Chapter 2
The Role of Hydrocarbons in Africa's Energy Mix

Abstract Africa is rich in hydrocarbon resources, with some countries ranking among the biggest exporters in the world. Compared of North Africa and also South Africa, where this endowment translated into the creation of domestic markets, in the rest of Sub-Saharan Africa investments have largely focused on the upstream industry for export. This chapter elaborates on the possible role of hydrocarbon resources in the future of SSA countries, taking into account the new reality that renewable energy is becoming more and more competitive as well as the fact that—despite increasing climate and environmental concerns that see international financing institutions increasingly reticent to support investments in fossil fuels—the sector remains strategic for many countries.

The African continent is richly endowed with hydrocarbon[1] resources, although they are distributed unevenly. With the exclusion of the North African region, oil and gas resources are generally exploited below potential and, where the sector has developed, investments have prioritized extraction for export over the development of domestic markets. In fact, Africa is a net exporter of hydrocarbons and it accounts for 8% of global gas exports and 10% of global oil exports (British Petroleum 2017a). Africa is a sort of frontier continent for oil and gas companies because it is the least explored in terms of resources and at the same time the least developed in terms of infrastructure. Notwithstanding uncertainties, today's estimates indicate that the region has enough oil, gas, and coal to supply its current and future demand on its own (International Energy Agency 2014) but, in most cases, there are obstacles of various nature that prevent countries from fully benefit from their exploitation.

Hydrocarbons already play a big role in the energy mix of African countries—and so does the capacity of resource-rich countries to extract, process, transport, commercialize, trade, and ultimately value them as social assets. Among commercial energy sources, oil, gas and coal indeed constitute the largest part of the African primary energy demand: excluding bioenergy from the account (see Chap. 2) oil accounts

[1] "Hydrocarbons" is a broader term than "fossil fuels": the latter refers to the use of the first in the energy sector, however these terms are often used interchangeably, including in this book.

M. Hafner et al., *Energy in Africa*, SpringerBriefs in Energy,
https://doi.org/10.1007/978-3-319-92219-5_2

for 42%, followed by natural gas (28%) and coal (22%). Renewables only constitute 8%, most of which comes from hydropower (British Petroleum 2017a).

As the global energy landscape transforms, so does the role of fossil fuels. The most notable global change is that the primacy of coal as the cheapest fuel for power generation is being challenged by a new competitor: low-cost photovoltaic (International Energy Agency 2017a). Once PV becomes affordable and available, it becomes particularly appealing for African countries because—unlike coal—the sun is available everywhere. This is bringing a whole new perspective on rural electrification (Chap. 4). Still, we are far from seeing fossil fuels becoming subordinate to renewables. As the world energy system evolves, oil remains fundamental for transportation and the petrochemical industry, natural gas becomes strategic all across the energy system (including flexible power generation to back up variable renewables), and coal remains a competitive fuel for baseload power generation for those countries that have easy access to it, or which energy system is already dependent on it. Importantly for SSA, hydrocarbon-based fuels also have an important role to play as an alternative to solid biomass for cooking.

When it comes to the issue of greenhouse gas emissions from the energy sector—a major drawback for the use of fossil fuels at global level—most analysts agree that climate concerns should not put the brakes on the electrification process in Africa, and that universal access to modern energy is in itself a prerequisite for sustainable development. CO_2 emissions from fossil fuel combustion could be at least partially offset by a reduction in the use of solid biomass in households, which causes forest degradation and in turn the ability of forest stocks to act as carbon sinks.[2] The local impact of pollution from hydrocarbons is a more problematic issue. Air pollution from coal-fired production and traffic congestion in cities, potential land and water contamination from oil and gas extraction: these are some environmental and social challenges that African societies will inevitably struggle with when developing fossil fuels, and which will require strong environmental regulations and responsible governance.

This chapter includes a short note on nuclear energy (Box 2.1), covered here only because its primary source (uranium) is a non-renewable one, like hydrocarbons. However nuclear energy is quite different from fossil fuels, and in many ways. While the combustion of fossil fuels is responsible for high emissions of greenhouse gases, nuclear is typically considered a carbon-free source. Also, large scale electricity production is practically the only energy use of uranium (if we exclude military applications), whereas hydrocarbons are versatile resources that can be used directly by final users, hence they are truly ubiquitous throughout the energy system. Finally, the upfront investment cost of nuclear power is much higher than fossil-fuel based options—which is the main reason why it is not expected to play a big role in the African electrification process.

[2] It should be noted that there is a huge uncertainty surrounding the actual CO_2 budget of the traditional use of firewood (Bailis et al. 2015), which makes a direct comparison with emissions from fossil fuels a tricky exercise.

Box 2.1 Nuclear Energy

Africa supplies around 18% of the world's uranium demand. All of it comes from the subcontinent and more specifically from Namibia (10%), Niger (7%), and South Africa (1%) (where it is a by-product of gold and copper mining). Previous mining activities in Gabon and Malawi were ceased because decreasing global prices of uranium made its extraction uneconomical. This is also the main reason why production never started in most of the countries that found uranium reserves, even though some of them were particularly rich of it, and highly motivated to begin extraction. Further African countries with known potential are: Algeria, Botswana, Central African Republic, Democratic Republic of Congo, Guinea, Equatorial Guinea, Mali, Mauritania, Morocco, Nigeria, Tanzania, Zambia, and Zimbabwe (World Nuclear Association 2017).

A number of countries are considering to start producing nuclear power but, as of today, the only active nuclear power plant in the continent ("Koeberg") is located in South Africa, where it supplies around 5% of the total power demand. South Africa plans to expand nuclear capacity, and nuclear is one of the technologies that South Africa aims at utilizing in order to reduce its dependency on coal, although recent policies seem to favour small scale, decentralised production over large, capital intensive projects, which ends up slowing down nuclear projects.

Nuclear is one of the most controversial energy sources and typically divides the public opinion. On the one hand, greenhouse gas emissions from nuclear are in the range of solar and wind, even looking at the whole life cycle of a nuclear power plant (although there is considerable uncertainty surrounding nuclear waste disposal, which remains so far unaccounted for in estimates) (Sathaye et al. 2011). On the other, the environmental impact of radioactive waste disposal is one of the main concerns of those who oppose nuclear energy, along with safety concerns, and the risk of nuclear proliferation (about this, it is worth noting that South Africa is the only country in the world that voluntarily dismantled its nuclear weapons, becoming a champion of "peaceful nuclear energy").

