa is mostly dominated by road transportation, as rail and air transportation are still underdeveloped. The regional data is skewed by the large markets. In Southern Africa, South Africa accounts for 59% of the fuel consumed on a volume basis. Most of the fuel consumed in this region is diesel. In Western Africa, Nigeria is the largest market, with 65% of the regional consumption, and the country's consumption is dominated by gasoline. On average, the diesel pump price is lower than gasoline prices in most countries. In a few countries (Lesotho, Malawi, Liberia, and Togo), gasoline is slightly cheaper than diesel (by less than 10%). In some countries, prices are fully controlled by the government in the form of consumers' subsidies. The lower crude oil price has put pressure on producer countries and provided a window of opportunity for non-producers to reduce subsidies. Most governments reduce subsidies while maintaining price structure, and talks about abolishing price structures have been limited, to date (CITAC/ICCT, 2016). Relatively lower domestic prices spur unofficial cross-border flows, such as smuggling. For example, lower prices in Nigeria could lead to unofficial exports to Togo and Benin (OECD/IEA, 2014). However, a few countries, including Nigeria and Angola, were successful in removing subsidies. In Nigeria, in 2013, the subsidization rate (relative to the benchmark price) for gasoline was estimated to be around 29% (OECD/IEA, 2014). As of January 2016, diesel pump prices exceeded gasoline prices by up to 40%. Gasoline was subsidized and amounted to 84% of the country's total fuel consumption (CITAC/ICCT, 2016). In 2016, the country removed kerosene subsidies, resulting in a 66% increase in pump prices (CITAC/ICCT, 2016), followed by a removal of gasoline subsidies (official source). In Angola, there has been continued liberalization with removal of all subsidies on diesel (CITAC/ICCT, 2016).

In Tables 5 and 6, within each country, the current price per liter of diesel and gasoline is provided, along with the percentage of national consumption of diesel and gasoline. For the volume of fuel consumption in each country, see Appendix C.

Table 5. Share of diesel versus gasoline consumption in Southern Africa in 2014.

Country	Percentage diesel in 2014	Diesel pump price (US ¢/ liter as of January 2016)	Percentage gasoline (share by volume in 2014)	Gasoline pump price (US ¢/liter as of January 2016)
Angola	70%	100	30%	119
Botswana	55%	71	45%	72
DRC	66%	157	34%	158
Lesotho	50%	63	50%	61
Madagascar	81%	99	19%	116
Malawi	63%	113	37%	110
Mauritius	61%	92	39%	116
Mozambique	76%	79	24%	101
Namibia	64%	63	36%	68
Seychelles	75%	127	25%	132
South Africa	53%	71–72	47%	80–77
Swaziland	54%	72	46%	73
Tanzania	68%	81	32%	88
Zambia	67%	78–99	33%	90
Zimbabwe	69%	115	31%	128

Table 6. Share of diesel versus gasoline consumption and fuel prices in Western Africa in 2014.

Country	Percentage diesel (share by volume in 2014)	Diesel pump price (US ¢/ liter as of January 2016)	Percentage gasoline (share by volume in 2014)	Gasoline pump price (¢/ liter as of January 2016)
Benin	73%	67	27%	73
Burkina Faso	63%	96	37%	109
Cape Verde	92%	87	8%	107
Côte d’Ivoire	73%	95	27%	100
The Gambia	78%	145	22%	150
Ghana	56%	87	44%	92
Guinea	51%	106	49%	106
Guinea-Bissau	77%	-	23%	-
Liberia	54%	85	46%	83
Mali	83%	104	17%	119
Niger	62%	90	38%	90
Nigeria	16%	61	84%	43
Senegal	84%	115	16%	132
Sierra Leone	67%	92	33%	92
Togo	57%	94	43%	87

II. FUEL SUPPLY IN SOUTHERN AND WESTERN AFRICA

Sub-Saharan Africa relies heavily on imports of refined products to meet its domestic demand. Although countries such as Nigeria and Angola are crude oil producers, they import most of their refined products.

The three main producers of sweet crude oil in Western Africa are Nigeria (the largest producer of crude in the region), Côte d'Ivoire, and Ghana. They export most of their crude oil out of the region to Europe, the United States, India, and Brazil (ICCT/UNEP, 2014; OECD/IEA, 2014). There are some flows of crude oil within the region, dominated by imports of crude oil from Nigeria to Côte d'Ivoire.

In Southern Africa, Angola remains the major producer, exporting most of its sweet crude oil out of the region, and the remainder to South Africa (ICCT/UNEP, 2014). Major destinations of African crude oil are Europe, India, China, and the United States. Europe has become a major destination and has increased its demand of sub-Saharan oil to cover its declining oil production and compensate Libyan oil disruption. Chinese refinery expansions have provided additional markets (OECD/IEA, 2014).

Gasoline and diesel consumed in the regions are primarily imported from Northwestern Europe and the Mediterranean, the Atlantic Basin (United States and Caribbean), India, and the Middle East (CITAC/ICCT, 2016). As the largest consumer of oil products, Nigeria imports—by a significant margin—refined products from outside the region (ICCT/UNEP, 2014). Niger has a small production, which is exported to Nigeria as refined products (OECD/IEA, 2014). Côte d'Ivoire is the main supplier of refined products to other nations in West Africa. The country refines oil products for its own consumption and exports to 12 countries in the region (Benin, Burkina Faso, The Gambia, Ghana, Guinea, Liberia, Mali, Niger, Nigeria Senegal, Sierra Leone, and Togo) (ICCT/UNEP, 2014). Although smaller in scale and influence, Senegal also acts as a refining hub by importing Nigerian crude, refining it for internal use, and exporting it to five of its neighbors (Guinea, Guinea Bissau, Liberia, Mali, and Sierra Leone) (ICCT/UNEP, 2014).

In Southern Africa, South Africa imports 95% of its crude oil requirements (OECD/IEA, 2014), but it is the major refining country and a key importing source for Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Zambia, and Zimbabwe (CITAC/ICCT, 2016; ICCT/UNEP, 2014). South Africa imports 95% of its crude oil requirements. The region is supplied from Asia, Europe, India, and the United States (CITAC/ICCT, 2016). Angola, a major exporter of crude oil, imports refined products, whereas Mozambique serve as a second hub, importing and then re-exporting to Malawi and Zimbabwe (ICCT/UNEP, 2014). Figures 10 and 11 summarize the gasoline and diesel imports to each region.

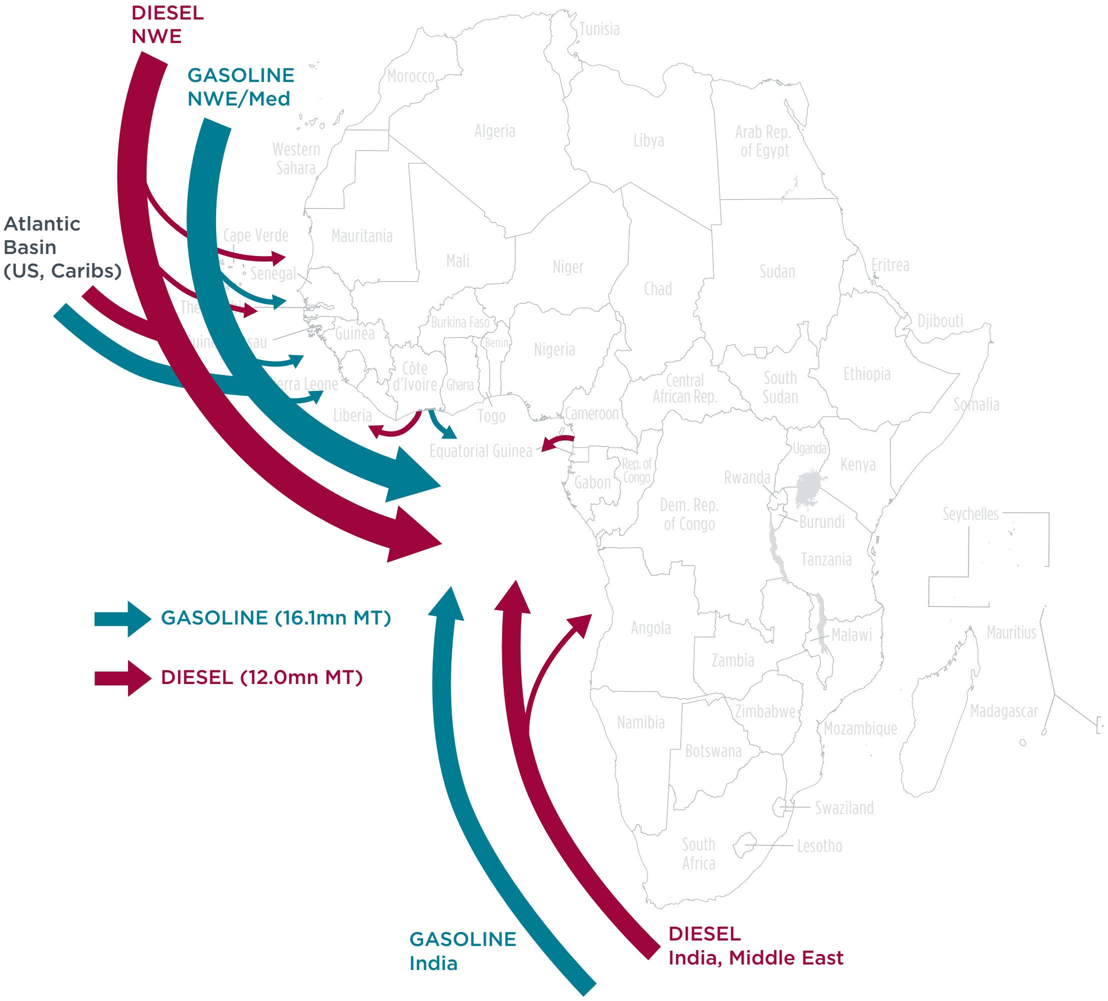

Figure 10. Gasoline and diesel imports to Western Africa in 2014.
Source: CITAC/ICCT (2016)

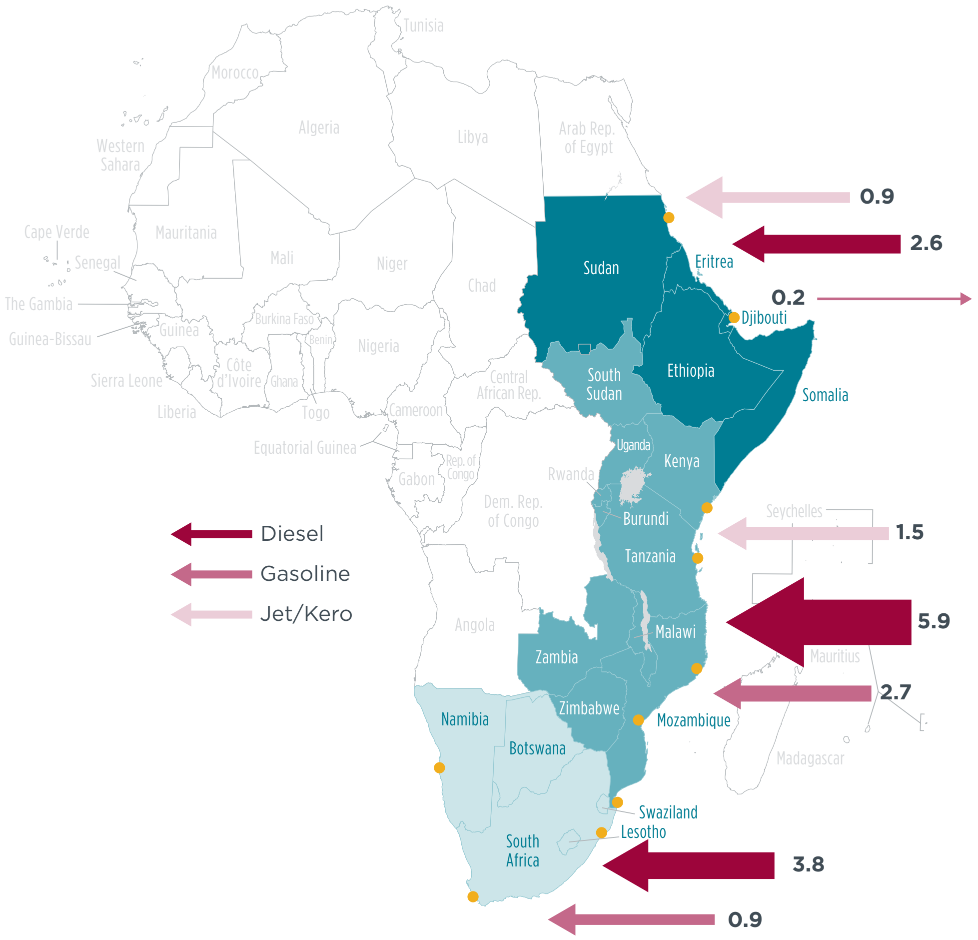

Figure 11. Gasoline and diesel imports to Southern Africa in 2014.
Source: CITAC/ICCT (2016)

III. REFINERIES OPERATIONS

Sub-Saharan Africa's refineries are decades old and in relatively poor condition due to years of underinvestment, which has made their operations less profitable (OECD/IEA, 2014). Additionally, they suffer from weak refinery capacities. Since the 1980s, several refineries have been closed in the Democratic Republic of Congo, Madagascar, Mozambique, Tanzania, and Zimbabwe in the Southern African region; and Liberia, Sierra Leone, and Togo in the Western African region. In Southern Africa, South Africa is the primary hub in the region, with the third largest refinery system in Africa, after Algeria and Egypt. In South Africa, most of the refined products consumed are refined in the country. South Africa's refineries run at approximately 90% utilization rates and supply more than two thirds of the domestic market (OECD/IEA, 2014). Fuel imports are dependent on demand and refinery operations. South Africa only imports products if there is an internal shortfall (CITAC/ICCT, 2016; ICCT/UNEP, 2014). In 2014, in Eastern and Southern Africa, refinery output was approximately 30 million metric tons, whereas in Western and Central Africa, refinery output reached approximately 14 million metric tons (CITAC/ICCT, 2016).

West African refineries tend to be small, simple, and characterized by high fixed costs and a lack of available finance. In Western Africa, refineries have recorded progress in their operations in 2014, particularly in Côte d'Ivoire with SIR and SMB and in Senegal with SAR. However, most refineries operated below their nameplate capacities (CITAC/ICCT, 2016). Nigeria's refineries run at approximately 20%, with some units at the KRPC, PHRC, and WRPC on frequent remedial maintenance (CITAC/ICCT, 2016; OECD/IEA, 2014). Tables 7 and 8 present refineries in both regions. Figures 12 and 13 indicate the historical progress of refinery output in both regions.

Table 7. Refineries in Southern Africa as of 2016.

Country	Refinery	Capacity (thousands of barrels per day)
Angola	Sonaref	65
South Africa	Chevref	100
	Enref	122
	Natref	108
	Sapref	180
	PetroSA GTL	45 (barrels of oil equivalent)
	Sasol CTL	160 (barrels of oil equivalent)
Zambia	Indeni*	26

*Supplies only to copper mines.
Source: CITAC/ICCT (2016)

Table 8. Refineries in Western Africa as of 2016.

Country	Refinery	Capacity (thousands of barrels per day)
Côte d'Ivoire	Société Ivoirienne de Raffinage (SIR)	68
	Société Multinationale de Bitumes (SMB)*	10
Ghana	Tema Oil Refinery (TOR)	45
Niger	Société de Raffinage de Zinder (SORAZ)	20
Nigeria	Kaduna Refining & Petrochemical Company (KRPC)	110
	Port Harcourt Refinery Company (PHRC)	210
	Warri Refinery & Petrochemicals Company (WRPC)	125
Senegal	Société Africaine de Raffinage (SAR)	27

*Principally a bitumen plant. Clean products are fed into the system at SIR.
Source: CITAC/ICCT (2016)

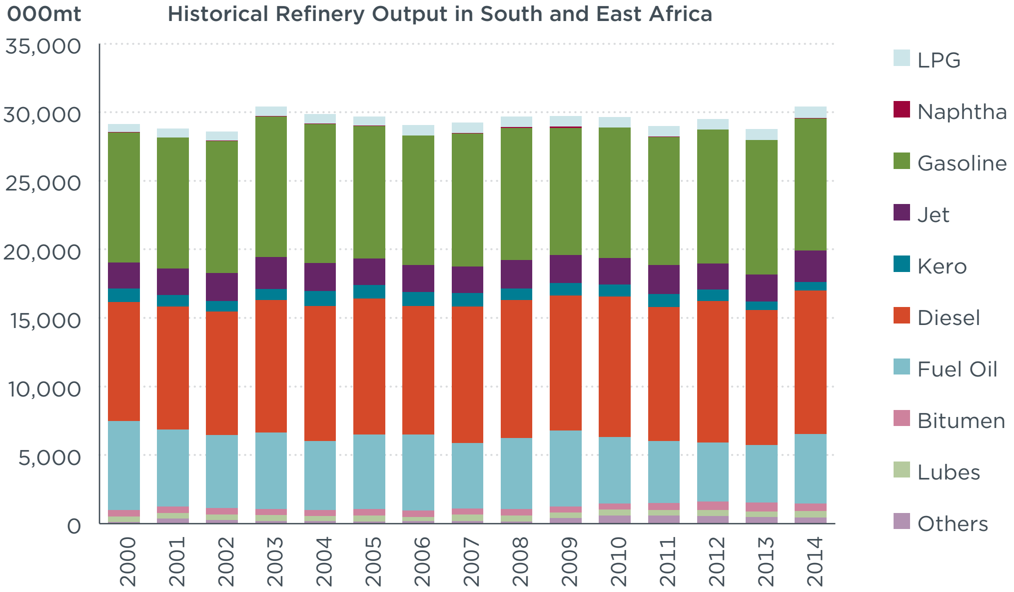

Figure 12. Historical refinery output in Eastern and Southern Africa.
Source: CITAC/ICCT (2016)

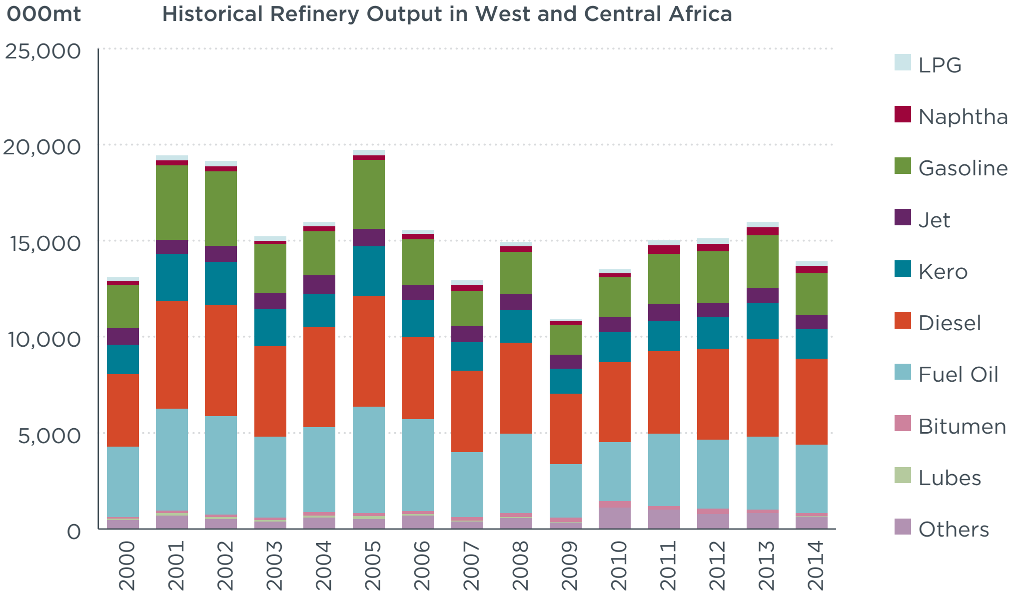

Figure 13. Historical refinery output in West and Central Africa.
Source: CITAC/ICCT (2016)

IV. FUEL SULFUR IN SOUTHERN AND WESTERN AFRICA

A baseline study of fuel sulfur content, prepared by CITAC for the ICCT, reveals that diesel sulfur levels in Southern and Western Africa are among the highest in the world (CITAC/ICCT, 2016). Levels in Western Africa are much more elevated than in Southern Africa. None of the 15 countries in Western Africa have met 50-ppm diesel sulfur level to date, but five countries in the region have committed to ban the imports of high-sulfur fuels by July 2017 (UNEP/CCAC, 2016a). In the region, diesel sulfur levels range between 1,000 ppm and 10,000 ppm. Approximately one third of the countries have diesel sulfur content that exceeds 5,000 ppm (i.e., Burkina Faso, The Gambia, Guinea-Bissau, Mali, Senegal, and Togo).