In sum, nuclear power is a very expensive technology that requires strong, ad hoc safety and environmental legislation to be in place, and that needs to be coupled with high power transmission capacity. Given the current infrastructural, financial, and governance landscape, new nuclear development in Africa faces significant uncertainty, and for sure it is not imminent (Krikorian and Evrensel 2017).

2.1 Reserves and Producing Countries

Hydrocarbons are the result of the slow transformation of organic material underground and underwater, in conditions of low oxygen, high temperatures, and high pressures. The formation of coal is substantially different from that of oil and gas, hence while oil and gas are frequently found in combination, coal deposits are completely unrelated.

When talking about hydrocarbons, there is an important difference to be made between "resources" and "reserves". In order to become reserves, resources need to be carefully assessed in quantity and quality, which takes a significant effort in terms of geological exploration. Also, reserves need to be commercially exploitable, meaning that it has to be possible—and economically sound—to extract the resource using available technology and at market conditions. Reserves can be ranked to various degrees of confidence that they can be recovered (possible, probable, proved). Let us first look at oil and gas reserves and then at coal.

2.1.1 Oil and Gas

A recent geological survey sets the upper bound of Africa's potential at 1,273 billion bbl of oil (including condensate gas from gas extraction) and 82 tcm of natural gas (including associated gas from oil extraction) and estimates that it would be "technically and economically feasible" to recover around 381 billion bbl of oil and 73.8 tcm of gas (Modelevsky and Modelevsky 2016). However, "proved" reserves according to BP are much smaller: 128 billion bbl of oil and 14 tcm of gas. Then, according to the IEA, "remaining recoverable resources" would amount to over 200 billion bbl of oil and 32 tcm of natural gas in SSA only (International Energy Agency 2014). Such disparities indicate that there is a significant uncertainty surrounding the hydrocarbon endowment of Africa, and particularly in SSA where hydrocarbon basins have generally been explored to a lesser extent.

Figure 2.1 is a map of all Africa's sedimentary basins identified so far with acknowledged or presumed hydrocarbon potential (32 out of 60 are under exploration or awaiting exploration). It is immediately visible that most of the oil and gas is found in "continental margin basins" along the coastline. In fact, a large part of the oil available in SSA (70%), as well as much of the production, comes from deep or ultra-deep water offshore fields.

Basins names: 1, Andalusian-Pre-Rif; 2, Western Tell; 3, Southern Tell; 4, Eastern Tell; 5, Eastern Atlas; 6, Tunisia–Sicily; 7, Middle Atlas; 8, Central Atlas; 9, Algerian–Libyan; 10, Sahara–East Mediterranean; 11, Gulf of Suez depression of the Red Sea–Suez basin; 12, West Moroccan; 13, Aaiun; 14, Tindouf; 15, Reggane; 16, Murzuq; 17, Kufra; 18, Red Sea depression of the Red Sea–Suez basin; 19, Senegal; 20, Taoudeni; 21, Mali–Niger; 22, Chad; 23, Gao; 24, Leone–Liberian; 25, Volta; 26, Chari; 27, Upper Nile; 28, South Aden; 29, Gulf of Guinea; 30, East African; 31,

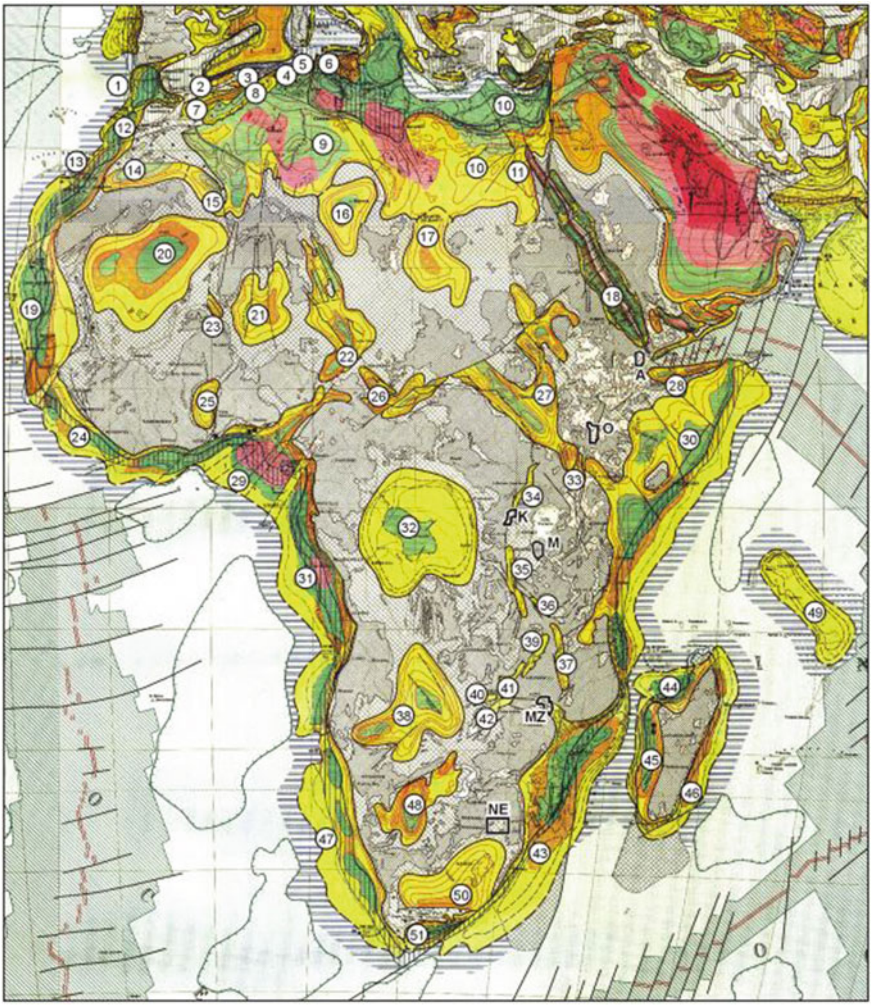

Fig. 2.1 Sedimentary basins with known or yet-to-find hydrocarbon potential. *Source* Modelevsky and Modelevsky (2016)

Kwanza–Cameroon; 32, Congo; 33, Turkana; 34, Albert; 35, Tanganyika; 36, Rukwa; 37, Nyasa; 38, Okavango; 39, Luangwa; 40, Kafue; 41, Luano; 42, Kariba; 43, Mozambique; 44, Majunga; 45, Morondava; 46, Eastern Madagascar; 47, Namibia; 48, Kalahari; 49, Seyshelles; 50, Karoo; 51, South Cape; A, Afar; K, Kivu; M, Malagarasi; O, Omo; MZ, Middle Zambezi; NE, basins of the northeastern part of South Africa.