In Southern Africa, diesel sulfur levels range between 50 ppm and 5,000 ppm. Tanzania and Mauritius have made more progress than the other countries in the region regarding diesel sulfur levels; both countries have already reached 50-ppm diesel sulfur content nationwide. Tanzania is part of the East African regional framework that enabled Eastern Africa's countries to move to 50-ppm diesel sulfur fuel in January 2015, including Burundi, Kenya, Rwanda, and Uganda (ICCT/UNEP, 2016). South Africa and countries that depend on South African fuels—Botswana, Lesotho, Namibia, and Swaziland—have two grades, 500-ppm and 50-ppm diesel sulfur fuels, and these countries need to make 50-ppm diesel sulfur fuels available nationwide. Finally, Angola, Madagascar, and the Seychelles still have diesel sulfur levels that exceed 500 ppm nationwide.

Although this report focuses primarily on diesel sulfur content, countries also need to move to upgrade their gasoline sulfur content to 150 ppm and impose limits on benzene and aromatics content to 3%. Gasoline sulfur levels in both regions are high, but levels in Western Africa are higher than in Southern Africa. In Western Africa, Côte d'Ivoire and Cape Verde are the best performers, with gasoline sulfur levels of 150 ppm or less. However, Benin, Guinea-Bissau, Liberia, and Togo have sulfur levels greater than 2,000 ppm. In Southern Africa, gasoline sulfur content ranges between 150 ppm and 2,000 ppm. The Seychelles and Tanzania have cleaner gasoline, with sulfur content of 150 ppm or less, whereas gasoline sulfur content in Madagascar still exceeds 2,000 ppm.

Tables 9 and 10 provide gasoline and diesel sulfur levels in both regions. Figure 14 summarizes the sulfur content of diesel fuels in both regions.

Table 9. Fuel sulfur level in Southern Africa as of 2016.

	Diesel (Max Sulfur, ppm)		Gasoline (Max Sulfur, ppm)		
Country	**Current standards**	**Planned standards**	**Current standards**	**Planned standards**	**Scope of activities**
Angola	1,500	-	500	-	-
Botswana	50-500	10		10	Dependent on South Africa, In 2015, 60% of imports came from South Africa, and 6% of fuel imported is already 50 ppm.
DR Congo	500	-	300	-	Geographically diverse market, with three distinct supply chains, two of which depend on imports from other countries.
Lesotho	50-500	10	500	10	Entirely dependent on South Africa.
Madagascar	5,000	500	2,000	-	
Malawi	50-500	-	1,000	-	Most refined products come from Mozambique, partly supplied by Tanzania. Refined products supplied by Tanzania are already at 50 ppm.
Mauritius	50	-	1,000	-	-
Mozambique	500	-	1,000	-	Has implemented 500 ppm diesel fuels since 2005. Most of the fuel comes from the Middle East through international tender.
Namibia	50-500	10	500	10	Dependent on South Africa.
Seychelles	500-5,000	-	110	-	-
South Africa	50-500	10	500	10	There is a commitment to deliver 10-ppm fuels by 2017 under the Department of Energy CF2 program. 43% of diesel fuel sold is 50 ppm as of 2016.
Swaziland	50-500	10	500	10	Entirely dependent on South Africa.
Tanzania	50	-	150	-	-
Zambia	500	-	1,000	-	-
Zimbabwe	500	-	500	-	Partly supplied by Mozambique.

🟩 50 ppm or less nationwide 🟨 50-500 ppm 🟥 Above 500 ppm 🟦 Country with refinery operations

Source: CITAC/ICCT (2016); UNEP/CCAC (2016d)

Table 10. Fuel sulfur level in Western Africa as of 2016.

	Diesel (Max Sulfur, ppm)		Gasoline (Max Sulfur, ppm)		
Country	**Current standards**	**Planned standards**	**Current standards**	**Planned standards**	**Scope of activities**
Benin	3,500	50	3,500	-	Has planned to import 50 ppm diesel fuels by July 2017.Suppliers include Côte d'Ivoire
Burkina Faso	10,000	-	500	-	Complex supply route, suppliers include Côte d'Ivoire and Togo. Sonabhy (the national oil company) is the major importing company.
Cape Verde	1,000	-	50	-	-
Côte d'Ivoire	3,500	50	150	-	Refines for its own consumption and exports within the region, currently refines AFRI-2 diesel and AFRI-3 gasoline.
The Gambia	5,000	-	500	-	
Ghana	3,000	50	1,000	-	Has planned to import 50-ppm diesel fuels by July 2017. National specifications amended from maximum sulfur content of 3,000 to 5,000 ppm since January 2014, in collaboration with the Ghana Standards Authority. The profile of sulfur levels in imported diesel as follows: 2013: 3,100 ppm; 2014: 2,270 ppm; 2015: 2,200–2,480 ppm (Ghana de-regulation regime); 2016: 2,000–2,500 ppm. Legislated sulfur limit of gasoline/petrol is 1,000 ppm. Profile of sulfur content in imported gasoline: 2013: 160 ppm; 2014: 130 ppm; 2015: 180–200 ppm; 2016: 180–200 ppm.
Guinea	2,000	-	1,500	-	Suppliers include Côte d'Ivoire and Senegal. A new modular refinery has been announced in Kamsar.
Guinea-Bissau	5,000	-	2,500	-	Suppliers include Senegal
Liberia	3,000	-	2,500	-	
Mali	10,000	-	500	-	Suppliers include Benin, Côte d'Ivoire, and Togo. The country has several small importing companies. Complex supply route.
Niger	2,000	-	1,000	-	Refines for its own consumption and export partly to Nigeria.
Nigeria	3,000	50	1,000	-	Has planned to import 50-ppm low-sulfur fuels by July 2017. Suppliers of refined products include Côte d'Ivoire. Refinery projects to build a new refinery and upgrade existing ones have been announced.
Senegal	5,000	-	1,000	-	Suppliers include Côte d'Ivoire and the SAR (local refinery).
Sierra Leone	3,000	-	1,000	-	
Togo	10,000	50	2,500	-	In 2016, sulfur content of imported diesel was between 3,000 and 7,000 ppm. The country has planned to import 50-ppm diesel fuels by July 2017. Imports are done through international tenders. Suppliers include Côte d'Ivoire.

🟩 50 ppm or less nationwide 🟨 50-500 ppm 🟥 Above 500 ppm 🟦 Country with refinery operations

Source: CITAC/ICCT (2016); UNEP/CCAC (2016a); UNEP/CCAC (2016c)

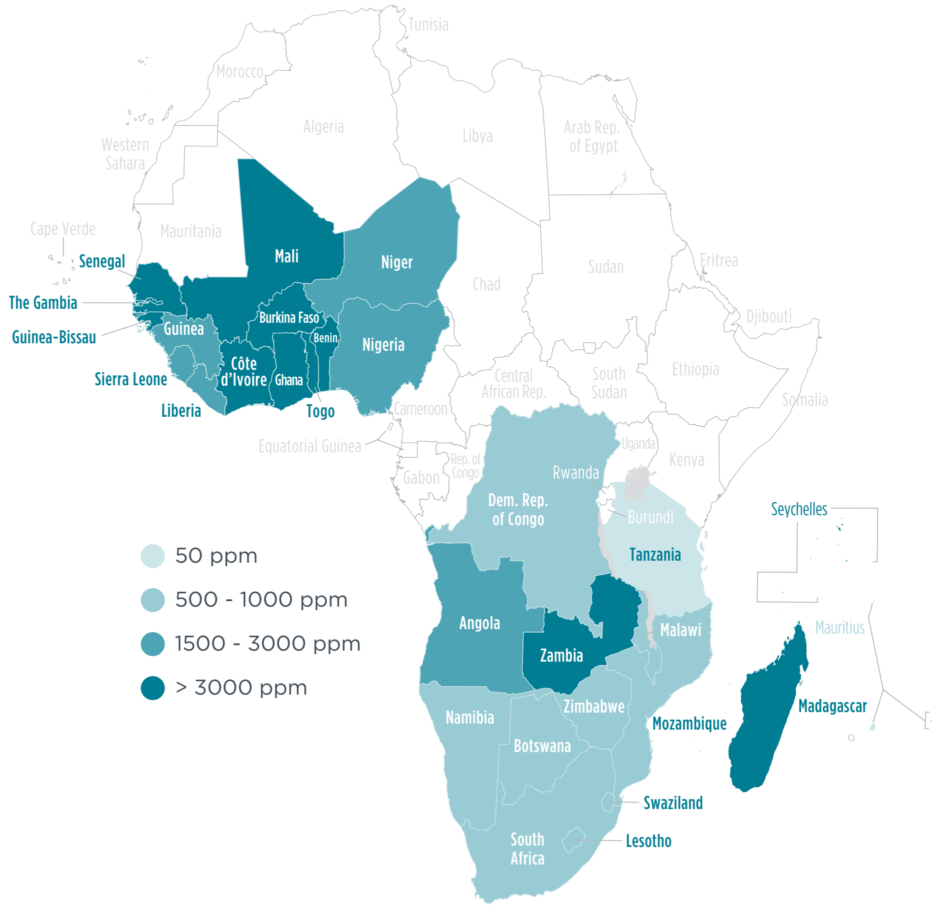

Figure 14. Map of sulfur content in Southern and Western Africa as of 2016.
Source: CITAC/ICCT (2016)

V. DEMAND GROWTH AND FUEL IMPORTS PROJECTIONS

Africa's demand for oil products is forecast to grow by over 3.1% per year, rising from 177 million metric tons per year in 2015 to 277 million metric tons per year by 2030. Part of the demand growth will be linked to increased urbanization and motorization (CITAC/ICCT, 2016). According to the IEA, Africa will be one of the regions with the highest demand growth of oil products in the medium term, partly due to a projected strong increase in vehicle population (OECD/IEA, 2015). Although some refinery projects are under way in a number of countries, Africa is expected to remain heavily dependent on imports of refined products to meet its demand, both in the near and long term (CITAC/ICCT, 2016; OECD/IEA, 2015). Figures 15 and 16 present the projections of clean product demands and scenarios for refinery outputs. Under the less optimistic scenario, when African refinery output grows by 5.7% to 117.3 million metric tons per year by 2030, growth will be insufficient to meet demand growth. Under a more optimistic scenario, where refinery output grows by 30% to 144 million metric tons per year by 2030, growth will still be insufficient to meet demand growth (CITAC/ICCT, 2016).

The consumption of diesel is projected to grow faster than the consumption of gasoline in both regions.

Figures 17 and 18 show that while gasoline consumption will grow slowly (1.7%) in Southern Africa, diesel demand will grow approximately twice as fast (3.3%). In 2025, diesel consumption in the Southern Africa region will continue to exceed gasoline consumption. Figures 17 and 18 indicate that in Western Africa, diesel consumption will grow faster than gasoline consumption—3.4% and 2.8%, respectively. However, in terms of total volume consumed, in 2025, West Africa's gasoline consumption will exceed diesel consumption, skewed by the large consumption of gasoline in Nigeria.

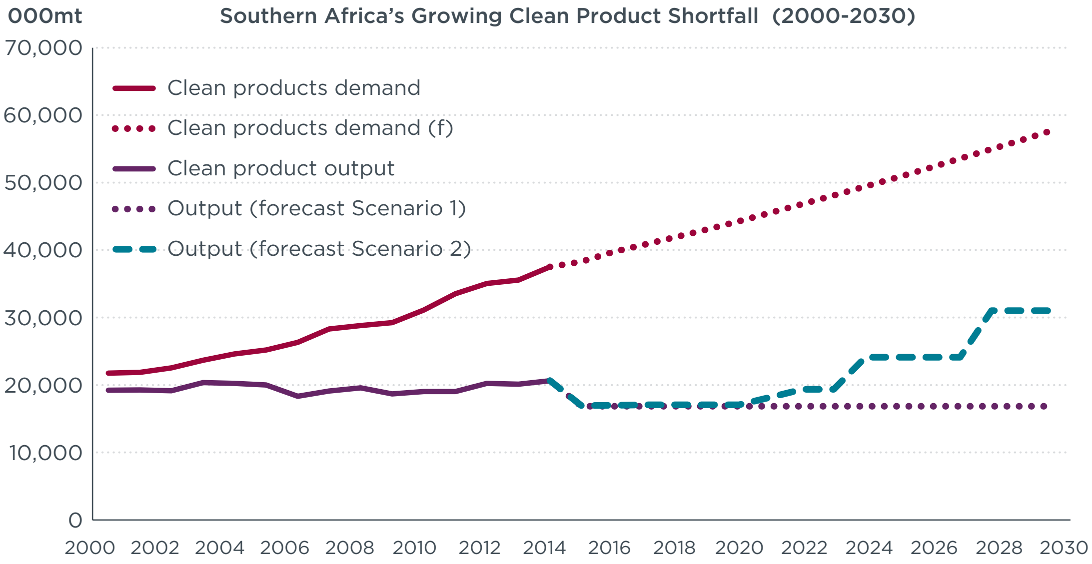

Figure 15. Clean products shortfall in Southern Africa, 2000–2030.
Source: CITAC/ICCT (2016)

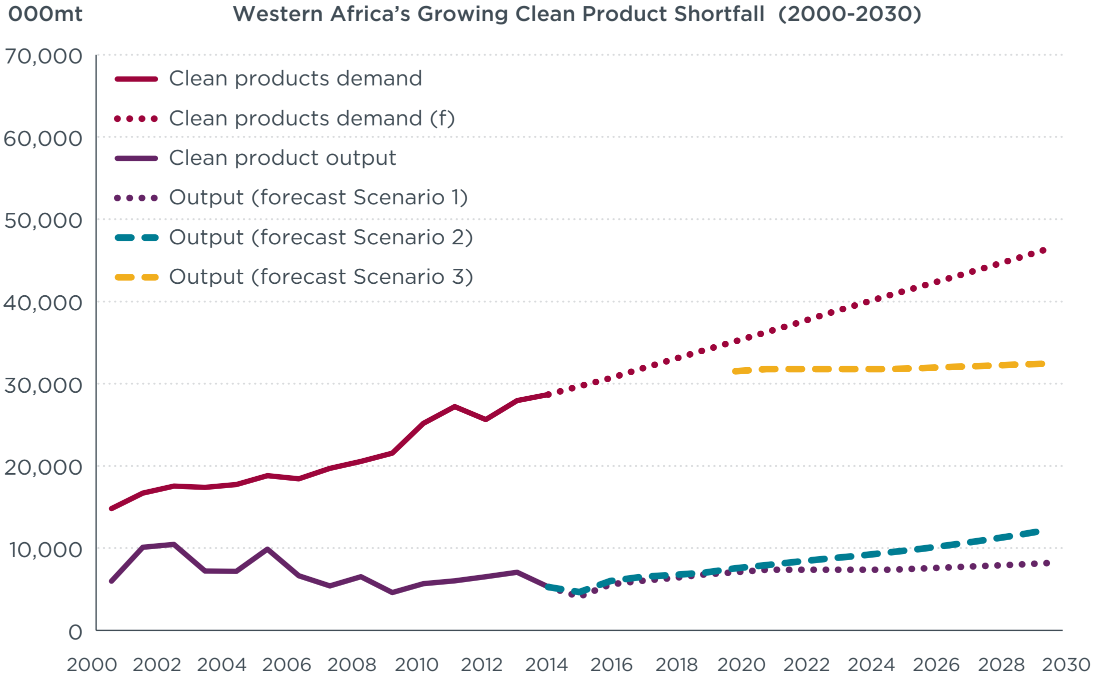

Figure 16. Clean products shortfall in Western Africa, 2000–2030.
Source: CITAC/ICCT (2016)

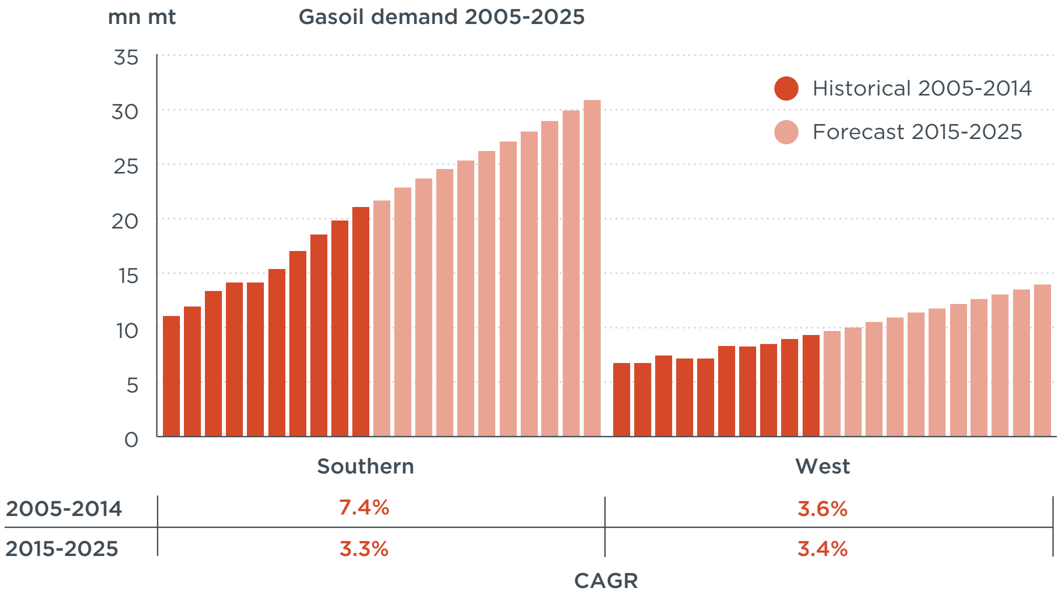

Figure 17. Historical and projected diesel demand in Southern and Western Africa, 2005–2025. *Source: CITAC/ICCT (2016)*

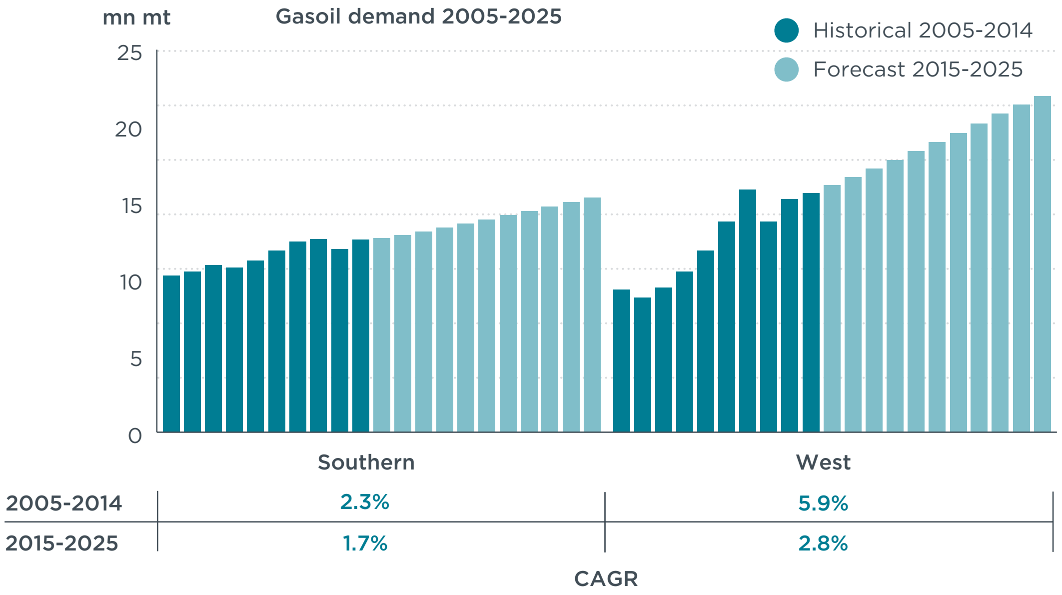

Figure 18. Historical and projected gasoline demand in Southern and Western Africa, 2005–2025. *Source: CITAC/ICCT (2016)*

VI. OPTIONS FOR LOWER SULFUR FUELS SUPPLY IN SOUTHERN AND WESTERN AFRICA

Countries in Southern and Western Africa rely on their domestic refineries or on imports of oil products to meet the demand for transportation fuels. The supply of clean fuels can be achieved by upgrading refineries or by importing low-sulfur fuels directly on the regional or international markets. For imported diesel fuels, the global availability of high-quality products on the international markets continues to increase (ICCT/UNEP, 2016).

A. IMPROVING REFINERY OPERATIONS

Most refineries in Southern and Western Africa are designed to process high-sulfur crude oil and need upgrades with desulfurization capabilities. All crude oil contains some fraction of sulfur as an impurity. Sour crudes have a sulfur content higher than 0.5%, and sweet crudes have a sulfur content lower than 0.5%. A widely used process to remove sulfur in fuel at a given refinery is hydro-desulfurization, and refineries lacking the desulfurization capacity need to be upgraded. Additionally, many refineries in the Southern and Western Africa regions are small or operate below nameplate capacity and need operational improvements and capacity increases.

Refinery projects have been announced in both regions, but most of them have been limited in progress predominantly due to a shortage of funding. In the Southern Africa region, Angola, South Africa, and Zambia have announced plans to upgrade their refineries. In South Africa, the government launched the Clean Fuels 2 (CF2) program in 2011, with the goal to introduce 10-ppm sulfur content and tighter benzene and aromatics specifications, with a deadline of 2017 for implementation. This requires significant investment in desulfurization technology at all refineries. Industry estimates have claimed a total cost of over US $4 billion. Two refineries have confirmed plans, as indicated in Table 11, but no work has been undertaken to date. Meeting the 2017 deadline and future developments depend on the position taken by the government and possibly on agreement on a cost-recovery mechanism for refiners. Chevron recently announced plans to sell its South African operations, making the future of Chevref, its refinery in Cape Town, uncertain (CITAC/ICCT, 2016); there are talks about some of the potential buyers not wanting to operate it, instead, they want to use the refinery as a storage space (UNEP/CCAC, 2016d). South Africa's refinery sector needs investments in the near term to avoid the risk of atrophy. Current investments are made in more import terminal space (UNEP/CCAC, 2016d). A new draft amendment of the CF2 program has been issued for public comment, but, to date, a revised timeline for 10-ppm sulfur fuel for diesel is still unspecified (UNEP/CCAC, 2016d). In Angola, a new refinery has been proposed in Lobito, scheduled to come online by 2017. The refinery will process Angola's crude oil into refined products that meet European and American specifications. These will be sold to domestic and international markets, including Europe and the United States (ICCT/UNEP, 2014). However, progress to date has been slow (CITAC/ICCT, 2016). In Zambia, upgrades target the bitumen production in the Indeni refinery, one of the oldest refineries in Africa. The bitumen unit of the Indeni refinery has been rehabilitated and is undergoing testing before re-commissioning. When the bitumen unit is re-commissioned, it will necessitate some changes to the refinery's crude slate, as its present feedstock blend is not optimal for bitumen production (CITAC/ICCT, 2016). This refinery does not target transportation fuels, but rehabilitating the refinery will reduce emissions from the copper mining sector.

Table 11. Refinery projects announced in Southern Africa as of 2016.

Country	Refinery	Refinery project	Progress to date
Angola	Lobito	New refinery proposed in Lobito.	Progress to date has been very limited.
South Africa	Natref	Plans confirmed for increased desulfurization and benzene extraction.	Progress to date has been limited.
	Satref	Plans confirmed for increased desulfurization and benzene extraction.	Progress to date has been limited.
Zambia	Indeni	Bitumen unit has been rehabilitated and is undergoing testing before re-commissioning.	Re-commissioning in progress.

In Western Africa, refinery projects (new refineries or upgrades of existing refineries) have been announced in Côte d'Ivoire, Ghana, Guinea, Nigeria, and Senegal, as indicated in Table 12. In Côte d'Ivoire, BEICIP and KPMG have recently performed technical and management audits of the SIR refinery, which requires a desulfurization unit and a benzene extraction unit to meet AFRI-5 specifications (CITAC/ICCT, 2016; UNEP/CCAC, 2016c). However, funding needs to be secured, with several financing options and a timeline of 2017 to 2020 for upgrades being proposed (UNEP/CCAC, 2016c). In Nigeria, Dangote Industries has announced its intention to construct a new refinery with a capacity of 400,000 barrels per day on the outskirts of Lagos. Funding has been announced, and the refinery will be designed to produce ultralow-sulfur fuels. But the estimated date of operations and the progress of technical and market studies need to be confirmed. In Senegal, plans were adopted in 2011 to increase capacity from its current 27,000 barrels per day to 62,000 barrels per day, and the reformer was refurbished recently (CITAC/ICCT, 2016). Other upgrades including a desulfurization unit has been announced, but progress has been uncertain to date (SAR, 2016). In Ghana, upgrade plans have proposed a new CDU (120,000 b/d), reformer, isomerizer, desulfurizer, hydrocracker, and bitumen unit; but, private funding is needed for implementation (CITAC/ICCT, 2016). With Ghana having committed to import 50-ppm fuel and granting a waiver for the Tema Oil Refinery (TOR) to produce low-sulfur fuels by 2020 (UNEP/CCAC, 2016b), progress for upgrades can be expected soon.

Table 12. Refinery projects announced in Western Africa as of 2016.

Country	Refinery	Refinery project	Progress to date
Côte d'Ivoire	Société Ivoirienne de Raffinage (SIR)	SIR is looking to add new desulfurization capacity for gasoline and diesel.	Ongoing discussions with the government for finance.
Ghana	Tema Oil Refinery (TOR)	Proposed new CDU, reformer, isomeriser, desulfurizer, hydrocracker, and bitumen unit.	Funding needed for upgrade of the refinery to produce 50-ppm diesel fuel as of December 2016.
Guinea	Kamsar (by Brahams Oil Refineries)*	New refinery expected to be built in Kamsar, with 10,000 bpd	As of March 2017, the initial phase of the project was in progress
Nigeria	Kaduna, Port-Harcourt, Warri, Dangote Industries refinery (Lagos)	Project to upgrade the refineries Dangote Industries has announced its intention to construct a new 650,000 b/d refinery on the outskirts of Lagos.	Funding needed for refinery upgrades
Senegal	Société Africaine de Raffinage (SAR)	Plans adopted to increase capacity and desulfurization	Progress to date has been limited.

Source: ARA (2017b); CITAC/ICCT (2016); UNEP/CCAC (2016c)
*Official name of refinery not provided

VII. IMPORTING LOW-SULFUR FUELS

Importing countries source refined products on the regional or international markets. In the Southern Africa region, South Africa is the major refining country and a key importing point for Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Zambia, and Zimbabwe. Specifications in those countries are linked to South Africa's standards (ICCT/UNEP, 2014; CITAC/ICCT, 2016). If South Africa successfully removes hurdles that impede its transition to low-sulfur fuels nationwide, then it will enable a fast transition to 50-ppm sulfur fuels in countries that depend on South Africa's fuels.

In the Western Africa region, Côte d'Ivoire is the key refining hub and import point for Benin, Burkina Faso, The Gambia, Ghana, Guinea, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo. The SIR refinery still delivers high-sulfur fuels, and there are ongoing discussions for financing mechanisms to upgrade the refinery. A transition to low-sulfur fuels in Côte d'Ivoire will make clean fuels available in countries that import their refined products directly from the SIR refinery's output.

At the international level, a global study on fuels markets indicates that low-sulfur fuels are available on most markets from which Southern and Western African countries import their transportation fuels, including Northwestern Europe, Asia, India, and the Middle East (ICCT/UNEP, 2016).

SECTION 3

Baseline study of vehicle population in Southern and Western Africa

As stated earlier in this report, availability, reliability, and consistency of vehicle data for imports and registrations are very limited in sub-Saharan Africa. Currently, sub-Saharan Africa records 2% of vehicle ownership per capita compared with 70% in the United States, 50% in Europe, and 6% in China (OECD/IEA, 2014). Leading markets are South Africa and Nigeria (IMF, 2005; OECD/IEA, 2014). Although vehicle ownership remains low in Southern and Western Africa (OECD/IEA, 2014), vehicle population is expected to continue growing, as a result of forecasted economic growth. Rapid urbanization and motorization across sub-Saharan Africa have led to high annual vehicle growth rates. For example, the annual vehicle fleet growth is estimated at 12% in Kenya (World Bank Transport and ICT Global Practice, 2016) and 10% in Ethiopia (UNEP/GFEI, 2012). In most countries, the market for new vehicles is weak, and in countries such as Cote d'Ivoire, the purchase of new vehicles by individual consumers represents only a smaller share of this market (15%) compared with the private sector (60%) and the public sector (20%; Jeune Afrique, 2017). Although comprehensive studies are scarce, countries with similar lifestyles, particularly those in Southern and Western Africa, are likely to record annual growth rates and profiles of new vehicle sales close to those indicated.

Sub-Saharan Africa is heavily reliant on imports of new and secondhand vehicles to meet its domestic demand. With the exception of South Africa, where the import and use of secondhand vehicles are banned, vehicle fleets are dominated by used vehicles imported primarily from the EU, Japan, and the United States (Black & McLennan, 2015). In general, policies for the adoption of vehicles are very different between developed markets and developing countries. Most developed markets, to boost domestic vehicle production or because of environmental concerns, have policies in place that encourage the scrappage of old vehicles and the purchase of new vehicles (Black & McLennan, 2015). Those policies could extend to costly inspections after a few years, such as those in Japan, making older vehicles costly to drive and new vehicles more attractive (Clerides, 2008). In sub-Saharan Africa, the fleet is dominated by secondhand vehicles, with affordability being the main driver of the imports of those vehicles. A secondhand vehicle in this context is a vehicle that has been registered and used before being exported for further use. Generally older and cheaper, those vehicles respond to the increasing need for mobility and serve as convenient and flexible means of transportation. A few countries in the regions have assembly operations for new vehicles with limited local content. Given the prevalence of imported secondhand vehicles in most sub-Saharan African countries, the vehicle technology included for emission control is strongly linked to those in the vehicles' country of origin, albeit with a time lag. Factors that may impact vehicle performance once they arrive in sub-Saharan African countries include the lack of fuel required for emission-control technologies to function properly, poor maintenance (OECD/IEA, 2014), and the extent to which the emissions-control systems have been tampered with during the import process. Only Nigeria and South Africa have vehicle emissions standards. However, matching fuel is not available in Nigeria and in most other countries in the region. Other countries have various restrictions on the imports of secondhand vehicles, mostly in the form of age-based or mileage-based restrictions, which are summarized in Figure 19 and further described in Tables 13 and 14.

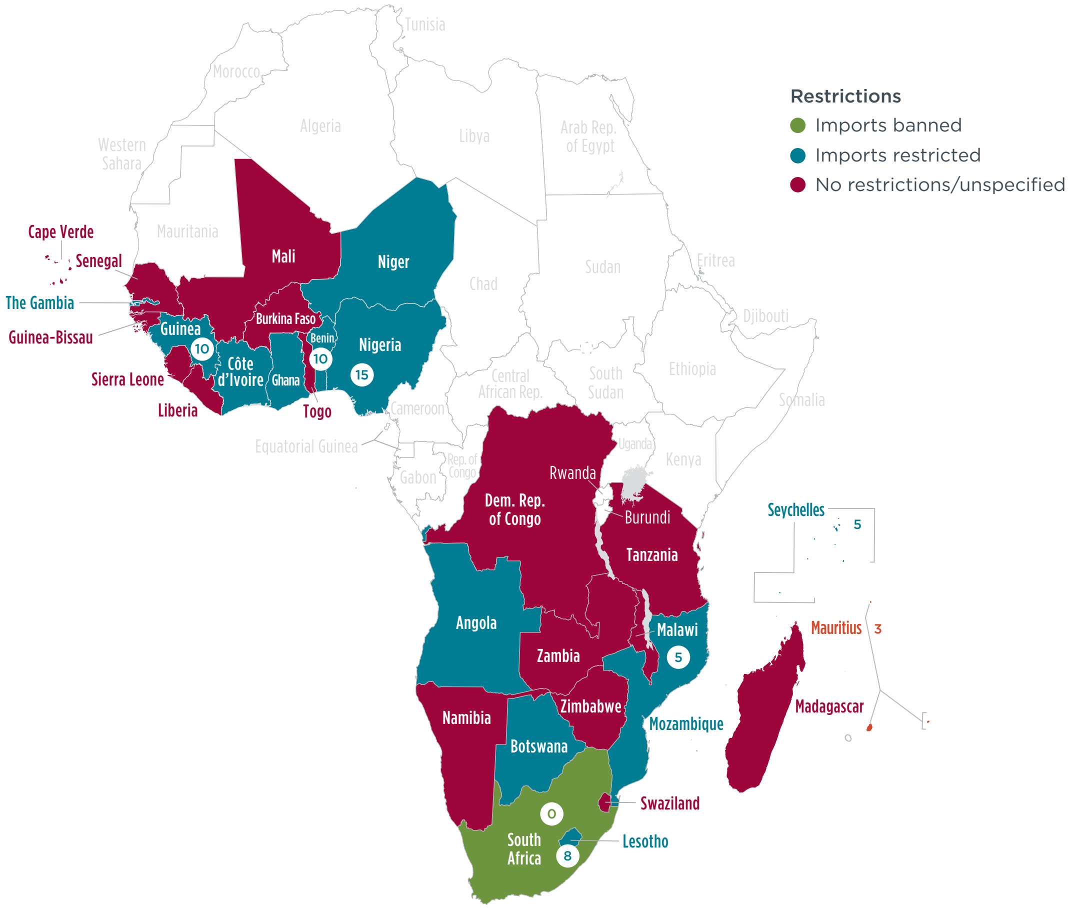

Figure 19. Vehicle import restrictions in Southern and Western Africa as of June 2015.*
Source: Data from PCFV Africa Matrix.
**Numbers indicate the age limit (in years) in the case of age-based restrictions.*

Table 13. Vehicle emissions standards and import limits in Southern Africa as of 2016.

Country	Vehicle emissions standards/ Restrictions on secondhand imported vehicles
Angola	Motor companies not allowed to import used vehicles; individuals allowed to import regardless of age
Botswana	
DR Congo	No import restrictions
Lesotho	Used vehicles must be less than 8 years old
Madagascar	
Malawi	No import restrictions
Mauritius	Has a 3-year age restriction
Mozambique	Used cars must be less than 5 years old; used vans must be less than 9 years old.
Namibia	
Seychelles	Used vehicles must be less than 5 years old
South Africa	Euro 2 for LDVs and Euro II for HDV adopted in 2006, average vehicle age is 13 years old, imported vehicles sold in the country are Euro 5 or 6. LCVs manufactured in the country are Euro 3 for diesel and mostly Euro 4 for gasoline.
Swaziland	
Tanzania	
Zambia	No import restrictions
Zimbabwe	

Source: PCFV Africa Matrix updated June 2015

Table 14. Vehicle emissions standards and import restrictions in Western Africa as of 2016.