Looking specifically at SSA, the following regions host major hydrocarbon basins at different levels of exploration and exploitation (International Energy Agency 2014)

I. the Niger Delta. This is the best known, most exploited, and richest hydrocarbon basin in the region. Reserves are located in the offshore territory of Nigeria, Cameroon, and Equatorial Guinea;
II. the East African Rift. Recent discoveries of oil have been made in Uganda and Kenya and exploration is ongoing in Democratic Republic of Congo, Rwanda, Burundi, Tanzania and Ethiopia;
III. the East African Coast. Major discoveries of gas have been made in the offshore territory of Mozambique and Tanzania, and geological surveys point at further resources in Seychelles and Madagascar;
IV. the West African Transform Margin. Initial discoveries of oil resources are awaiting the assessment of commercial viability in Ghana, Liberia, Mauritania, Sierra Leone, and Ivory Coast;
V. the West Coast Pre-Salt. Exploration is ongoing in the deep layers of basins offshore of Angola, Namibia, and all the way up to Congo, Gabon, Equatorial Guinea, and Cameroon. Recent major discoveries have been made in Congo and Gabon (James and Wright 2016).

A fundamental question when it comes to non-renewable sources is for how long extraction can be sustained before complete depletion. At current rates of extraction, recoverable reserves of African oil should last for around 100 years, and those of gas for over 900 years (assuming no gas flaring) (International Energy Agency 2014). This type of estimate (ratio of reserves on production, R/P) compares two numbers that can actually vary quite significantly in time. In SSA, rates of extraction can be expected to increase significantly following growing demand, but proven reserves may do so as well. Future discoveries could be expected in currently under-explored basins (including in Central Africa), as well as in the deeper layers of better known basins (Modelevsky and Modelevsky 2016). Also, the recent shale revolution that makes it possible to recover unconventional oil and gas that is "trapped" in fine-grained rock (i.e. shale) formations, is making many countries reassess their actual potential. This is the case, for instance, of the Democratic Republic of Congo with its shale oil resource of 100 billion barrels (World Energy Council 2016), South Africa, where estimates indicate 11 tcm of shale gas in the Karoo Basin (International Energy Agency 2014), and Algeria, which has one of the largest shale gas reserves in the world (20 tcm) (Tagliapietra 2017).

The biggest oil producers in SSA today are Nigeria and Angola, together accounting for almost half of the entire African production (Table 2.1). In North African countries, Algeria and Libya have similar production levels, although since the civil war of 2011 Libya has been producing far below its potential. Oil is also extracted in many other SSA countries. Some, like South Sudan and Chad, have quite high R/P ratio, indicating that there is a certain potential to increase production—at least in principle, because of course the profitability of investments depends on many factors, among which access to global markets, global oil prices (notoriously unpredictable) as well as country-specific political, financial, and security risks. All in all, oil investments in SSA tend to be less attractive than in other resource-rich regions,

Table 2.1 Oil reserves and production (2016)

Country	Proved oil reserves (billion bbl)	Reserves-to-production (R/P) ratio	Oil production (thousand bbl/day)
Algeria	12.2	21.1	1,579
Egypt	3.5	13.7	691
Libya	48.4	310.1	426
Tunisia	0.4	18.4	63
Angola	11.6	17.5	1,807
Chad	1.5	56.1	73
Congo	1.6	18.4	238
Equatorial Guinea	1.1	10.7	280
Gabon	2.0	24.1	227
Nigeria	37.1	49.3	2,053
South Sudan	3.5	80.9	118
Sudan	1.5	39.6	104
Others	3.7	43.2	233
Total Africa	128.0	44.3	7,892

Source British Petroleum (2017b)
Note According to ENI, other countries with proved reserves of over 0.1 billion barrels include: Cameroon, Ivory Coast, Democratic Republic of Congo, Ghana, and Tunisia (ENI 2017a)

and the reason is to be found precisely the presence of these risks (International Energy Agency 2014).

Notwithstanding difficulties, new oil markets are taking shape (e.g. Uganda and Kenya) and others are strengthening (e.g. Ghana, which in 2016–2017 has been boosting production to the point of doubling its oil revenues (Oxford Business Group 2017)). Notably, the growth of SSA oil production today is driven by small producers, though most of them may already start experiencing a decline in production as early as 2020. A similar future is expected for the oil giant Angola. In contrast, Nigeria, Kenya, Uganda, and even South Africa (if counting synthetic fuel produced via coal-to-liquid transformation) are expected to boost production (International Energy Agency 2014).

When it comes to natural gas, the situation is not too dissimilar (Table 2.2). About 90% of Africa's natural gas production comes from Algeria, Egypt, Libya, and Nigeria, which dominates SSA's production. Once again, there are important prospective newcomers, notably Mozambique and Tanzania that are currently evaluating the opportunities available to make use of their newly discovered reserves—their potential being estimated at 2.8 and 1.3 tcm, respectively (US Energy Information Administration 2014; Department for International Trade Tanzania, Government of the UK 2015). Other countries are also considering to scale up gas production, for instance Senegal (Reuters 2017).

Table 2.2 Gas reserves and production (2016)

Country	Proved gas reserves (tcm)	Reserves-to-production (R/P) ratio	Gas production (bcm)
Algeria	4.5	49.3	91.3
Egypt	1.8	44.1	41.8
Libya	1.5	149.2	10.1
Nigeria	5.3	117.7	44.9
Others	1.1	54.9	20.2
Total Africa	14.3	68.4	208.3

Source British Petroleum (2017b)
Note According to ENI, other countries with proved reserves of over 0.1 tcm include Angola, Cameroon, Congo, and Mozambique. These and others with lower reserves (e.g. Ivory Coast) have production in place (ENI 2017b)

About one sixth of proven natural gas reserves in SSA are associated with oil (International Energy Agency 2014), and gas flaring—the practice of burning associated gas from oil extraction—is widespread. On top of being a major waste of energy, this practice emits large amounts of CO_2. Nigeria is responsible of around 60% of SSA's gas flaring, and Angola, Congo, and Gabon follow. Fortunately, all of these countries are taking important steps towards solving the problem, either by starting to market the excess gas or by re-injecting it to sustain production.