Country	Vehicle emissions standards/ Restrictions on secondhand imported vehicles
Benin	From December 29, 2000, the import age restriction is 10 years for LDVs and 13 years for tourism vehicles. There is a requirement for control emissions, but that is not specified.
Burkina Faso	No import restrictions
Cape Verde	
Côte d'Ivoire	A fine of FCFA 150.000 is imposed on vehicles older than 10 years and an additional FCFA 10.000 for every year (older than 10 years).
The Gambia	Import of secondhand vehicles is restricted through taxation; increases in vehicles exceeding 10 years and roadworthiness must be proven before import.
Ghana	Used vehicles over 5 years old pay graduated penalty according to year of manufacture and capacity.
Guinea	Ban on importation of cars above 10 years lifted in 2001
Guinea-Bissau	
Liberia	
Mali	No import restrictions
Niger	
Nigeria	Euro 3 standards for LDVs
Senegal	
Sierra Leone	
Togo	

Source: PCFV Africa Matrix updated June 2015

The IEA, in its New Policies scenario, considers an overall number of passenger LDVs that triples by 2040, with much of the growth in Nigeria and South Africa. Similarly, the number of commercial vehicles and buses will grow from 8 million in 2012 to 25 million in 2040 (OECD/IEA, 2014; Figure 20).

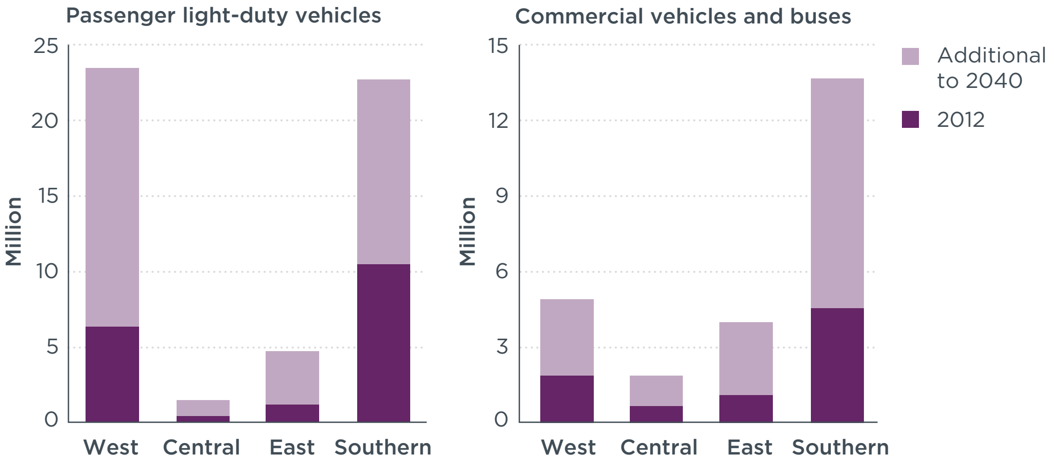

Figure 20. Vehicle stock in sub-Saharan Africa by type in the IEA New Policies scenario.
Source: OECD/IEA (2014)

SECTION 4

Barriers to and opportunities involved in a transition to clean fuels and vehicles

Several challenges—particularly economic, political, and technological barriers—have impeded countries around the world, and specifically in Africa, from transitioning to clean fuels and vehicles standards. The ICCT and UNEP have explored these issues in depth in the Global Strategy to Introduce Low-Sulfur Fuels and Cleaner Diesel Vehicles (ICCT/UNEP, 2016). The key barriers relevant to Southern and Western Africa are summarized below.

I. BARRIERS TO CLEANER FUELS

A. CONSTRAINTS TO SOURCE REFINED PRODUCTS FOR IMPORTERS

These constraints are more acute in landlocked countries and small markets without refineries. The complexity of the supply chain with diverse supply routes makes specifications in those countries dependent on their coastal sources or driven by the regional levels (CITAC/ICCT, 2016). In Southern Africa, countries are dependent, to various extents, on South Africa, Mozambique, and Tanzania. In Western Africa, Côte d’Ivoire is the main supplier, with Senegal and Niger partly supplying their neighbors. Togo has a storage space and partly supplies the inland market (Mali and Burkina Faso). Mali and Burkina Faso have complex supply routes, with up to five routes for Mali. DR Congo (Southern region) has a three-route supply chain, two of which depend on imports through other countries (CITAC/ICCT, 2016). A recent report documenting the role of Swiss trading groups in supplying refined fuels in Africa shows the complexity of the current system (Public Eye, 2016). It also demonstrates that the current weak fuel-quality standards limit the quality of fuels brought into the markets.

B. LIMITED INSTITUTIONAL CAPACITY

In most countries, the institutional capacity to implement clean fuel and vehicle standards needs to be strengthened. For example, limited local capacity to test fuel in the countries is a challenge. Adulterated fuels are reported across and within many countries. Those fuels are generally cheaper and sold on informal markets. With tighter fuels standards, local capacity to test fuels on imports and on the ground needs to be strengthened. In general, product quality is more difficult to control at retails sites than directly at the refinery or as it is offloaded from ships. However, both are necessary to ensure fuel quality standard compliance. Botswana has planned to increase local capacity to test and ensure that imported fuel meets national specifications. The country has one unit in Lobatse, and another mobile unit needs to be accredited (UNEP/CCAC, 2016d).

C. INVESTMENTS FOR REFINERY UPGRADES

In refining countries, significant investments are needed upfront to upgrade refineries to meet low- and ultralow-sulfur fuels specifications. The ICCT and Ensys conducted a refinery transport fuels baseline analysis, in which 245 refineries in developing countries were analyzed, to determine their capacity to produce 50-ppm low-sulfur fuels (ICCT/ Ensys, 2015). The results for refineries in Southern and Western Africa are summarized in Table 15. The estimates by Ensys include capital costs for desulfurization, improvement in refining capacity, and utilization rate, which could contribute to meeting the growing domestic and regional demand for refined products. Adding additional units is expected to increase not only capital expenditures, but also operational costs (ICCT/UNEP, 2016). An additional study has been conducted for refineries to transition to 10-ppm ultralow-sulfur fuels, as shown in Table 16.

Table 15. Investment required for refinery upgrades in Southern and Western Africa as of 2014.

Country	Refinery	Investment required ($million)*
Angola (Luanda)	Sonangol	$59
Côte d’Ivoire (Abidjan)	Société Ivoirienne de Raffinage	$131
Ghana (Tema)	Tema Oil Refinery Co. Ltd	$142
Nigeria (Kaduna)	Kaduna Refinery & Petrochemical Co. (NNPC)	$239
Nigeria (Port Harcourt Alesa Eleme)	Port Harcourt Refining Co. (NNPC)	$133
Nigeria (Port Harcourt Rivers State)	Port Harcourt Refining Co. (NNPC)	$437
Nigeria (Warri)	Warri Refinery & Petrochemical Co. (NNPC)	$331
Senegal (M’Bao, Dakar):	Société Africaine de Raffinage	$91
South Africa (Cape Town)	Caltex Oil SA	$378
South Africa (Durban)	Engen Petroleum Ltd	$238
South Africa (Sasolburg)	National Petroleum Refiners of South Africa Pty Ltd	$375
South Africa (Durban)	Shell and BP PLC Petroleum Refineries Pty	$297
Zambia (Bwana Nkubwa Area Ndola)	(Indeni Petroleum Refinery Co. Ltd)	$58

Source: ICCT-Ensys (2015)
*Investment includes both desulfurization for gasoline and diesel, and capacity additions. Year for US dollar is unspecified. This is an indicative range; more accurate estimates can be obtained from refinery-specific studies.

Table 16. Additional investment required for 10-ppm ultralow-sulfur fuels as of 2014.

Country	Refinery	Refinery type	Investment required ($ Million)*	
			50-ppm Ensys study	Additional investment for 10-ppm Mathpro study (low–high)
Côte d'Ivoire	Société Ivoirienne de Raffinage (SIR)	Hydrocracking	131	35.5–73.4
South Africa	Shell and BP PLC Petroleum Refineries Pty. Ltd.	Coking	297	39.2–90.6

Source: ICCT-MathPro (2015)
*Includes gasoline and diesel.

In Côte d'Ivoire, according to an audit, an estimated investment of US $450 million is needed to upgrade the SIR refinery to meet the AFRI-5 specifications (UNEP/CCAC, 2016c). Several financing options are being discussed for implementation between 2017 and 2020 (UNEP/CCAC, 2016c). In South Africa, the Clean Fuel 2 (CF2) program targets 10-ppm sulfur for both gasoline and diesel fuels (SAPIA, 2016). As of 2015, no refinery was equipped to meet the CF2 diesel grade, and two were producing some 50-ppm sulfur content diesel. Expected investment in refinery is large, often not economical within the regulated price structure, and requires intervention from the government (UNEP/CCAC, 2016d). The investments in refineries to meet the CF2 program (10-ppm sulfur fuel and other specifications) are estimated to cost approximately US $3.9 billion (2009 $) (UNEP/CCAC, 2016d). Difficulties in securing financing and economic downturn in the country can further exacerbate the barriers to refinery upgrades. In Ghana, an estimated US $120 million is needed to upgrade the TOR to produce 50-ppm fuels by 2020 (ARA, 2017b)

Table 17 compares investments required globally, with a total of approximately US $7 billion needed in Africa. For a single refinery, upgrades to produce 50-ppm low-sulfur fuels are estimated to cost approximately US $4,000 per barrel per day of additional capacity, on average. However, larger refineries will have lower per-barrel costs than smaller refineries (ICCT/ Ensys, 2015).

Table 17. Cost of refinery investment required to deliver low-sulfur fuels by region as of 2014.

Region	Investment required ($ billion)
Africa	7
Europe and Central Asia	5
Greater Caribbean	11
Middle East	16
Rest of Asia	12
South America	7
Southeast Asia	13

Source: ICCT/ Ensys (2015)

The required investments could seem substantial, leading to legislative and institutional inertia. The structure of refineries' ownership can further complicate the prospects of securing investments. For state-owned refineries, governments may be reluctant to finance upgrades using direct public expenditure (ICCT/UNEP, 2016). At the same time, for energy security reasons, along with some socioeconomic considerations (e.g., the protection of local jobs linked to refineries), governments may be unwilling to allow the closure of ailing refineries with a questionable long-term future. For mixed-ownership or privately owned refineries, difficulties in reaching an agreement between co-owners over necessary refinery upgrades or financing options can impede the transition (CITAC/ICCT, 2016; ICCT/UNEP, 2016). Because of the lack of finance, and with refineries producing high-sulfur fuels, countries may be unwilling to adopt standards that are more stringent than the specifications of the refined products that their domestic refineries can deliver.

D. MARKET EVOLUTION AND PRICING CONDITIONS

Refiners will not make investments in hydro-desulfurization unless there is a clear market for lower-sulfur fuels and a price premium that offsets the costs incurred to produce them. Many low-and middle-income countries, especially those that produce oil, control the retail price of fuels by imposing controls or limits on fuel prices, effectively subsidizing fuel consumption. In most non-oil-producing countries, prices are regulated, but not subsidized, when assessed against a benchmark. This interference with the market price of fuels means that oil products are not directly responsive to changes in international markets (OECD/IEA, 2014), and, in refining countries, refiners may be unable to pass on the capital and operational costs of desulfurization to consumers, making investments not financially viable. In importing countries where prices are controlled, importers have no option to pass on higher costs of low-sulfur fuel purchased on the market (ICCT/UNEP, 2016).

Subsidies impose fiscal and economic burdens on developing countries, but removing them is a difficult political process, because they sometimes lead to social upheavals and the loss of political capital for the ruling government; however, with good timing and management, the process of removing them can be smooth (ICCT/UNEP, 2016; IMF, 2013). Nigeria and Angola have been successful in removing fuel subsidies. In 2013, the subsidization rate (relative to the benchmark price) for gasoline was estimated at 29% in Nigeria and 32% in Angola. Angola also had a 58% subsidization rate on diesel (OECD/IEA, 2014). Today, both countries have successfully removed those fuel subsidies.

Worldwide excess refinery capacity, the growing supply of low-sulfur fuels on the global market, and the declining price premium make the imports of clean fuels very attractive and put pressure on refineries in Southern and Western Africa to upgrade. However, for refiners, lower price differentials could further weaken the financial case for refinery upgrades and increase the need for government support based on the expected public health benefits.

E. COST TO CONSUMERS

Decision makers are reluctant about cost increase burdens that will be imposed on consumers following the implementation of low-sulfur policies. In Southern and Western Africa, although a cost study on the price differential on imports for high-sulfur fuels versus low-sulfur fuels is needed, the likelihood of increase is dependent on the market, or the region. In South Africa, where both 50-ppm and 500-ppm grades are sold, the price differential between both grades has dropped significantly (ICCT/UNEP, 2016). As of 2016 in South Africa, 43% of diesel fuels are already 50-ppm sulfur, and the price differential about 5 SA cents per liter (UNEP/CCAC, 2016d). In Botswana, where 6% of imported fuel is already at 50-ppm sulfur, the per-liter price of 50-ppm sulfur fuel is about 1 US cent more expensive than the 500-ppm sulfur fuel, and, according to the Botswana Department of Energy, changing the price policy is straightforward (UNEP/CCAC, 2016d).

However, in Kenya, the transition to East African Standards has not led to any price increase (UNEP/CCAC, 2016a). More generally, according to the global sulfur strategy report, the price differential between high- and low-sulfur fuels have declined over time, and there is a possibility for pump prices to drop in some markets (ICCT/UNEP, 2016). In the case of multiple grades co-existing during the transition in Western or Southern Africa, a labeling program is required to inform consumers and guide their choices. One goal is to clearly prevent countries from mixing high and low sulfur fuels, while trying to find a market for high-sulfur products from refineries during the transition period, to make available the best quality fuels for consumers and to support importers in their efforts to bring clean fuels. In South Africa, some consumers are already opting for high-quality fuels. According to the ICCT UNEP report (2016), in general, it is possible to add a premium on clean fuel prices (except when those prices are set by the government), because the expected price increase from refinery upgrades to produce low-sulfur fuels is lower than the fluctuations of the fuel prices on the market (ICCT/UNEP, 2016).

II. BARRIERS TO VEHICLE EMISSION STANDARDS AND CLEAN VEHICLE PROGRAMS

The major barriers to clean vehicle programs and vehicle emissions standards are the incremental costs of new vehicles. Mandating cleaner vehicles will lead to incremental vehicle costs, including vehicle technology costs required for better emissions-control systems, vehicle maintenance costs required to operate cleaner vehicles, and other requirements (Miller & Façanha, 2016), passed on to vehicle manufacturers or consumers (Miller & Façanha, 2016). As stated earlier in this report, both regions still depend on imported secondhand vehicles, some of which are old or have reached their useful lifetime.

From a consumer's perspective in sub-Saharan Africa, the affordability of secondhand vehicles (compared with newer or cleaner vehicles) and the need for mobility make those vehicles more attractive. More significantly, many countries send the wrong signal to consumers by imposing higher import taxes and tariffs on new or cleaner vehicles and lower taxes on old, polluting vehicles. Those policies conflict with the need for governments to address vehicle-related air pollution and to promote public health.

The adoption and implementation of clean vehicle policies can be impeded by resistance from the transportation sector, including owners, operators, and drivers of privately owned trucks, minibuses, buses, and urban taxis who are organized in associations, coalition groups, or unions. Those stakeholders could see the programs as a major economic constraint, which could lead to policy resistance. Hostile reactions to these policies could be exacerbated when there is no sign of available financial support to address incremental costs or when there is a lack of evidence of operational cost savings or improved service.

Contrary to more developed markets where comprehensive studies have informed policymakers on the cost-effectiveness of the adoption of clean fuels and/or vehicle policies (e.g., Brazil, China, India, Mexico, United States), to date such studies are scarce or limited in Southern and Western Africa, leaving decision makers uncertain about the costs and benefits of a transition to clean fuels and vehicles policies, on a per-country basis or at the regional level.

For the entire fleet, including secondhand and new vehicles, weaker local capacities to enforce inspection and maintenance programs fail to remove non-roadworthy vehicles from the fleet. If standards were adopted, additional capacities would be required for compliance and enforcement, to ensure that vehicles comply with standards in the real world.

III. OPPORTUNITIES FOR CLEAN FUELS AND VEHICLE STANDARDS

Despite barriers, multiple pathways exist for countries to achieve low-sulfur-fuel goals, including refineries upgrades and updates to tenders on imports of refined products. The CCAC HDDI has engaged in providing strong support to countries to promote a global transition and market for cleaner fuels and vehicles (ICCT/UNEP, 2016). Nations in Southern and Western Africa have committed to a timeline to meet 50-ppm low-sulfur fuels by 2020, signaling a political will to adopt clean fuel standards. In the past, both regions made a strong achievement to successfully phase out lead in gasoline. To date, countries in the region and other parts of the world can learn from desulfurization projects that have been successful in the developed world and accelerate their transition to clean fuels (ICCT/UNEP, 2016). But, opportunities of learning from successful countries across the continent exist, proving that achieving low-sulfur fuels in the region is attainable: Eight countries (Burundi, Kenya, Mauritius, Morocco, Rwanda, The Seychelles, Tanzania, and Uganda) have successfully transitioned to low-sulfur fuels, and some of them are already on track to achieve ultralow-sulfur fuels. In each region, significant progress has been made; South Africa and Botswana already have both 50-ppm and 500-ppm grades, and five countries in Western Africa (Benin, Côte d'Ivoire, Ghana, Nigeria and Togo) have committed to import low-sulfur fuels by July 2017 and upgrade their refineries to comply by 2020 (UNEP/CCAC, 2016c; UNEP/CCAC, 2016d).

Policymakers; advocacy groups; and local, regional, and international organizations have increasingly engaged and raised concerns for the need to address the growing urban air pollution in Southern and Western Africa, and its health impacts. The African Refiners Association (ARA) has developed a set of specifications, AFRI-1 to AFRI-5 (ARA, 2017a), as a roadmap for refineries in Africa to produce low-sulfur fuels (see Appendix D).

Successful financing mechanisms in other parts of Africa and the world could serve as learning opportunities. Partnership of private, public, and development/donor finance has been a way to secure investments to upgrade local refineries. By coupling desulfurization to investments in increased refinery capacity, investors can improve the financial case for projects by allowing costs to be recouped through increased sales revenue (ICCT/UNEP, 2016). In Africa, Egypt is an example where the decision to produce 10-ppm sulfur fuels was made to gain access to development funding that was contingent on delivering improvements in local environmental quality (ICCT/UNEP, 2016).

Those pathways will generate significant health benefits while simultaneously improving energy security, particularly in oil-producing countries if their crude oil is refined locally and if refineries operate efficiently. In Nigeria, upgrading existing refineries and bringing online the Dangote refinery could make the country a net exporter of refined products. Cote d'Ivoire is already an exporter of refined products in the sub-region, and upgrading the SIR refinery will improve its competitiveness for the supply of clean products on the West African market. In a 2014 study, the IEA indicates that Ghana imports most of its refined products while it produces levels of crude oil that could meet its demand if its refinery had higher operations rates (OECD/IEA, 2014). The incremental costs to consumers of implementing low-sulfur fuels are not high. Another study done in 2009 estimates the incremental cost that consumers face following a transition to AFRI-4 gasoline and diesel in 2020 in an open market at US ¢3.6/liter for Southern Africa and US ¢6.25/liter for Western Africa (World Bank/ICF International, 2009). At the global level, providing 50-ppm sulfur-content diesel fuels could increase pump prices by US ¢0.6 to US ¢2.1, depending on the baseline fuel sulfur content (ICCT/UNEP, 2016).

Upgrading a refinery to produce low-sulfur fuels seems cost-prohibitive, but enormous societal gains will be achieved when those costs are compared with the health benefits and the fuel imports bills. For importing countries, the declining price premium and the large supply of low-sulfur present an opportunity to revise tenders and accelerate the transition to clean fuels. Although comprehensive cost–benefit analyses for clean fuels and vehicles in Southern and Western Africa are not available, partly because of the lack of data about those regions, the results of such studies across the world indicate that benefits largely exceed costs, for example in China, India, Mexico, and the United States (Miller & Façanha, 2016).

For clean vehicles policies, opportunities exist to implement vehicle emissions standards and regulation of imports of secondhand vehicles, with a few countries that limit the age of imported secondhand vehicles. However, when low-sulfur fuels become available, countries have an opportunity to tighten their vehicles standards. To achieve world-class vehicle emissions standards, after-treatment emissions control systems are required. In particular, diesel particulate filters are needed to meet Euro 5 standards for LDVs and Euro VI standards for HDVs. Vehicles and fuels act as a system, and filters require a maximum of 50-ppm sulfur content diesel fuel to function, and ideally 10- or 15-ppm for optimized performance and maximum emissions-reductions benefits (see Appendix B). In the Southern Africa region, Mauritius and Tanzania have already reached the 50-ppm limit on sulfur fuels and can tighten their vehicle emissions standards to Euro 4 and IV, to capture the benefits of cleaner vehicles, then move to ultralow-sulfur fuels and adopt more stringent emissions standards enabled by the fuel. South Africa, a G20 member and a country that bans the import of secondhand vehicles, can adopt, along with clean fuels, world-class vehicle emissions standards (Euro 5 for LDVs and Euro VI for HDVs; Kodjak, 2015). In Southern and Western Africa, South Africa is the only country with vehicles standards and matching fuels available, although these standards are less stringent (Euro 2 for LDVs and Euro II for HDVs). However, imported vehicles sold in the country are mostly Euro 5 or 6, and customers of those vehicles are requesting 50-ppm sulfur content fuels. LCVs manufactured in the country are Euro 3 for diesel and mostly Euro 4 for gasoline (UNEP/CCAC, 2016c). Nigeria has Euro 3 vehicle standards, but available diesel fuels (3,000-ppm sulfur) do not match the standards.

Some countries, including Mauritius and the Seychelles, have tight limits on the age of imported secondhand vehicles (3 and 5 years). When those restrictions are strictly applied, they enable importing countries to benefit from vehicle technology that is effective in the countries from which those vehicles are imported, serve as implicit standards by aligning standards in the importing country and country of origin with a short time gap, prevent polluting vehicles from entering the fleet, and progressively clean the on-road fleet as polluting vehicles reach their retirement and the share of clean vehicles increases.

SECTION 5

Recommended timeline for clean fuel and vehicle standards in Southern and Western Africa and potential emissions reductions

Based on the information presented in this report on the progress toward clean fuels in Southern and Western Africa, it is clear that the governments' goal to achieve 50-ppm fuels by 2020 is reasonable for most countries in both regions, with all countries being able to reach this milestone by 2025. Most countries in the region and the world should be able to reach 10-ppm sulfur fuels by 2030. Importing countries can adopt 50-ppm sulfur fuels faster, as several West African nations have committed to do (UNEP/CCAC, 2016a), by tightening their standards and taking advantage of the availability of low-sulfur standards on the global market. Implementing new standards in those countries should not take more than 2 years (ICCT/UNEP, 2014, 2016). However, countries with refining capacity need additional time between the promulgation of the rule and implementation to secure funding and carry out refinery upgrades. This should not exceed an additional 5 years (ICCT/UNEP, 2014, 2016). Most importing countries should be able to meet the 2020 timeline for low-sulfur fuels, and refining countries should reach the goal by 2025 at the latest. In any event, meeting the recommended timeline should be given a high priority, because delayed actions will result in missed opportunities and increased emissions and health costs, as described in Table 18 for Nigeria. Countries that have already met 50-ppm sulfur content can require the most stringent vehicle emissions standards enabled by the fuel.

To illustrate the potential emissions-reduction benefits of achieving clean fuel and vehicle standards, the ICCT has developed a region-specific fleet model. Many models were built to analyze vehicle and fuel policies in developed markets, but few models integrate vehicle emissions and fuel policies for developing countries. Transportation policies are context dependent, and, in sub-Saharan Africa, the large share of imported secondhand vehicles combined with the prevalence of high-sulfur diesel fuels is not always captured in models developed for new vehicle markets. Attributes such as vehicles emissions certification levels need to be adjusted with available fuels. The tool is based on the ICCT's Global Transportation Roadmap Model with required adjustments for secondhand vehicles (ICCT, 2016) and provides two major advantages: First, it quantifies the potential emissions reductions levels of different policy scenarios, and the timeline associated with those scenarios. The quantification and timeline guide policy makers and stakeholders in developing policy strategies and pathways to achieve targeted level of reductions. Second, the tool offers flexibility to integrate emissions from two- or three-wheelers, when these are major modes of transportation in countries, or to model emissions from new vehicles, assuming these vehicles enter the fleet at age zero. The input data for imported secondhand vehicles have been extracted from the IEA Mobility Model database. A full description of the model, methodology, and assumptions are available in Appendix E.

The ICCT modeled the impacts on air quality, public health, and climate of three different scenarios of fuel sulfur standards, imported secondhand vehicle restrictions, and the timeline associated with the implementation of those standards. The analysis focuses on near-term regulatory timeframes (limited to 2050) and quantifies diesel and gasoline consumption, and emissions of pollutants that impact climate (i.e., BC, CH_4, N_2O, and CO_2) and public health (i.e., $PM_{2.5}$, NO_X, HC, and CO), based on the adoption and implementation of low-sulfur fuels (50 ppm), ultra-low sulfur fuels (10-ppm), and regulations on used imported vehicles. Emissions reductions are estimated relative to the baseline, reference trajectory, in which future mode share and activity growth have been projected.

The scenarios in this study are as follows: (a) The baseline scenario reflects the current standards, with the continuation of the high-sulfur diesel fuels that are prevalent in most countries. (b) Low-sulfur fuel (LSF) is the first improvement scenario where countries adopt and implement 50-ppm sulfur fuel by 2020. (c) Ultralow-sulfur fuel and age limits (ULSF & Age limits) is a more stringent improvement scenario where countries, in addition to the previous low-sulfur improvement, adopt and implement 10-ppm ultralow-sulfur fuels in 2025, combined with a 5-year age-based restriction on all imported secondhand vehicles.

Nigeria was selected to showcase the potential benefits of a specific pathway to lower sulfur fuels and cleaner vehicles. The country has committed to transitioning to 50-ppm by July 2017 (UNEP/CCAC, 2016a). Although Nigeria has a current official diesel sulfur content of 3,000 ppm, this analysis considers a conservative 2,000 ppm as actual sulfur content. The following model runs present the results for $PM_{2.5}$ emissions. Results for other pollutants (BC, CH_4, N_2O, SO_4, NO_X, HC, and CO) are available in the full model. Diesel was the fuel selected to present the emissions reduction from moving to low-sulfur diesel sulfur, which is one of the objectives of the HDDI.

Under the baseline scenario, there is continuation of 2,000-ppm sulfur fuel (Figure 21). There is no timeline for cleaner diesel. Fuel sulfur remains at 2,000 ppm, the matching fuel for Euro I emission standards (see Appendix B). There are no restrictions on imports, and secondhand vehicles that enter the fleet in 2020 are a mix of cleaner Euro V and VI vehicles currently sold in Europe, Japan, and the United States, alongside older vehicles. Because of the lack of matching fuels, cleaner vehicles that enter the fleet after 2020 cannot emit at Euro IV or higher levels. In 2035, most vehicles still emit at Euro II levels. There is no decline in diesel $PM_{2.5}$ emissions, and the country misses out on the benefits of clean vehicles.

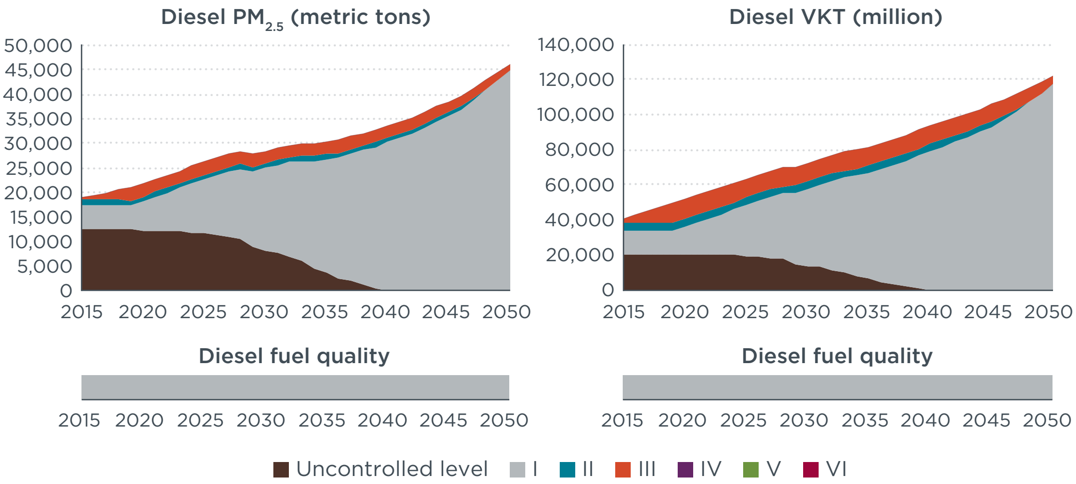

Figure 21. Baseline: continuation of 2,000-ppm sulfur fuel.

Under the first improvement scenario, or LSF, Nigeria adopts and implements 50-ppm low-sulfur fuels in 2017, as planned (UNEP/CCAC, 2016a; Figure 22). The chart of diesel fuel quality grade indicates the transition in 2017, from 2,000-ppm fuels to 50-ppm low-sulfur fuels, which are the matching fuel for Euro IV emissions standards (see Appendix B). There are no restrictions on imports, and secondhand vehicles that enter the fleet in 2020 are a mix of cleaner Euro V and VI vehicles currently sold in Europe, Japan, and the United States, alongside older vehicles. The 50-ppm limits on diesel fuel enable advanced vehicle emission-control technologies to be used with clean vehicles, subsequently reducing emissions of $PM_{2.5}$. Clean vehicles (Euro IV and higher) that enter the fleet in 2020 emit at Euro IV levels. The magnitude of the reduction grows as the share of cleaner vehicles increases in the fleet. In 2035, more than half of the vehicles emit at Euro IV or higher levels. In 2050, almost all vehicles emit at Euro IV levels, resulting in a large, sustained reduction in vehicle $PM_{2.5}$ emissions.

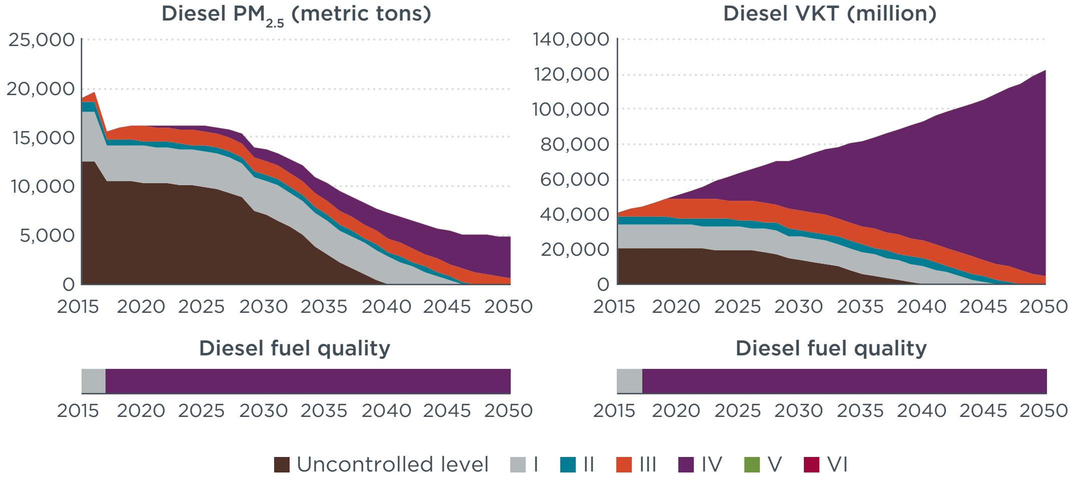

Figure 22. First improvement scenario (LSF): Nigeria implements 50-ppm low-sulfur diesel fuels in 2017.

Following the implementation of 50-ppm low-sulfur fuels in 2017 (previous scenario, LSF), Nigeria further adopts and implements 10-ppm ultralow-sulfur fuels in 2025, coupled with a 5-year age-based restriction on imports of all secondhand vehicles (Figure 23). The chart of diesel fuel quality indicates the transition in 2025, from 50-ppm fuels to 10-ppm ultralow-sulfur fuels, which are the matching fuel for Euro V and VI emissions standards (see Appendix B). There is a 5-year age-based restriction on imports, which enables Nigeria to align with the vehicles emissions standards of the countries from which secondhand vehicles are imported, albeit with a time lag. All secondhand vehicles that enter the fleet in 2025 are cleaner Euro V and VI vehicles, first sold in Europe, Japan, and the United States in the year 2020. The 10-ppm ultralow-sulfur limit enables advanced vehicle emission-control technologies to be optimized with clean vehicles, subsequently reducing emissions of $PM_{2.5}$. Euro V and VI vehicles that enter the fleet in 2025 emit at Euro V and VI levels. The largest reductions occur when the contribution of cleaner vehicles grows in the overall fleet. In 2050, almost all vehicles emit at Euro V and VI levels, which virtually eliminates $PM_{2.5}$ from the vehicle fleet.

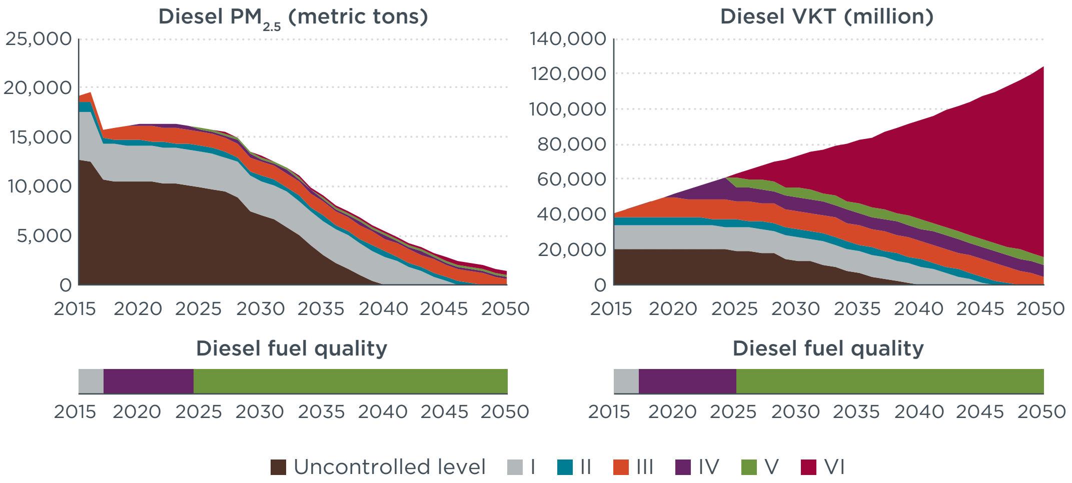

Figure 23. Second improvement scenario (ULSF & Age limit): In 2025, Nigeria implements 10-ppm ultralow-sulfur fuels and a 5-year age-based restriction on all imported secondhand vehicles.

When implementation is delayed, the country misses out on emissions-reductions benefits. Table 18 analyzes the lost share of emissions reduction if Nigeria delays the implementation of 50-ppm diesel fuels until 2020.

Table 18. Costs of delaying implementation of 50-ppm diesel fuels by 3 years in Nigeria.

Year of implementation	Cumulative $PM_{2.5}$ emissions (2017–2035)		Cumulative $PM_{2.5}$ reduction
	Baseline	Low-sulfur fuels	2017–2035
2017	507,000	283,000	–224,000
2020	507,000	297,000	–210,000

	2017: Implementation of 50-ppm sulfur diesel fuels policy	2020: Implementation of 50-ppm sulfur diesel fuels policy (3-year delay)
Cumulative $PM_{2.5}$ reduction from baseline	224,000	210,000
Lost share of emissions benefits with delay		6%

The CCAC HDDI puts a stronger focus on the reduction of on-road diesel BC emissions. Figure 24 presents the potential emissions reductions of BC in 2035 under the three scenarios, disaggregated by vehicle types. The results for Nigeria imply opportunities to substantially reduce BC emissions by cleaning up buses, minibuses, and heavy-freight trucks.