2.1.2 Coal

Compared to oil and natural gas, proved coal reserves are much more geographically confined in the southern part of the continent (Fig. 2.2; Table 2.3). Of the total estimated 36 billion tonnes proven coal reserves in the subcontinent, 90% are located in South Africa. Coal reserves in Mozambique, Zimbabwe, and Botswana are also conspicuous (estimated 25 billion tonnes for the first two; 21 billion tonnes for the third), less so those of Malawi, Swaziland, Tanzania, and Zambia. Overall, a large part of SSA coal reserves are of high quality (anthracite and bituminous) (British Petroleum 2017b).

Considering the relative paucity of coal reserves in the continent (most of the global coal production takes place the northern hemisphere where the majority of coal reserves are located) the weight of South Africa really stands out: the country is the seventh largest producer in the world (British Petroleum 2017a). The coal industry in South Africa is also quite advanced, technologically speaking, and the country is a global leader in coal-to-liquids technology.

Apart from South Africa, which leads coal production in the region (95%), SSA coal reserves are largely undeveloped, the main reason being the remoteness of

Fig. 2.2 Coal deposits (red: anthracite and bituminous; green: lignite). *Source* (Britannica Online Encyclopaedia) 2010 © EB, Inc

Table 2.3 Coal reserves and production in Africa (2016)

Country 2016	Proved coal reserves (million tonnes)	Reserves-to-production (R/P) ratio	Coal production (million TOE)
South Africa	9,893	39	142.4
Zimbabwe	502	186	1.7
Others	2,822	276	6.3
Total Africa	13,217	–	150.4

Source British Petroleum (2017b)

potential mines and the lack of infrastructure (rails and ports) (International Energy Agency 2014). But there are also other reasons. In Nigeria for instance, despite a significant potential, there is relatively little production because the country historically prioritized developing oil (and more recently gas). In Tanzania, it was the poor quality of reserves that made the country reconsider investments in coal mining and coal based power production (Othieno and Awange 2016).

2.2 Demand

Oil demand is growing unequivocally across the subcontinent (it recently overtook coal as the most consumed source of energy in the region) and it is driven mainly by the transport sector. Oil is also important for power generation, including for back-up—a key feature of SSA industry. As anticipated, oil consumption in SSA remains very low if compared to the rest of the world and, of the entire regional demand, half of it comes from South Africa and Nigeria alone, which are also the only two countries with a noteworthy petrochemical industry (International Energy Agency 2014).

Natural gas is the least consumed of hydrocarbons in SSA today, but it is undoubtedly gaining importance. The most notable advantage of natural gas is that, when it comes to power production, it is a cheaper alternative to oil and a cleaner alternative to coal (and oil). However at the same time, the infrastructure required to handle it is the most complex because in order to be transported, natural gas needs to be either compressed (CNG) or liquefied (LNG) (Fig. 2.3). On top of being the largest producer, Nigeria is also by far the main consumer of natural gas in SSA, with 5.2 bcm consumed in 2015 followed from a distance by South Africa, with 2.3 bcm (Organization for Economic Co-operation and Development). The main sectors of gas consumption in Nigeria are power production (60%) and industrial uses such as cement and fertilizer production (Occhiali and Falchetta 2018), whereas in South Africa natural gas is used exclusively for the production of synthetic liquid fuels (Department of Energy, Republic of South Africa).

Figure 2.3 is a schematic representation of oil refining and gas processing, aimed at transforming raw materials into final petroleum products. These have very different properties that make them more or less suitable for different uses, however their actual demand is linked to availability as much as it is to the presence of subsidies. In fact particularly in developing countries, consumer subsidies for petroleum products are typically set up in order to facilitate access among the poorest—although quite often they end up benefiting the wealthier and creating market distortions (Whitley and van der Burg 2015).

North African countries rely on fossil fuels all across the spectrum of their economy (including agriculture and households) and they are heavily subsidised. Elsewhere in Africa too, prices of oil products are either subsidised (in producing countries) or at least regulated to protect consumers from global oil price fluctuations (International Energy Agency 2014). In general, in SSA the use of diesel is more widespread than gasoline both in the transport sector and for (back-up) power generation. For household consumption, on the other hand, kerosene and LPG are the most common substitutes to solid biomass. The first is a product of oil refining, while the second can be produced both from crude oil and natural gas processing. The use of these fuels is subsidized in most oil producing countries (especially kerosene) as well as in some importing countries with dedicated policies, like Senegal (LPG) (International Energy Agency 2014).

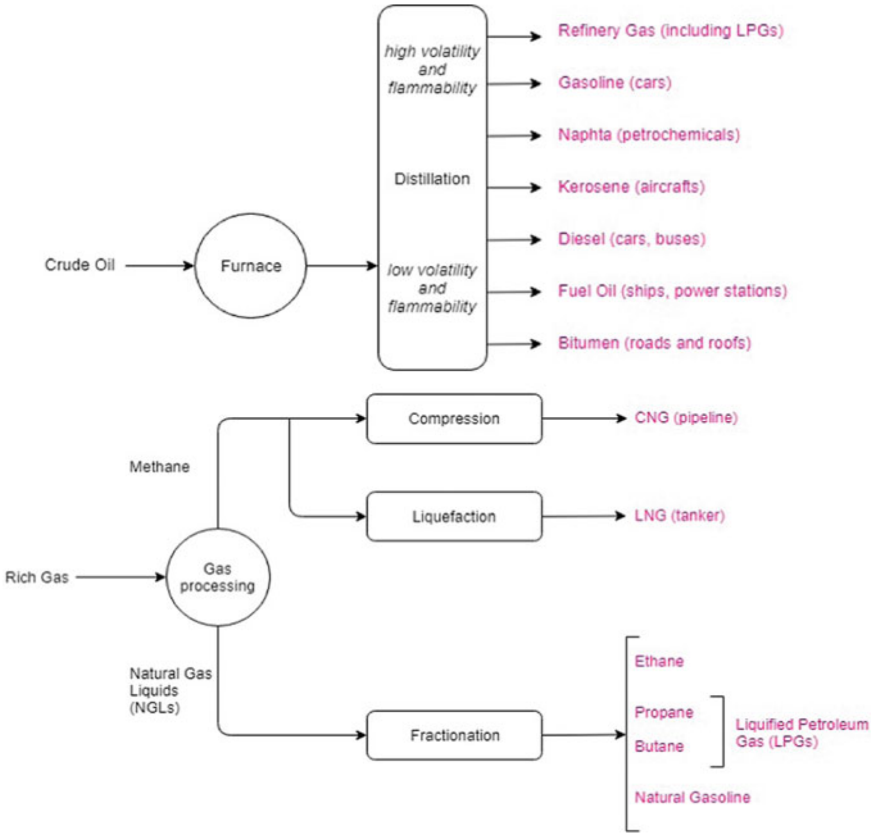

Fig. 2.3 Petroleum products from oil refining (above) and natural gas processing (below). *Sources* Author's elaboration. *Note* Petrol is synonym of gasoline; Paraffin is kerosene; Pipeline NG is CNG