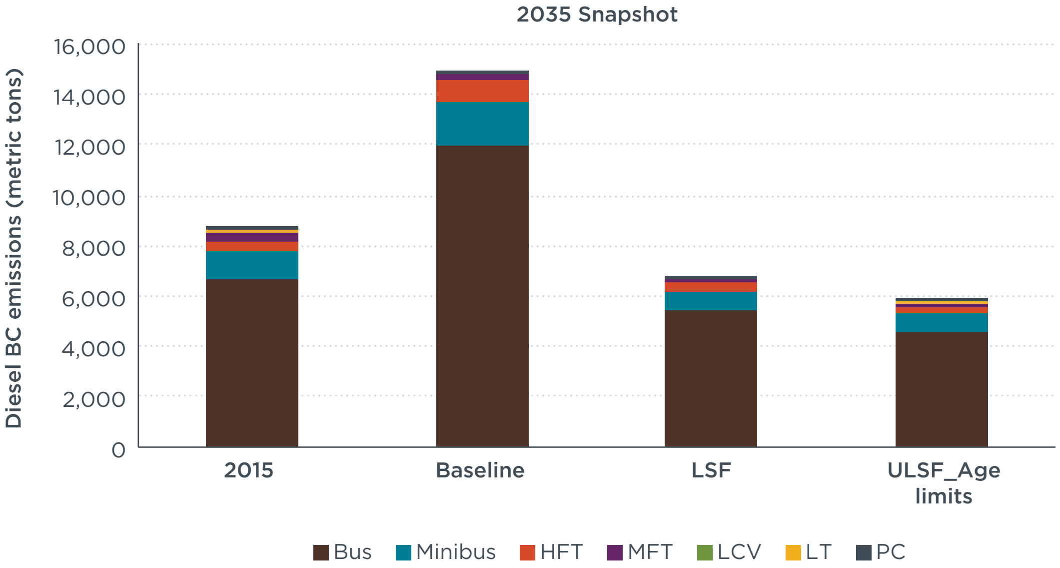

Figure 24. BC emissions by vehicle type in 2035.
HFT = heavy-freight truck, MFT = medium-freight truck, LCV = light commercial vehicle, LT = light truck, PC = passenger car.

This model is a quantitative means of understanding the benefits of short- and near-term policy actions. The scenarios are based on projections that may be subject to uncertainties. These are explained in Appendix E. Limited data were available for imported secondhand vehicles in this study. Although this analysis relies on the best data available, governments are invited to track and make available better information on the number of imported vehicles, vehicle and fuel type, age, country of origin, and level of emission controls that would improve the quality and certainty of the analysis for a given country.

The benefits of providing low-sulfur fuels are even larger than those presented in this analysis, given the potential emissions reduction from non-road diesel-powered equipment, such as diesel generators, agriculture, and construction equipment. This analysis assumes that the functioning of the emissions-control device is reversible, with a disabled system due to the lack of matching fuels returning to normal operation when low-sulfur fuels are introduced. This might not always be the case, particularly when the emission-control device becomes permanently damaged or does not return to its optimal level of performance. In this study, we have conservatively assumed a vehicle growth of 3%. This growth is likely to be an underestimate of actual growth in most countries. For example, the World Bank estimates an annual vehicle growth of 10% for Ethiopia (UNEP/GFEI, 2012) and 12% for Kenya (World Bank Transport and ICT Global Practice, 2016), and those countries may have similar lifestyles as some of the countries in Southern and Western Africa.

SECTION 6

Recommended strategies for adoption of clean fuel and vehicle standards in Southern and Western Africa

Meeting the fuel and vehicle standard targets recommended in this report would yield significant health and climate benefits for countries. However, it is also true that there are substantial political and economic hurdles to overcome. This section discusses strategies the ICCT recommends that governments pursue regionally, nationally, and locally to ensure a successful transition to cleaner fuels and vehicles in the regions.

A harmonized transition to low-sulfur fuels is central to faster and effective implementation in both regions and should leverage regional cooperation under the SADC for the Southern Africa region and the ECOWAS for the Western Africa region. Both regions could rely on new and existing frameworks within those regional organizations (e.g., the Council of Ministers, regional technical meetings) and the ability for those organizations to facilitate the sharing of information, the formulation and enactment of common legislation, the identification of regional leading countries, and regional barriers. ECOWAS and SADC, which have engaged to assist countries for implementation in their specific regions, are also the best-suited venues to discuss obstacles that countries might face—financial, institutional, or economic—to ensure that no country is left behind. In Southern and Western Africa, with countries interconnected to some extent in terms of fuel supply, and with the prevalence of illegal fuel flows within and across borders, a harmonized implementation in terms of specifications and timeline for clean fuels policies is the best approach for a successful clean fuel program. At the global level, according to the Global Sulfur Strategy, a regional transition provides an opportunity for importing countries to influence the global fuel market and serves as an incentive for refiners to invest in refinery upgrades for cleaner fuels (ICCT/UNEP, 2016).

Furthermore, to take advantage of the momentum toward clean fuels policies, countries in Southern and Western Africa should make those policies more comprehensive and, in particular, strengthen their specifications on both diesel and gasoline and impose limits on sulfur, benzene, and aromatics. To date, the ARA has set some fuels specifications with the goal to reach AFRI-4 by 2020 and AFRI-5 by 2030 (see Appendix D). These specifications are important milestones for countries. However, to align with the Global Sulfur Strategy's goal of meeting 10-ppm sulfur fuels by 2030 (ICCT/UNEP, 2016) and to enable countries to adopt Euro 5/VI and Euro 6/VI vehicles standards, ARA needs to set a timeline for AFRI-6 specifications that targets 10-ppm or 15-ppm ultralow-sulfur fuels, closer to the European specifications, because most countries are importers and Western Europe is one of the major fuel suppliers of West African countries (CITAC/ICCT, 2016; Public Eye, 2016). This 10-ppm ultralow-sulfur fuels stringent policy will contribute to the reduction of the overall sulfate particle emissions, and the timeline could be met earlier by countries that wish to implement refineries upgrades to 10 ppm in one step, instead of moving to 50 ppm and then to 10 ppm.

Stronger policies go hand in hand with quality control, compliance, and enforcement. Because of fuels flows, regional collaboration is an effective way to ensure fuel quality. This could be modeled on the East African Standards, with a committee that includes the national standards bodies of partner countries, along with representatives from the private sectors and consumer organizations (East African Community, 2012). Compliance testing could be done at different points along the supply chain, but should include regular fuel quality testing at fuel stations. Regulators should enforce minimum financial penalties for noncompliance with fuel specifications at retail services. Fuel quality testing and enforcement data (i.e., penalties collected) should be publicly available.

In the process of transitioning to cleaner fuels, a patchwork of fuel specifications in importing and refining countries could be expected, with some countries having several grades, depending on the complexity of the supply chain. In countries where multiple fuel grades will be sold, it is important to establish and label low- and ultralow-sulfur fuels to inform consumers.

In refining countries, when determining whether to upgrade refineries or switch to imports, cost-effectiveness should be taken into consideration, including the timeline for implementation; economic impacts; and environmental impacts, in addition to energy security and independence. In all countries, governments should collect and report data on costs and origin of both imported and refined fuels. When AFRI-4 fuels become available, the ICCT recommends that all countries should limit vehicle imports to Euro 4/IV, and then to Euro 6/VI when AFRI-6 10-ppm sulfur fuels become available.

Within each country, coordinated efforts across areas of responsibility are necessary to accelerate the transition to clean fuels and vehicles. Those policies require engagement from stakeholders, including transportation, public health, energy, environment, and finance ministers. The success of those policies would require a portfolio of approaches, including regulations, monetary and fiscal incentives, inspection and maintenance, compliance and enforcement, and information (OECD/IEA, 2016). Table 19 suggests national ministries that need to coordinate their efforts for effective implementation for each type of measure toward cleaner fuels and vehicles.

Table 19. Suggested coordination across national ministries for implementation of clean fuels and vehicles measures.

Type of measure	National ministries				
	Environment	Health	Transport	Energy	Finance
Ambient air quality standards	✔	✔			
Refinery upgrades	✔			✔	✔
Revision of tenders/fuel quality	✔			✔	✔
Light- and heavy-duty vehicle standards	✔		✔		✔
Regulation on secondhand imported vehicles	✔		✔		✔
Taxes/subsidies/ financial incentives for clean fuels and/or clean vehicles	✔		✔	✔	✔

Source: Adapted from OECD/IEA (2016).

Strategies for information and communication with the public, unions, and other stakeholders, including the health sector, could emphasize the substantial health benefits for society, the longer lifetime of vehicles, improved service, and efficiency that will benefit owners and passengers of formal and informal public transportation, taxis, buses, and trucks. Additionally, the adoption of targets for ambient air quality standards or interim targets coupled with air quality monitoring, along with availability of daily information on air quality levels and its health impacts (particularly on more exposed groups) will further increase awareness and favor support for clean air programs that improve air quality.

Additional strategies and country-specific details are provided for refining and importing countries separately in the next section.

IV. REFINING COUNTRIES

With relatively lower refining capacities, most refining countries in the regions meet local demand for refined products with imported diesel fuels. In addition to securing financing to upgrade refineries, countries could accelerate the transition to low-sulfur fuels by tightening their standards to import 10-ppm or 50-ppm sulfur fuels. Table 20 provides the list and profile of refining countries in Southern Africa in relation to their clean fuel goals. South Africa already has some 50-ppm sulfur fuel available. In the region, it is the major refining country and a key importing point for several other countries. Specifications in Botswana, Lesotho, Malawi, Mozambique, Namibia, Swaziland, Zambia, and Zimbabwe are linked to South African standards (CITAC/ICCT, 2016; ICCT/UNEP, 2014). South Africa has low barriers to achieving clean fuels and vehicles standards nationwide. Currently, the country has 50-ppm and 500-ppm sulfur fuels available and is developing a plan to transition to more stringent, 10-ppm sulfur fuels standards. Once the transition to low- and ultralow-sulfur fuels is successful, it will benefit the SADC region, where many countries depend on South Africa's fuels. Additionally, the country has Euro 2 vehicle standards for LDVs, along with a ban on imports of secondhand vehicles. With 50-ppm fuels, the country can adopt more stringent emissions standards, and with 10-ppm, it can go further and adopt world-class vehicle emissions standards.

Angola has planned to build a new refinery in Lobito and to upgrade the existing Luanda refinery. Progress to secure financing for those projects has been limited to date. Interim standards while securing financing to upgrade refineries and tightening standards on imported diesel fuels will enable the country to transition faster to low-sulfur fuels. In Zambia, although the Indeni refinery is targeted to copper mining and not directed to vehicle fuels, upgrading the refinery to produce cleaner fuels will reduce emissions from the non-road sector. For the road transportation sector, the country needs to tighten standards and imports specifications.

Table 20. Southern African fuel-refining countries that require refinery upgrades as of 2016

Country	Regulatory framework	Agency	Country's profile
Angola	Ministerial decree	Ministerio dos Petroleos	Meeting Angola's demand of low-sulfur diesel fuels with domestic supply depends on securing financing to build the new refinery in Lobito. With tighter standards, the Luanda refinery should make a case for financial viability and investments for upgrades. However, revising imports conditions to source 50-ppm sulfur fuels will enable Angola to transition to low-sulfur fuels by 2020.
South Africa	National Standards Document	SABS (South African Bureau of Standards)	A key supplier of refined products in the sub-region, South Africa has relatively lower barriers to meet 50-ppm sulfur fuels nationwide. The country has set a goal of achieving the Clean Fuels 2 (CF2; 10-ppm diesel and gasoline) in 2017. The final decision on the timeframe regarding when the country will shift to 10-ppm sulfur fuels is still pending, and the 2017 deadline is on hold. A swift decision will facilitate a smoother transition not only for the country but also for its neighbors. With the prohibition of secondhand imported vehicles and the availability of low-sulfur fuels, South Africa can tighten its vehicle emissions standards to Euro 4/IV and eventually leapfrog to Euro 6/V.
Zambia	National Standards Document	Zambia Bureau of Standards	Meeting the 2020 commitment could be achieved by tightening fuel-imports specifications. Upgrading the Indeni refinery will reduce emissions from the copper mining sector. However, the financial case for upgrades still needs to be made.

In the Western Africa region, all refining countries, except Côte d'Ivoire and Niger, rely to some extent on imported fuels to meet domestic demand. In the region, Ghana took the lead by deciding to import low-sulfur fuels by March 2017, with Nigeria following by July 2017 (UNEP/CCAC, 2016a). In Nigeria, three quarters of the oil products consumed are imported (ICCT/UNEP, 2014). Much of the imported fuel comes from countries where low-sulfur fuels are available (although they occasionally import higher sulfur fuel from Central Asia). The recent commitment to import low-sulfur fuels in Nigeria could improve the overall quality of fuels not only within the country, but also in the sub-region, because the ships that bring in refined products for Nigeria also supplies other importing countries, such as Benin (ICCT/UNEP, 2014; UNEP/CCAC, 2016a). At the same time, significant investments are required to upgrade existing refineries. The Dangote industry has planned to build the largest refinery in Africa, with targeted ultralow-sulfur fuels destined for both domestic demand and exports. Côte d'Ivoire, the key refining hub of the sub-region, has a more critical role and is looking for financing to start upgrades of the SIR refinery to meet the 2020 timeline. The country refines oil products for its own market and exports high-sulfur fuels to 12 of its neighbors (Benin, Burkina Faso, The Gambia, Ghana, Guinea, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo; ICCT/UNEP, 2014). To date, the SIR delivers AFRI-2 diesel and AFRI-3 gasoline fuels (UNEP/CCAC, 2016c). The country has set 2017 as the year to start the upgrades of its SIR refineries to meet AFRI-5 specifications, including 50-ppm sulfur for diesel and gasoline, and meeting the 2020 timeline is dependent on the progress of the upgrades. If this happens, it will benefit countries that rely on Côte d'Ivoire's fuels (ICCT/UNEP, 2014). In the meantime, the likelihood of multiple grades in the sub-region is high, requiring labeling the different fuel grades that are available. Although smaller in scale and influence, Senegal also acts as a refining hub and coastal import point for some inland markets by importing Nigerian crude, refining it for internal use, and exporting to five of its neighbors (Guinea, Guinea Bissau, Liberia, Mali, and Sierra Leone; ICCT/UNEP, 2014). Table 21 provides the profile of refining countries in Western Africa in relation to their clean fuel goals.

Table 21. West African fuel-refining countries that require refinery upgrades as of 2016.

Country	Regulatory framework	Agency	Country's profile
Côte d'Ivoire	Presidential Decree	Presidency	Côte d'Ivoire plays a critical role in the sub-region because it supplies most of its neighbors with fuel. Moving to 50-ppm sulfur fuel requires significant investment for hydrodesulfurization and benzene extraction at the SIR refinery. Different ways for financing are being discussed. Refinery upgrades are planned from 2017 to 2020. Although the output of the refinery covers domestic demand for refined products, upgrading the SIR refinery needs to be accelerated to provide cleaner products within the country and to keep a competitive advantage of selling cleaner products on the regional markets.
Ghana	National Standard Document	Ghana Standards Authority	The timeline for implementation of the imports of 50-ppm diesel fuels has been revised to July 1, 2017 (as of March 2017), and significant progress has been made toward reaching this deadline. A technical committee on fuel standards has drafted revised standards for both diesel and gasoline. As of March 2017, the draft has been circulated for comments from stakeholders. The Tema Oil Refinery (TOR) is capable of producing 500-ppm sulfur fuel depending on the grade of crude oil for processing, and the Platon Gasoil Refinery produces diesel at 1,000-ppm sulfur. An estimated investment of US $120 million is required to upgrade the TOR refinery and increase operating capacity. The regulatory framework of the downstream sector is robust, with an independent regulator (National Petroleum Authority).
Niger	-	-	

Country	Regulatory framework	Agency	Country's profile
Nigeria	National Standard Documents	Key regulators are DPR (government downstream regulator) and SON (Standards of Nigeria)	Along with four ECOWAS countries, Nigeria has committed to importing 50-ppm sulfur fuels by July 2017, with a waiver for refineries to meet this target by 2020. As of March 2017, significant progress has been made toward meeting the deadline of July 1, 2017, for importing clean fuels, with strong collaboration between decision makers and stakeholders (ministries, Standards of Nigeria [SON], the Petroleum Product Pricing and Regulatory Agency [PPPRA], the Nigerian National Petroleum Corporation [NNPC], the Department of Petroleum Resources [DPR], the National Automotive Design and Development Council [NADDC], etc.) Nigeria plays a key role in the sub-region. A strategic investment plan for a roadmap of 24 months has been developed for the rehabilitation of the Port-Harcourt, Warri, and Kaduna refineries to reach 90% of their capacity utilization levels. Plans include the co-location of plants at offshore refineries, pipeline security, crude oil supply, and people development. Tenders for imports of products under the Direct Sale of Crude Oil and Direct Purchase of Products (DSDP) program should target cleaner products. The Dangote Oil Refinery will be designed to produce ultralow-sulfur fuels. As of March 2017, the projected 650,000 bpd from the Dangote refinery, and 400, 000 bpd from other refineries could make Nigeria a net exporter of refined products. With its ambition to become a major vehicle manufacturer in Africa, Nigeria can move to more stringent vehicle emissions standards.
Senegal	Ministerial Decree	Ministry of Energy, Infrastructure and Air Transport	Smaller refining hub, upgrades are required to produce 50-ppm sulfur fuels.

Source: ARA (2017b); CITAC/ICCT(2016); UNEP/CCAC (2016a, 2016c)

V. IMPORTING COUNTRIES

A few importing countries, including Mozambique in the Southern region and Togo in the Western region, serve as second hubs and as importing points for the inland market. Togo is an important storage hub serving the inland market. Togo has also committed to transitioning to 50-ppm sulfur fuels by July 2017, which will be useful for countries that import from Togo. Tables 22 and 23 provide the profiles of importing countries in Southern and Western Africa.

Table 22. Southern African fuel-importing countries as of 2016.

Country	Regulatory framework	Agency	COUNTRY'S PROFILE
Botswana	Law linking specification to South African standards	Ministry of Minerals, Energy and Water Resources	Growing supply of 50-ppm sulfur fuel since 2015. 6% of imported fuel is 50-ppm sulfur. The mining sector is sourcing 50-ppm sulfur fuel as part of their environmental commitments. The government is converting all of its fuel-storage facilities to accommodate 50-ppm sulfur fuel in 2016.
DR Congo	Ministerial decree	Ministère des Hydrocarbures	Eastern DR Congo already has 50-ppm sulfur diesel because of supply via Eastern Africa countries.
Lesotho	Specifications linked in law to South African standards	Ministry of Energy	
Madagascar	Ministerial decree	Ministère de l'Energie et des Mines	
Malawi	Official Tender	National Oil Company of Malawi	Refined product imported through Tanzania is already 50-ppm sulfur fuel.
Mauritius	Official Tender	State Trading Company	Has met 50-ppm sulfur diesel nationwide and enforced a 3-year age restriction on secondhand vehicles. Mauritius could transition to 10-ppm and adopt stronger vehicle emissions standards.
Mozambique	Official Tender	Imopetro (state oil company)	Mozambique is a key import point for product imports into inland markets and supplies Malawi and Zimbabwe. The country has committed to implement 50-ppm sulfur fuel in 2016, with 1 to 6 months of transition.
Namibia	Law linking specification to South African standards	Ministry of Energy	Namibia has already planned to move to 10-ppm ultralow-sulfur fuels.
Seychelles	Official Tender	Seypec (state oil company)	
Swaziland	Law linking specification to South African standards	Ministry of Natural Resources & Energy	
Tanzania	Regional harmonized standards	East African Community	Has already achieved 50-ppm diesel and 150-ppm gasoline nationwide and could share best practices. Tanzania could transition to ultra-low sulfur fuels and implement stronger vehicle emissions standards.
Zimbabwe	Ministerial decree	Ministry of Energy and Power Development	Committed to implementing 50-ppm sulfur fuel and to finding ways to import low-sulfur fuels.

Source: ARA (2017b); CITAC/ICCT(2016); UNEP/CCAC (2016d)

Table 23. Western African fuel-importing countries as of 2016.

Country	Regulatory framework	Agency	COUNTRY'S PROFILE
Benin	Ministerial Decree	Ministry of Energy	Coastal source, Benin has committed to import 50-ppm sulfur fuels by July 2017.
Burkina Faso	Official Tender	Sonabhy (state oil company)	Complexity of the supply route, dependent on regional fuel levels and coastal neighbors.
Cape Verde	Official Tender	Enacol (state oil company)	
The Gambia	-	-	
Guinea	Official Tender	SGP (state oil company)	New refinery announced in Kamsar, owned by Brahms Oil Refinery and estimated to start in 2019. The refinery is expected to process various grades of crude oil from West Africa and to produce AFRI-4 diesel and gasoline fuels. This is a small and modular refinery (10,000 bpd) for the local market.
Guinea-Bissau	-	-	
Liberia	Ministerial Decree	Ministry of Commerce & Industry	
Mali	Interministerial Decree	Ministries of Mines & Energy, Economy, Industry & Commerce, Environment	Complexity of the supply route, dependent on regional levels and coastal neighbors.
Sierra Leone	National Standard Document	Sierra Leone Standards Bureau	
Togo	Interministerial Decree	Arrêté interministériel n° 010 PM/ MEMPT/ MCITDZF/MEFP	Important import point and storage hub for the inland market. Togo has committed to import 50-ppm sulfur fuels by July 2017. Refined products are imported through international tenders, and meeting the 50-ppm depends on updates on tenders.

Source: ARA (2017b); CITAC/ICCT(2016); UNEP/CCAC (2016a, 2016c)

Conclusion

This report provides a rationale for the implementation of clean fuel and vehicle standards in Southern and Western Africa. The results of this analysis indicate that countries' goal of implementing AFRI-4 fuels by 2020 is achievable; in particular, the five West African countries that have committed to importing 50-ppm diesel fuels by July 1, 2017, can meet their timeline. Furthermore, all countries in the region and in other parts of the world should be able to reach this milestone by 2025, and most countries should be able to reach 10-ppm diesel fuels by 2030, in line with the Global Sulfur Strategy. When clean fuels become available, countries should implement Euro 4/IV or more stringent vehicle emissions standards and regulations on the imports of secondhand vehicles enabled by the fuels. The clean fuels and vehicles will generate substantial public health benefits, particularly by reducing emissions of particulate matter (a pollutant harmful to public health) and diesel black carbon (a short-lived climate pollutant).

The study also finds that meeting countries' timelines is critical because delayed implementation will incur additional emissions reductions and health costs. The availability of low-sulfur fuels on the international markets and the declining price premium on low-sulfur fuels provide an opportunity for the import of clean fuels and make the need to upgrade refineries more urgent.

In the countries of Southern and Western Africa, inspection and maintenance for vehicles, along with compliance and enforcement programs, are necessary to maintain a cleaner fleet and to ensure that vehicles and fuels are clean in the real world.

Looking forward, and in order for countries to increasingly benefit from data-driven transportation policy analysis, all countries should collect and report data on imported vehicles, including emission and fuel economy certification levels. Southern and Western African countries are clearly far behind much of the rest of the world, but recent progress by these countries in setting a timeline for clean fuels provides great momentum for the implementation of long-term clean fuels and vehicles policies.

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APPENDIX A. GDP GROWTH AND POPULATION PER COUNTRY IN SOUTHERN AND WESTERN AFRICA IN 2015

Table 24. GDP growth and population per country in Southern Africa.

Country	Real GDP (%) 2015[a]	Population in 2015[b] (millions)
Angola	3.8	25
Botswana	4.5	2.3
DR Congo	9.0	77.3
Lesotho	4.3	2.1
Madagascar	4.0	24.2
Malawi	5.5	17.2
Mauritius	3.5	1.3
Mozambique	7.5	28
Namibia	5.6	2.5
Seychelles	3.7	0.1
South Africa	2.0	54.5
Swaziland	2.6	1.3
Tanzania	7.4	53.5c
Zambia	6.5	16.2
Zimbabwe	3.2	15.6

[a]Projected GDP growth. [b]Population as of mid-2015.
[c]Refers to the United Republic of Tanzania (UN World Population Prospects 2015, Table S2).
Source: GDP (African Economic Outlook, 2015) and population (UN World Population Prospects, 2015).

Table 25. GDP growth and population per country in Western Africa.

Country	Real GDP (%) 2015[a]	Population in 2015[b] (millions)
Benin	5.6	10.9
Burkina Faso	5.5	18.1
Cape Verde	3.1	0.5
Côte d’Ivoire	7.9	22.7
The Gambia	4.2	2.0
Ghana	3.9	27.4
Guinea	0.9	12.6
Guinea-Bissau	3.9	1.8
Liberia	3.8	4.5
Mali	5.4	17.6
Niger	6.0	19.9
Nigeria	5.0	182.2
Senegal	4.6	15.1
Sierra Leone	-2.5	6.5
Togo	5.7	7.3

[a]Projected GDP growth. [b]Population as of mid-2015.
Source: GDP (African Economic Outlook, 2015) and population (UN World Population Prospects, 2015).

APPENDIX B. VEHICLE EMISSIONS STANDARDS AND BENEFITS OF LOW-SULFUR FUELS

I. BENEFITS OF LOW-SULFUR FUELS AND AFTERTREATMENT EMISSIONS-CONTROL SYSTEMS

Sulfur is a natural element in crude oil. The level of sulfur in fuels influences emissions and air pollution caused by motor vehicles. High-level sulfur fuels result in high emissions of sulfate particles associated with early deaths and other negative health impacts (Kodjak, 2015). On the contrary, low-sulfur fuels benefit air quality in two ways: When low-sulfur fuels are available at refueling stations, there is an immediate, direct benefit of sulfate particle emissions reductions from the entire in-use fleet (Kodjak, 2015). There is also an indirect benefit, because low-sulfur fuels enable automakers to incorporate advanced emission-control technologies on vehicles (Kodjak, 2015). Those technologies, referred as *aftertreatment systems*, are required to control the emissions of those regulated pollutants, particularly NO_x and $PM_{2.5}$, which are among the most harmful pollutants. The most common aftertreatment systems to reduce NO_x emissions are lean NO_x traps or selective catalytic reduction with ammonia, and those to reduce $PM_{2.5}$ are the diesel oxidation catalyst and diesel particulate filters (Kodjak, 2015). Higher sulfur levels in fuels inhibit the functioning of emission-control devices, and, particularly for diesel particulate filters, soot particles clog and make the filters ineffective (Kodjak, 2015; U.S. EPA , 2012). When low-sulfur fuels are available, a wider range of aftertreatment emissions-control technologies can be used, with a greater potential to reduce $PM_{2.5}$ and NO_x (Sharpe, Fung, Kamakaté, Posada, & Rutherford, 2011).

II. TAILPIPE EMISSION STANDARDS

Major economies regulate their vehicle emission-control programs with stringent vehicle emissions standards. Emissions standards are limits on the amount of pollutants released by or evaporated from new vehicles and engines over a predefined test cycle (Sharpe et al., 2011). However, vehicle emissions standards are closely linked with the quality of fuel available (Sharpe et al., 2011), and nations with low-and ultralow-sulfur fuels available have an immediate opportunity to implement more stringent vehicle emissions standards (U.S. EPA , 2012). Many countries have based their emissions standards on the European Union model. A set of technologies is required for each standard.

Stringent fuel and vehicle standards have a significant benefit on PM reduction, as described in Figure 25. The transition from one Euro emissions standard to the next reduces $PM_{2.5}$ emissions by a certain percentage, for both LDVs and HDVs. Compared with the baseline uncontrolled level, the potential emissions reduction could reach 99%, thus eliminating almost all of the $PM_{2.5}$.

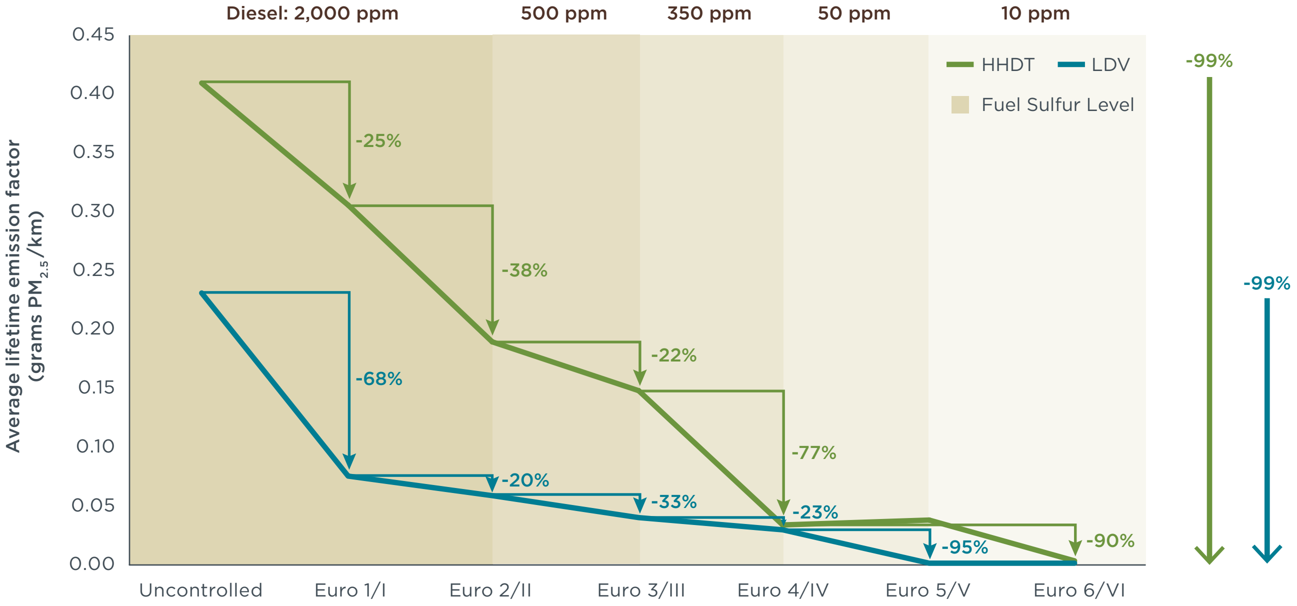

Figure 25. European tailpipe emission standards and matching fuel sulfur content.
Source: Chambliss, Miller, Façanha, Minjares, & Blumberg (2013)

APPENDIX C. DIESEL AND GASOLINE CONSUMPTION IN SOUTHERN AND WESTERN AFRICA IN 2014

Table 26. Diesel and gasoline consumption in Southern Africa in 2014.

Country	Diesel consumption (2014; barrels/day)	Gasoline consumption (2014; barrels/day)	Percentage of regional consumption
Angola	75,900	33,300	15
Botswana	10,300	8,400	3
DR Congo	13,400	7,000	3
Lesotho	1,800	1,800	0
Madagascar	9,100	2,200	2
Malawi	3,100	1,800	1
Mauritius	5,200	3,300	1
Mozambique	14,200	4,600	3
Namibia	12,400	7,100	3
Seychelles	1,200	400	0
South Africa	226,100	198,800	59
Swaziland	2,800	2,400	1
Tanzania	31,700	15,100	6
Zambia	13,700	6,700	3
Zimbabwe	7,000	3,200	1
Total	427,900	292,900	100
Southern Africa's share	59%	41%	

🟧 Fuel consumption dominated by diesel

Source: CITAC/ICCT (2016)

Table 27. Gasoline and diesel consumption in Western Africa in 2014.

Country	Diesel consumption (2014; barrels/day)	Gasoline consumption (2014; barrels/day)	Percentage of regional consumption
Benin	8,200	3,100	2
Burkina Faso	9,500	5,500	3
Cape Verde	2,200	200	0
Côte d'Ivoire	17,500	6,600	4
The Gambia	1,400	400	0
Ghana	35,000	27,100	11
Guinea	6,600	6,300	2
Guinea-Bissau	1,000	300	0
Liberia	3,300	2,800	1
Mali	14,000	2,900	3
Niger	5,800	3,500	2
Nigeria	59,000	298,800	65
Senegal	18,200	3,500	4
Sierra Leone	4,700	2,300	1
Togo	2,800	2,100	1
Total	189,200	365,400	100
Western Africa's fuel share	34%	66%	

🟧 Fuel consumption dominated by diesel 🟦 Fuel consumption dominated by gasoline

Source: CITAC/ICCT (2016)

APPENDIX D. AFRI SPECIFICATIONS

GASOIL / DIESEL

Property	AFRI-1	AFRI-2	AFRI-3	AFRI-4	AFRI-5
Sulphur content, mg/kg mass, max.	8000	3500	500	50	50
Density at 15°C, kg/m^3, min - max.	800 - 890	800 - 890	800 - 890	820 - 880	820 - 880
Cetane Index (calculated), min.	42	45	45	45	46
Cetane Number, min.	n/a	n/a	n/a	n/a	49
Polycyclic Aromatic Hydrocarbons (PAH), mass %, max.	n/a	n/a	n/a	n/a	11
Lubricity (HFRR @ 60 °C), micron, max.	to be reported	to be reported	460	460	460
Oxidation stability (Hr)(1)	20	20	20	20	20
FAME content, vol%, max.	7	7	7	7	7

1. Applicable only to gas oil / diesel containing more than 2% v/v FAME.
2. In cases of dispute ASTM D3244 / EN ISO 4259 shall be used.

Figure 26. AFRI diesel specifications.

Source: ARA (2017)

UNLEADED GASOLINE

Property	AFRI-1	AFRI-2	AFRI-3	AFRI-4	AFRI-5
RON, min.(1)	91	91	91	91	91
MON, min.	81	81	81	81	81
Lead content, mg/l max.(4)	5	5	5	5	5
Sulphur content, mg/kg, max.	1000	500	300	150	50
Benzene content, vol%, max.	to be reported	to be reported	5	1	1
Aromatics, vol%, max.	n/a	n/a	n/a	n/a	42
Density at 15°C, kg/m^3 min-max	n/a	n/a	n/a	n/a	725-780
RVP, kPa, max.	n/a	n/a	n/a	n/a	65
Ethanol content, vol%, max.(2)	5	5	5	10	10

1. A higher grade of gasoline may be marketed if required.
2. Imported gasoline to be free from oxygenates.
3. In cases of dispute ASTM D3244 / EN ISO 4259 shall be used.
4. No intentional addition of lead.

Figure 27. AFRI gasoline specifications.

Source: ARA (2017)

APPENDIX E. METHODOLOGY FOR FLEET MODEL

MODEL INPUTS AND ASSUMPTIONS

Outputs: estimated impacts of imported secondhand vehicles
Climate: BC, CH_4, N_2O, CO_2 (thousand metric tons)
Health: $PM_{2.5}$, NO_X, HC, CO (thousand metric tons)
Diesel and gasoline consumption (million liters)
Regional flexibility
Any country with sufficient data inputs
Inputs for most countries in Southern and Western Africa
Vehicle types based on IEA definitions
Passenger: PC, LT, Bus, Minibus, 2W
Freight: LCV, MFT, HFT
Two fuel types cover virtually all secondhand imports
Diesel
Gasoline
Time horizon: 2050
New vehicles could be modeled by assuming age = 0

Table 28. IEA vehicle classification.

LDV : Light-duty vehicle	Four-wheel motorized road vehicle carrying persons (up to 8 persons) and/or goods (up to 3.5 tons, including vehicle weight)
LCV : Light commercial vehicle	LDV aiming at goods transportation up to a gross vehicle weight of 3.5 tons
LT : Light truck	LDV aiming at persons' transportation with a gross vehicle weight between 2 tons and 3.5 tons, generally includes sport utility vehicles and pick-up trucks
PC : Passenger car	LDV aiming at persons' transportation up to a gross vehicle weight of 2 tons
MFT : Medium-freight truck	Vehicle dedicated to goods transport, with total mass (including vehicle) between 3.5 tons and 15 tons (Classes 2–7 in the United States)
HFT : Heavy-freight truck	Vehicle dedicated to goods transport, with total mass (including vehicle) higher than 15 tons (Class 8 in the United States).
HDV : Heavy-duty vehicle	Vehicle dedicated to goods transport, with total mass (including vehicle) higher than 3.5 tons.
2W : Motorized two-wheeler	
3W : Motorized three-wheeler	

Table 29. Input data description, assumption, and sources.

Input	Description	Source
Sulfur content of fuel	Sulfur content of available gasoline and diesel	Domestic production or import regulations
Imports	Annual vehicle imports	IEA Mobility Model (MoMo) estimates
Average age	Assumed age of imported vehicles	Age-based import restrictions
Share of imports by fuel type	Gasoline and diesel share for vehicle imports	Countries' data or ICCT expert judgment
Average Euro level	Assumed emissions level of available imports	Assumption based on EU standards
Fuel efficiency by model year	Historical standards in exporting countries	IEA MoMo estimates
Annual vehicle activity	Vehicle kilometers traveled (VKT) per year	IEA MoMo estimates
Carbon intensity by fuel type	Grams CO_2 per liter fuel	ICCT World Bank BC reduction model
Emission factors	Grams per VKT without sulfur effects	ICCT Roadmap model
Euro level with available fuel	Relates actual emissions level to certification	ICCT expert judgment
Sulfur effects for diesel $PM_{2.5}$	Emission factor multipliers by sulfur content	ICCT Roadmap model
Survival curves	Share of vehicles remaining after X years	ICCT expert judgment
VKT degradation curves	VKT at age X relative to new	ICCT expert judgment

Carbon intensity by fuel type

Gasoline conversion factor: 2320 g/L
Diesel conversion factor: 2650 g/L

Table 30. Emission factors of pollutants by fuel type and Euro certification level (grams per vehicle-km)*.