The demand of coal is strictly linked to power production, with the exception of South Africa where coal is also processed for other uses. Because of its vast reserves, the country built up its entire energy system around coal, which supplies 70% of the total primary demand of the country mostly in the form of electricity, but also as synthetic diesel for the transport sector (covering about 40% of demand) and coal gas (i.e. the product of gasification of coal) used in industry and the residential sector (Department of Energy, Republic of South Africa). In SSA, coal-to-power takes place in small electricity-producing countries that sometime rely heavily on it, like Botswana (96% of total power production), Mauritius (42%), Niger (71%) and Zimbabwe (44%). While many more plan to increase coal-fired power production or introduce it (e.g. Malawi) and the sector can attract international investors (see Chap. 5), a relatively low number of power plants are actually under construction in SSA (End Coal).

2.3 Energy Trade (Out of Africa)

While demand of hydrocarbons is growing, Africa is still the energy macro-region with the lowest average oil and gas consumption in the world, and in terms of coal consumption is only second to the coal-poor regions of Middle East and South America (British Petroleum 2017b). This is because, with a few exceptions, domestic markets are poorly developed, and the bulk of hydrocarbon resources extracted in SSA is devoted to exports. Oil and gas investments in SSA feed the upstream oil and gas sector (extraction) much more than the midstream (refining and transport) and downstream (distribution) industry.

Most oil producing countries, including Angola and Nigeria, export over 85% of their production to Europe, Asia, and the US. The same is true for gas from Nigeria, Equatorial Guinea, and Mozambique, and prospects for exports are particularly bright now that with offshore gas liquefaction facilities (FLNG) it is possible to step in global LNG markets without developing potentially unsecure onshore infrastructure (Reuters 2017). Even coal trade leans towards inter-continental export, not only from South Africa but also from smaller producers, like Mozambique and Nigeria (International Energy Agency 2014).

A remarkable fact is that, when it comes to oil and gas products like LPG, gasoline, diesel, and so on, SSA relies almost entirely on imports from Europe and the Middle East (Fig. 2.4). Both the weight of crude oil export, as well as the importance of imports vis-à-vis final demand, are immediately clear glancing at Fig. 2.5, which is a representation of the oil production sector in Nigeria in 2013.

Exporting fossil fuels (like other mining products) is a major source of income for African countries, however governments typically fail to effectively reinvest fiscal revenues in the development of internal energy markets.

2.4 Insufficient Infrastructure

As anticipated in Chap. 2, the lack of infrastructure necessary to process, transport and distribute energy to the final users is a characteristic of the SSA region in contrast with South Africa, with its fairly decent power grid, and the North African region with its far-reaching power and gas infrastructure.

The fact that oil production is oriented to exports (5 million barrels per day), while the region is dependent on oil products import (1 million barrel per day), highlights the inadequacy of refineries, which are few and poorly maintained. This way, SSA countries miss out on the opportunity to export high-margin refined products (e.g. gasoline) and tend to import lower quality ones like heavy diesel (that western countries find difficult to sell at home due to environmental regulation).

The only country in the subcontinent with a major capacity of refineries is South Africa, which serves about two thirds of its own domestic demand of oil products. Some small producing countries (like Cameroon, Chad, Ivory Coast, Niger) are self-

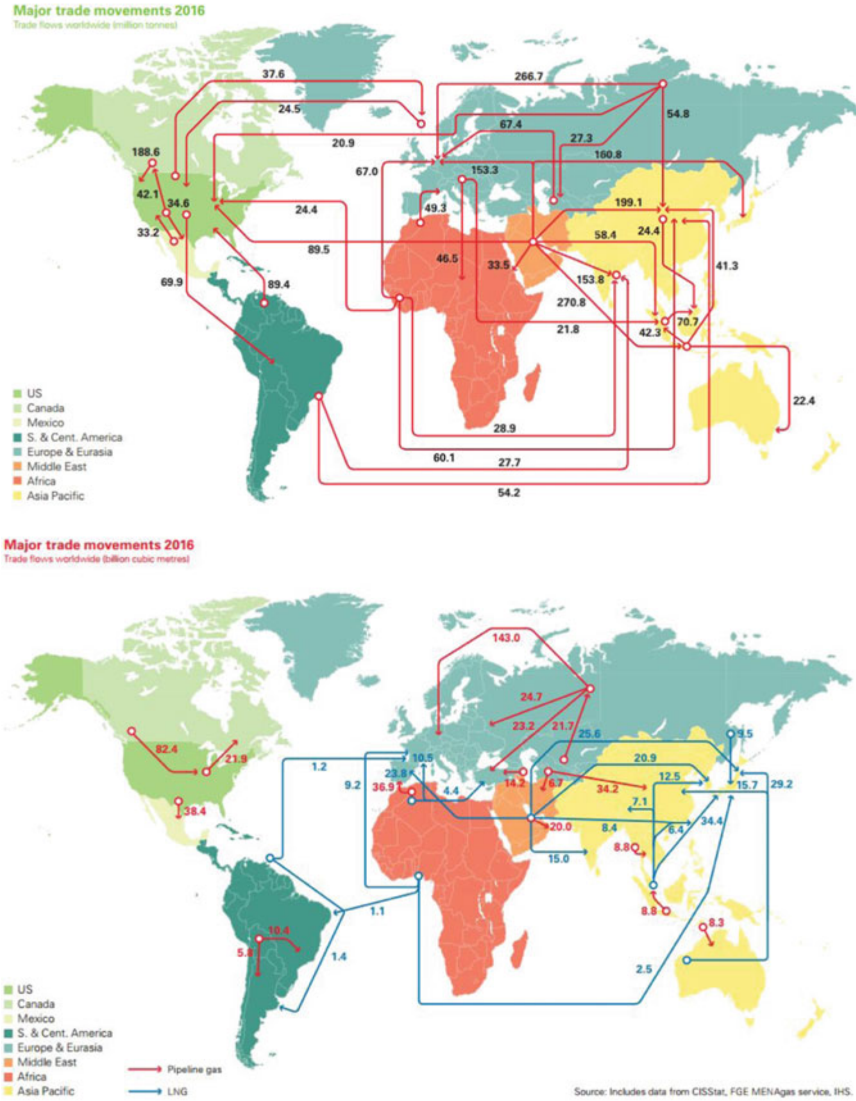

Fig. 2.4 Global trade of oil (above) and gas (below) (2016). *Source* British Petroleum (2017b). *Note* Inter-regional flows reported in the map do not correspond to actual import/export routes

sufficient with their own refineries, but this is in stark contrast with the rest of SSA. On top of having low refining capacities, the utilization rates of refineries are low and declining: the average in Africa today is 60% in 2016, the lowest of all continents (British Petroleum 2017b). In fact, there are both financial and logistical constraints

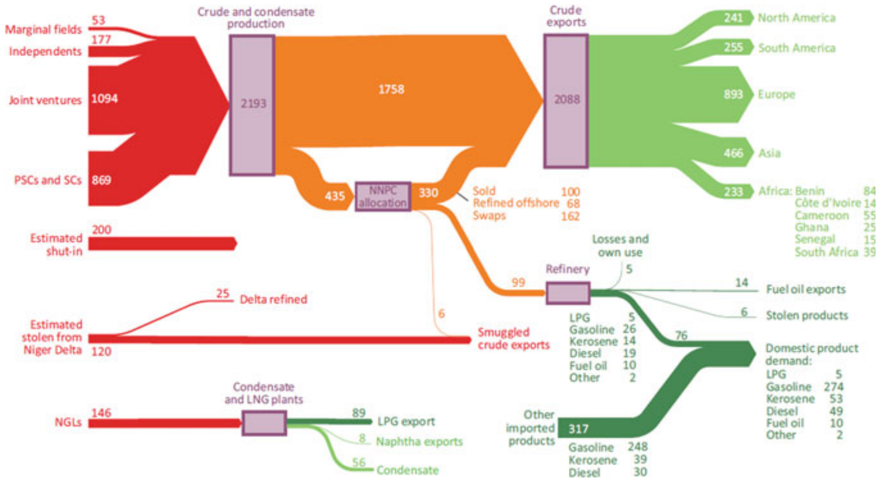

Fig. 2.5 Nigerian oil production sector. *Source* International Energy Agency (2014)

related to building new capacity and securing a continuous supply of crude oil to existing processing plants.

The transport and distribution of fossil fuels is challenging because the penetration of pipelines is inadequate—and so is, generally, the storage capacity within countries (Fig. 2.6). In fact many countries—particularly land-locked ones—are highly vulnerable to import cuts (International Energy Agency 2014). One of the practical problems of transporting oil and gas is the occurrence of theft episodes along pipeline tracks, which can significantly interrupt and reduce supply flows (see the weight of oil theft in Nigeria in Fig. 2.4). Moreover, it is not uncommon that pipelines need to cross dangerous areas where insurgent groups can tactically damage them or take control of supply.

Plans, more or less advanced, exist to build pipelines or other connections (via rail and road as in the case of South Sudan-Djibouti-Ethiopia) in:

- Kenya (Omondi 2018): oil;
- Uganda-Tanzania (Business Daily 2016): oil;
- South Sudan-Djibouti-Ethiopia (The Reporter Ethiopia 2017) (Ford 2017): oil;
- Mozambique-South Africa (Macauhub 2011) (Business Report 2017): oil and gas;
- Mozambique-Botswana (Zimbabwe Independent 2018) (extension of Mozambique-Zimbabwe) oil;
- From Nigeria to Algeria (trans-Saharan (Business Day 2017): gas;
- From Nigeria-Morocco, offshore (The North African Post 2017): gas.

When it comes to natural gas, the high cost of mid- and downstream (i.e. transport and distribution) infrastructure has been one of the main hindrances to the development of domestic gas industries in SSA countries. The gas pipeline in Nigeria that takes natural gas from the Niger delta to the interiors of the country is so far the only

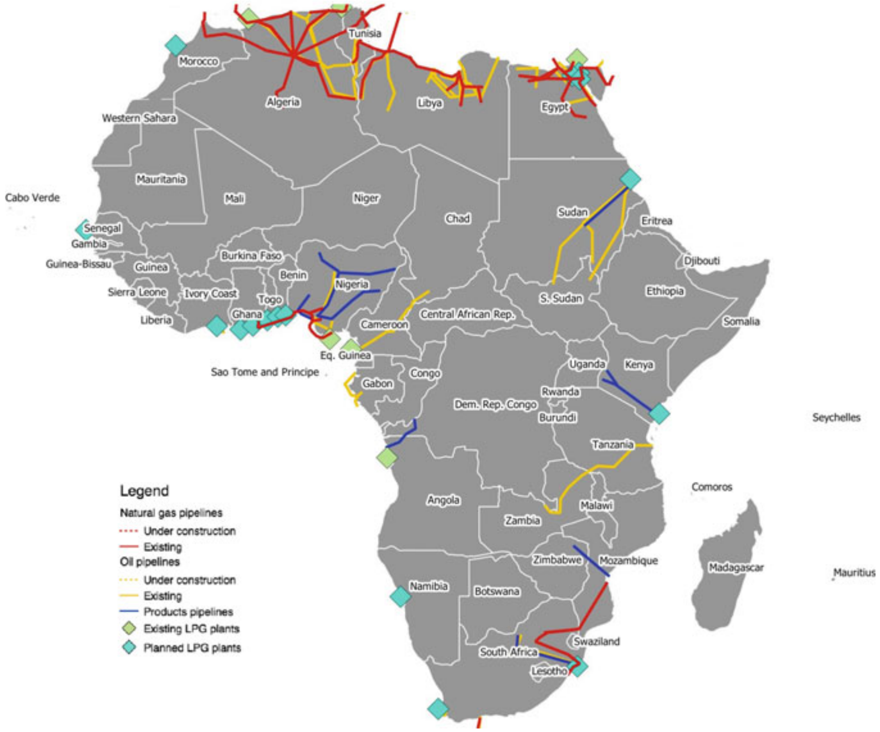

Fig. 2.6 Oil and gas infrastructure. *Source* authors' elaboration. Information from (Theodora) (International Energy Agency 2014; Corbeau 2016)

example in SSA of a gas network built for internal distribution, and its management is far from smooth. This pipeline has been constantly affected by intermittency of supply due to the occurrence of theft and vandalism episodes, which delayed significantly its construction and casted doubts on the profitability of its potential extension. Exporting gas ends up being a safer choice for international companies: indeed, they regularly prioritise export over domestic supply despite having legal obligations to serve domestic demands first (Occhiali and Falchetta 2018).