ID	Veh type	Fuel type	Ctrl level	CO	NO$_x$	PM	HC	CH4	N2O	BC	OC
HFT0Diesel	HHDT	Diesel	Uncontrol	2.350	11.328	0.410	0.631	0.085	0.030	0.205	0.164
HFT1Diesel	HHDT	Diesel	Euro 1	1.857	7.833	0.307	0.497	0.085	0.011	0.199	0.080
HFT2Diesel	HHDT	Diesel	Euro 2	1.630	8.358	0.189	0.328	0.052	0.010	0.123	0.049
HFT3Diesel	HHDT	Diesel	Euro 3	1.802	6.666	0.149	0.301	0.024	0.006	0.104	0.031
HFT4Diesel	HHDT	Diesel	Euro 4	0.784	4.581	0.035	0.046	0.005	0.017	0.026	0.006
HFT5Diesel	HHDT	Diesel	Euro 5	1.388	2.803	0.034	0.028	0.005	0.048	0.029	0.007
HFT6Diesel	HHDT	Diesel	Euro 6	0.810	0.333	0.004	0.023	0.005	0.045	0.001	0.002
HFT0Gasoline	HHDT	Gasoline	Uncontrol	93.789	4.890	0.050	4.938	2.851	0.001	0.017	0.014
HFT1Gasoline	HHDT	Gasoline	Euro 1	61.490	2.832	0.009	0.219	0.126	0.014	0.004	0.003
HFT2Gasoline	HHDT	Gasoline	Euro 2	17.966	2.691	0.008	0.219	0.126	0.013	0.004	0.003
HFT3Gasoline	HHDT	Gasoline	Euro 3	4.635	2.272	0.009	0.169	0.097	0.011	0.005	0.004
HFT4Gasoline	HHDT	Gasoline	Euro 4	4.037	2.272	0.008	0.169	0.097	0.011	0.005	0.004
HFT5Gasoline	HHDT	Gasoline	Euro 5	4.037	0.784	0.008	0.069	0.039	0.004	0.005	0.004
HFT6Gasoline	HHDT	Gasoline	Euro 6	4.037	0.200	0.004	0.069	0.039	0.001	0.001	0.001
PC0Diesel	LDV	Diesel	Uncontrol	0.846	0.898	0.240	0.160	0.018	0.000	0.132	0.093
PC1Diesel	LDV	Diesel	Euro 1	0.449	0.850	0.078	0.077	0.009	0.003	0.054	0.022
PC2Diesel	LDV	Diesel	Euro 2	0.386	0.876	0.064	0.065	0.004	0.005	0.051	0.012
PC3Diesel	LDV	Diesel	Euro 3	0.194	0.845	0.043	0.038	0.001	0.005	0.036	0.005
PC4Diesel	LDV	Diesel	Euro 4	0.169	0.655	0.031	0.019	0.000	0.006	0.027	0.004
PC5Diesel	LDV	Diesel	Euro 5	0.169	0.681	0.002	0.019	0.000	0.006	0.000	0.001
PC6Diesel	LDV	Diesel	Euro 6	0.169	0.256	0.002	0.019	0.000	0.006	0.000	0.001
PC0Gasoline	LDV	Gasoline	Uncontrol	26.519	2.417	0.002	2.406	0.100	0.008	0.000	0.002
PC1Gasoline	LDV	Gasoline	Euro 1	3.050	0.364	0.002	0.208	0.020	0.020	0.001	0.002
PC2Gasoline	LDV	Gasoline	Euro 2	1.518	0.174	0.002	0.076	0.014	0.012	0.001	0.002
PC3Gasoline	LDV	Gasoline	Euro 3	1.246	0.080	0.001	0.023	0.003	0.003	0.000	0.000
PC4Gasoline	LDV	Gasoline	Euro 4	0.605	0.050	0.001	0.013	0.003	0.002	0.000	0.000
PC5Gasoline	LDV	Gasoline	Euro 5	0.605	0.037	0.001	0.013	0.003	0.002	0.000	0.000
PC6Gasoline	LDV	Gasoline	Euro 6	0.605	0.037	0.001	0.013	0.003	0.002	0.000	0.000
Minibus0Diesel	LHDT	Diesel	Uncontrol	1.962	4.652	0.311	1.130	0.044	0.030	0.155	0.124
Minibus1Diesel	LHDT	Diesel	Euro 1	0.704	3.365	0.125	0.225	0.044	0.005	0.081	0.032
Minibus2Diesel	LHDT	Diesel	Euro 2	0.569	3.580	0.065	0.151	0.028	0.004	0.042	0.017
Minibus3Diesel	LHDT	Diesel	Euro 3	0.644	2.782	0.062	0.141	0.020	0.003	0.043	0.013
Minibus4Diesel	LHDT	Diesel	Euro 4	0.348	1.898	0.016	0.022	0.002	0.006	0.012	0.003
Minibus5Diesel	LHDT	Diesel	Euro 5	0.625	1.488	0.014	0.013	0.002	0.017	0.011	0.003
Minibus6Diesel	LHDT	Diesel	Euro 6	0.358	0.233	0.002	0.010	0.002	0.018	0.000	0.001
Minibus0Gasoline	LHDT	Gasoline	Uncontrol	4.060	4.841	0.068	3.801	0.049	0.006	0.028	0.022
Minibus1Gasoline	LHDT	Gasoline	Euro 1	0.769	2.592	0.023	2.421	0.005	0.071	0.007	0.006
Minibus2Gasoline	LHDT	Gasoline	Euro 2	0.487	1.472	0.009	0.268	0.003	0.040	0.002	0.001
Minibus3Gasoline	LHDT	Gasoline	Euro 3	0.471	1.632	0.006	0.313	0.004	0.045	0.001	0.001
Minibus4Gasoline	LHDT	Gasoline	Euro 4	0.221	0.357	0.005	0.060	0.001	0.010	0.001	0.001
Minibus5Gasoline	LHDT	Gasoline	Euro 5	0.221	0.288	0.004	0.060	0.001	0.008	0.001	0.001
Minibus6Gasoline	LHDT	Gasoline	Euro 6	0.221	0.288	0.004	0.060	0.001	0.008	0.001	0.001
MFT0Diesel	MHDT	Diesel	Uncontrol	2.035	8.124	0.281	0.720	0.034	0.030	0.140	0.112
MFT1Diesel	MHDT	Diesel	Euro 1	0.982	4.854	0.175	0.306	0.034	0.005	0.114	0.046

ID	Veh type	Fuel type	Ctrl level	CO	NO$_x$	PM	HC	CH4	N2O	BC	OC
MFT2Diesel	MHDT	Diesel	Euro 2	0.856	5.176	0.101	0.205	0.021	0.005	0.066	0.026
MFT3Diesel	MHDT	Diesel	Euro 3	0.974	4.000	0.087	0.189	0.013	0.003	0.061	0.018
MFT4Diesel	MHDT	Diesel	Euro 4	0.481	2.755	0.022	0.029	0.002	0.008	0.017	0.004
MFT5Diesel	MHDT	Diesel	Euro 5	0.873	1.879	0.021	0.017	0.002	0.022	0.015	0.004
MFT6Diesel	MHDT	Diesel	Euro 6	0.496	0.273	0.002	0.014	0.002	0.021	0.000	0.001
MFT0Gasoline	MHDT	Gasoline	Uncontrol	67.620	3.201	0.072	4.857	0.988	0.001	0.041	0.033
MFT1Gasoline	MHDT	Gasoline	Euro 1	47.309	2.225	0.013	0.252	0.051	0.016	0.010	0.008
MFT2Gasoline	MHDT	Gasoline	Euro 2	15.862	2.126	0.012	0.252	0.051	0.015	0.010	0.008
MFT3Gasoline	MHDT	Gasoline	Euro 3	4.113	1.768	0.013	0.198	0.040	0.012	0.011	0.009
MFT4Gasoline	MHDT	Gasoline	Euro 4	3.659	1.768	0.012	0.198	0.040	0.012	0.011	0.009
MFT5Gasoline	MHDT	Gasoline	Euro 5	3.659	0.609	0.012	0.081	0.017	0.004	0.011	0.009
MFT6Gasoline	MHDT	Gasoline	Euro 6	3.659	0.149	0.004	0.081	0.017	0.001	0.002	0.002
LT0Diesel	LDV	Diesel	Uncontrol	0.846	0.898	0.240	0.160	0.018	0.000	0.132	0.093
LT1Diesel	LDV	Diesel	Euro 1	0.449	0.850	0.078	0.077	0.009	0.003	0.054	0.022
LT2Diesel	LDV	Diesel	Euro 2	0.386	0.876	0.064	0.065	0.004	0.005	0.051	0.012
LT3Diesel	LDV	Diesel	Euro 3	0.194	0.845	0.043	0.038	0.001	0.005	0.036	0.005
LT4Diesel	LDV	Diesel	Euro 4	0.169	0.655	0.031	0.019	0.000	0.006	0.027	0.004
LT5Diesel	LDV	Diesel	Euro 5	0.169	0.681	0.002	0.019	0.000	0.006	0.000	0.001
LT6Diesel	LDV	Diesel	Euro 6	0.169	0.256	0.002	0.019	0.000	0.006	0.000	0.001
LT0Gasoline	LDV	Gasoline	Uncontrol	26.519	2.417	0.002	2.406	0.100	0.008	0.000	0.002
LT1Gasoline	LDV	Gasoline	Euro 1	3.050	0.364	0.002	0.208	0.020	0.020	0.001	0.002
LT2Gasoline	LDV	Gasoline	Euro 2	1.518	0.174	0.002	0.076	0.014	0.012	0.001	0.002
LT3Gasoline	LDV	Gasoline	Euro 3	1.246	0.080	0.001	0.023	0.003	0.003	0.000	0.000
LT4Gasoline	LDV	Gasoline	Euro 4	0.605	0.050	0.001	0.013	0.003	0.002	0.000	0.000
LT5Gasoline	LDV	Gasoline	Euro 5	0.605	0.037	0.001	0.013	0.003	0.002	0.000	0.000
LT6Gasoline	LDV	Gasoline	Euro 6	0.605	0.037	0.001	0.013	0.003	0.002	0.000	0.000
LCV0Diesel	LDV	Diesel	Uncontrol	0.846	0.898	0.240	0.160	0.018	0.000	0.132	0.093
LCV1Diesel	LDV	Diesel	Euro 1	0.449	0.850	0.078	0.077	0.009	0.003	0.054	0.022
LCV2Diesel	LDV	Diesel	Euro 2	0.386	0.876	0.064	0.065	0.004	0.005	0.051	0.012
LCV3Diesel	LDV	Diesel	Euro 3	0.194	0.845	0.043	0.038	0.001	0.005	0.036	0.005
LCV4Diesel	LDV	Diesel	Euro 4	0.169	0.655	0.031	0.019	0.000	0.006	0.027	0.004
LCV5Diesel	LDV	Diesel	Euro 5	0.169	0.681	0.002	0.019	0.000	0.006	0.000	0.001
LCV6Diesel	LDV	Diesel	Euro 6	0.169	0.256	0.002	0.019	0.000	0.006	0.000	0.001
LCV0Gasoline	LDV	Gasoline	Uncontrol	26.519	2.417	0.002	2.406	0.100	0.008	0.000	0.002
LCV1Gasoline	LDV	Gasoline	Euro 1	3.050	0.364	0.002	0.208	0.020	0.020	0.001	0.002
LCV2Gasoline	LDV	Gasoline	Euro 2	1.518	0.174	0.002	0.076	0.014	0.012	0.001	0.002
LCV3Gasoline	LDV	Gasoline	Euro 3	1.246	0.080	0.001	0.023	0.003	0.003	0.000	0.000
LCV4Gasoline	LDV	Gasoline	Euro 4	0.605	0.050	0.001	0.013	0.003	0.002	0.000	0.000
LCV5Gasoline	LDV	Gasoline	Euro 5	0.605	0.037	0.001	0.013	0.003	0.002	0.000	0.000
LCV6Gasoline	LDV	Gasoline	Euro 6	0.605	0.037	0.001	0.013	0.003	0.002	0.000	0.000

*The table indicates the emission factors for two out of the six vehicle types.

Table 31. Emission control level adjustment with available fuel.

ID	Category	Fuel type	Manufactured Euro level	Fuel sulfur requirement (ppm)	2000	500	350	150	50	10	Comments
LDV0Gasoline	LDV	Gasoline	0		0	0	0	0	0	0	
LDV1Gasoline	LDV	Gasoline	1		1	1	1	1	1	1	
LDV2Gasoline	LDV	Gasoline	2	2000	2	2	2	2	2	2	
LDV3Gasoline	LDV	Gasoline	3	150	2	2	2	3	3	3	TWC catalyst effectiveness and durability reduced by higher sulfur levels.
LDV4Gasoline	LDV	Gasoline	4	50	2	2	2	3	4	4	TWC catalyst effectiveness and durability reduced by higher sulfur levels.
LDV5Gasoline	LDV	Gasoline	5	10	2	2	2	3	4	5	TWC catalyst effectiveness and durability reduced by higher sulfur levels.
LDV6Gasoline	LDV	Gasoline	6	10	2	2	2	3	4	6	TWC catalyst effectiveness and durability reduced by higher sulfur levels.
LDV0Diesel	LDV	Diesel	0		0	0	0	0	0	0	No aftertreatment. Sulfur effects only.
LDV1Diesel	LDV	Diesel	1		1	1	1	1	1	1	No aftertreatment. Sulfur effects only.
LDV2Diesel	LDV	Diesel	2	500	2	2	2	2	2	2	No aftertreatment. Sulfur effects only.
LDV3Diesel	LDV	Diesel	3	350	3	3	3	3	3	3	No aftertreatment. Sulfur effects only.
LDV4Diesel	LDV	Diesel	4	50	1	2	3	3	4	4	DOC will be impacted by high levels of sulfur.
LDV5Diesel	LDV	Diesel	5	10	1	2	2	2	4	5	DPF will be removed with higher levels of sulfur .
LDV6Diesel	LDV	Diesel	6	10	1	2	2	2	4	6	DPF will be removed with higher levels of sulfur .
HDV0Gasoline	HDV	Gasoline	0		0	0	0	0	0	0	Same assumptions as LDVs.
HDV1Gasoline	HDV	Gasoline	1		1	1	1	1	1	1	
HDV2Gasoline	HDV	Gasoline	2	2000	2	2	2	2	2	2	
HDV3Gasoline	HDV	Gasoline	3	150	2	2	2	3	3	3	Same assumptions as LDVs.
HDV4Gasoline	HDV	Gasoline	4	50	2	2	2	3	4	4	Same assumptions as LDVs.
HDV5Gasoline	HDV	Gasoline	5	10	2	2	2	3	4	5	Same assumptions as LDVs.
HDV6Gasoline	HDV	Gasoline	6	10	2	2	2	3	4	6	Same assumptions as LDVs.
HDV0Diesel	HDV	Diesel	0		0	0	0	0	0	0	No aftertreatment. Sulfur effects only.
HDV1Diesel	HDV	Diesel	1		1	1	1	1	1	1	No aftertreatment. Sulfur effects only.
HDV2Diesel	HDV	Diesel	2	500	2	2	2	2	2	2	No aftertreatment. Sulfur effects only.
HDV3Diesel	HDV	Diesel	3	350	3	3	3	3	3	3	No aftertreatment. Sulfur effects only.
HDV4Diesel	HDV	Diesel	4	50	1	2	4	4	4	4	DOC & SCR (vanadium) are not highly impacted by sulfur levels under 500
HDV5Diesel	HDV	Diesel	5	10	1	2	4	4	4	5	DOC & SCR (vanadium) are not highly impacted by sulfur levels under 500
HDV6Diesel	HDV	Diesel	6	10	1	2	2	2	4	6	DPF & SCR (zeolite) will not function above 50 ppm and will be removed.

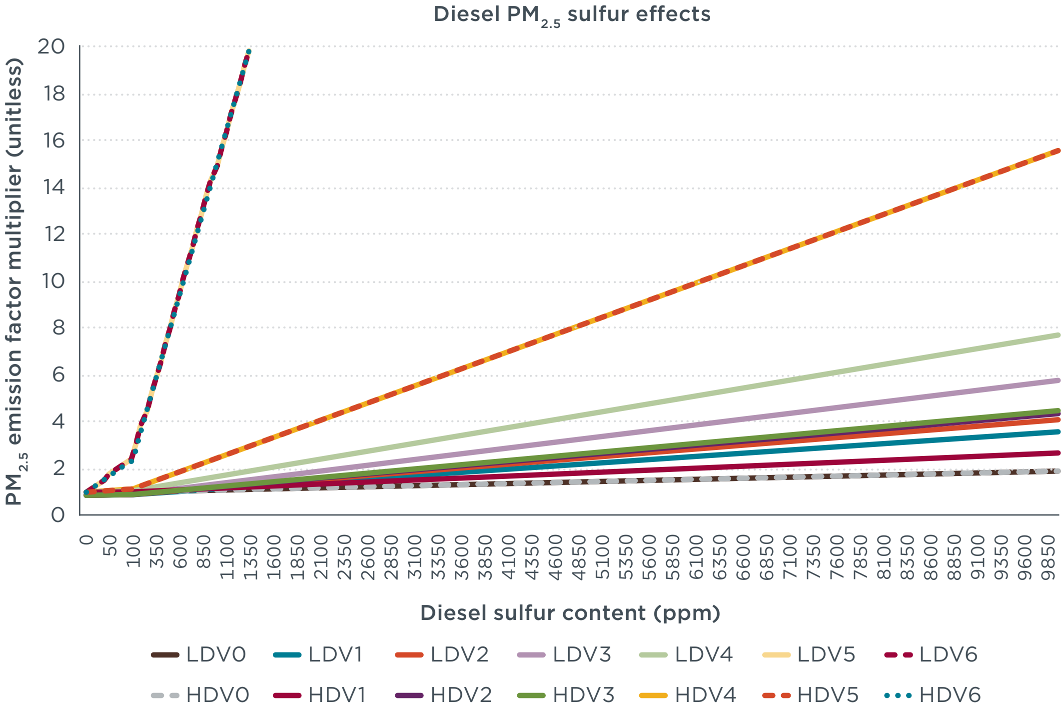

Figure 28. Multiplier effects of diesel sulfur content on $PM_{2.5}$ emissions factors for LDVs and HDVs.

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