2.5 A Long-Term Perspective on Fossil Fuel Development

Fossil fuels can help energizing SSA, but their development is not going to be straightforward. Particularly in the power sector, renewables are starting to compete with fossil fuels—even on costs, and even in Africa (Fig. 2.7). The dilemma of SSA governments is clear: should they take the risk of building infrastructural, carbon lock-ins around fossil fuels? The question is perhaps even broader than this: should they even

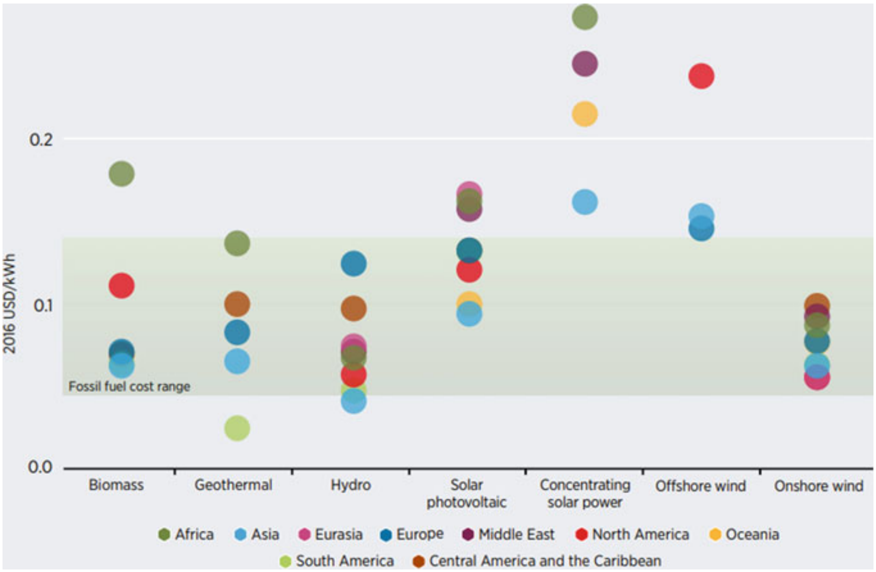

Fig. 2.7 Regional weighted average levelised cost of electricity by technology. *Source* International Renewable Energy Agency (2018) © IRENA 2018

aim at embarking on a path dependency on energy-intensive development (Fouquet 2016)? At the end of the day, it will be up to each single country to envision its own energy policy and, if available, how to value hydrocarbon reserves. It is therefore worth taking a fresh look at the benefits that fossil fuels can deliver in SSA as well as the issues that they will carry with them in the long run.

One first consideration goes to the opportunity of "leapfrogging" coal: the timing is good. Global projections paint a bleak picture for the sector, which is experiencing record rates of decline in production and consumption and receives less and less support from international financing institutions (British Petroleum 2017b; International Energy Agency 2017a) (Shankleman and Warren 2017). South Africa—the coal giant—is also under pressure to diversify its energy mix now that the most accessible mines are depleting and new mines will require significant investments (International Energy Agency 2014). Still, coal is far from dead in Africa. Even in Morocco, where renewable energy plays such a big role in the country's vision of a sustainable development, coal remains an integral part of the power system.

Climate and environmental concerns are resonating in the international community, so much so that international financial institutions now tend to support almost exclusively renewable energy projects because they do not come with the trade-off of climate emissions. And while coal is the most under pressure, it is not alone. Emblematically, the World Bank Group recently announced it will no longer support upstream oil and gas projects, starting from 2019 (World Bank 2017). This will not, of course, put a halt to investments, but the difference is that country institutions willing to attract private investors in oil, gas, and coal will have to negotiate directly with them.

While the interest of international investors in African oil and gas is high, doing business in Africa is not easy. Overall, the main challenges that oil and gas investors face in Africa are related to political instability and the lack of clear fiscal regimes and legal frameworks, generalized corruption, poor infrastructural base, and lack of skilled resources (PwC 2017). Fortunately, many countries are putting more pressure on oil and gas developers to ensure certain levels of production to supply internal markets first, to improve local content, or to respect environmental standards, but without a parallel commitment to making energy governance more efficient and transparent, this may only result in investors losing interest (Ernst & Young 2014).

In SSA the weight of renewable energy in the electrification process will be unprecedented, bringing not only solutions to remote areas off-grid, but also opening opportunities for large scale, clean and cheap power generation (Chap. 4). While in principle renewables and fossil fuels are not mutually exclusive, their competition may lead to sub-optimal consequences. Notably, without dedicated policies, cheap renewables may end up displacing natural gas instead of the more polluting, and much less versatile coal even where the first one is domestically available (de Strasser et al. 2017). Similarly, without a concrete vision to eradicate the use of solid biomass using all sensible means, the potential role of natural gas and LPG as cooking fuels risks being underplayed in favour of other, less effective solutions.

2.5.1 Natural Gas Potential

Natural gas has a strategic advantage over other fossil fuels in the sector of power generation. Like coal, natural gas can provide a steady supply to urban and industrial areas but crucially, gas fired plants are also a better fit to variable renewable energies, thanks to their higher operational flexibility and lower capital cost. With the deployment of the huge renewable energy potential in Africa, most of which is variable and not dispatchable (like solar and wind), there will be a need for dispatchable power plants which will operate in mid-load: it is here that gas has an advantage over coal (Gonzalez-Salazar et al. 2018). Gas fired power generation is often cheaper than coal based power generation, in fact the investment cost of a gas fired power plant are half (combined cycle) or a quarter (gas turbine) compared to a coal fired power plant. Operating costs are higher if gas prices are high, but they may be quite low if gas is domestic and cannot be exported easily.

Notably, natural gas is the cleanest among fossil fuels. While greenhouse gas emissions from the industry are not negligible, the potential to abate them is quite high and reasonably cheap to realize. However, the real environmental advantage of using gas is the cleanliness on the user side: less air pollution, reduced risk of land and water contamination.

Most of the environmental impact of natural gas occurs upstream, which is where responsible planning will be critical to avoid ecological damage. A serious issue to be considered carefully is the viability of shale gas fracking, particularly in water-scarce regions where the risk of groundwater contamination is perhaps not worth taking.

International pipelines for natural gas require high investments. And, more critically, they are considered fixed links, whereby a geopolitical conflict may result in pipelines to become idle (there many examples of this phenomenon in the Middle East). LNG chains, though also being very capital intensive, are much more flexible, as tankers can easily change destination en route, if needed. This flexibility should motivate global LNG producers—as well as current and perspective African ones—to sell in Africa and even pioneering the creation of new markets there. Potential African producers include Mozambique and Tanzania, who would add to the already established production in the west coast (Angola, Nigeria and Equatorial Guinea). Other than Egypt who is already a LNG buyer (temporarily: until its own production builds up again), today's potential LNG importers include Benin, Ivory Coast, Ghana, Kenya, Morocco, Namibia, Senegal, South Africa, and Sudan. Clearly, importing LNG is mainly an opportunity for coastal countries, but can also be seen as the beginning of further cross-country trade (Corbeau 2016).

In practice, the presence of large power plants or big industrial players like steel, cement, or even fertilizer production to which natural gas is a feedstock, is a necessary condition for residential uses to kick-off (even though not sufficient). In SSA, a promising model to develop internal gas markets seems to be starting from gas-to-power (i.e. using power producers as anchor customers) supported by floating regasification units (FSRU—Floating Storage Regasification Unit). These are faster to build and easier to operate than traditional regasification units, and when demand of LNG imports is no longer there (for instance because own gas production has taken off) the FSRU can just be moved to another country. There are already many examples worldwide of this new technology. Today in Africa only Egypt uses one, but projects at different stages of development exist in Ghana, Morocco, South Africa, Namibia and Kenya. Once "anchored" to power production, the availability of gas may stimulate the demand of industry, transport, and cooking.

For the latter a caveat is needed. In general, it does not make economic sense to build a gas distribution system exclusively for cooking. Notably, if there is no demand for residential heating—as it would be the case in Africa—the relatively modest volumes of natural gas demanded for cooking does not justify the investment in distribution infrastructure. Furthermore, the horizontal and often informal expansion of most urban agglomerates in Africa makes distribution costly, and risky. That said, natural gas distribution could target high-income, densely populated neighbourhoods in cities where gas is available, like Accra (Ghana), Lagos (Nigeria), or Abidjan (Ivory Coast) but it is clear that this type of investment would require considerable motivation and explicit support from the side of policy makers.

2.5.2 *The Case of LPG for Cooking*

Today, LPG (i.e. propane, butane, or a mix of the two) is already the most utilised alternative to solid biomass for cooking in SSA; still, only 7% of SSA's population have access to it and LPG use is mostly concentrated in a few countries: Angola, Ghana, Nigeria, and Sudan (International Energy Agency 2017b). LPG can be used for multiple purposes, including transport, but in SSA its real potential probably lies in its use as a modern cooking fuel—as well as, once available, as heat for small income generating activities like food processing, brick making, metal casting, and so on (McDade 2004).

Together with ethanol, methanol, biogas, and electricity, LPG is among the few cooking fuels that can meet the indoor pollution standards set by the World Health Organization, and several studies point at its suitability for cooking in the developing world. In particular, when compared to kerosene which is the second most utilised fossil-fuel based cooking fuel, LPG is much less hazardous to handle.

However the case for LPG can—and should—be made even without claiming that it is the best available option. As explained in Chap. 1, the lack of clean cooking in SSA is a social plague that can be truly addressed only with the parallel promotion of a mix of all available alternatives. LPG is a valuable option, but its wide uptake requires a significant policy effort. In fact, consumers (both urban and rural) base their choices not only on the availability of alternatives, but also on opportunity costs, and cooking preferences.

The truth is, subsidies play a major role in determining which fuel is preferred by users. The experience of Senegal is emblematic: after a successful strategy, LPG ended up reaching as much as 70% of urban users, but as soon as the government decided to lift subsidies there was a massive drop in consumption. Hence, if the ambition is to bring LPG cooking also to rural users, the most critical elements of success will be the existence of far reaching LPG value chains on the one hand and the effectiveness of targeted pro-poor cross-subsidization on the other. It is not excluded that smarter payment methods could also help accelerating access to LPG distribution (the same way this is happening with solar lanterns—see Chap. 4), either as a purely market-driven solution or in combination with subsidies. So far, however, the accumulated experience in implementing this solution is still limited (International Energy Agency 2017b).

Particularly for rural customers, accessibility remains highly problematic. The distribution of LPG from production sites or import stations to the single users requires the careful handling, storage, and transport, of pressurised gas (in comparison, the transport of liquid kerosene is less complicated). Clearly, this type of supply chain cannot be improvised for safety reasons, and a multitude of factors like the poor state of roads in rural SSA or the handling of pressurized cylinders by untrained people, can become significant elements of risk.

Despite these issues, there is ample evidence that—once available and affordable—LPG responds to the needs of customers, which is not trivial. For instance, the experience of South Africa shows that (subsidised) LPG cooking can take root even where electrical cooking is available and cheap (Kimemia and Annegarn 2016). At the same time in India—where the use of solid biomass is also widespread—LPG seems to be responsible of the first signs of reduction in solid biomass consumption after decades of promotion of improved biomass stoves, which ended up delivering poor results (International Energy Agency 2017b).

LPG is not a new solution, and its promotion in different parts of the world has already resulted in both success stories and failures. Some SSA countries like Ghana, Cameroon, and Senegal are already embarking in ambitious LPG programs, but experience is also accumulating on larger scales in countries like China, Brazil, India, and Indonesia as well as in North Africa, where LPG is commonly used.

In sum, promoting LPG requires a high level of economic, infrastructural, and logistic commitment, but it is also a fairly effective solution not to be missed for resolving the pressing problem of unsafe cooking. Notably, women are the best positioned promoters of clean cooking solutions because they are the first beneficiaries of improved indoor pollution and reduced time for cooking, which is why linking LPG programs to gender-focused and women-led development initiatives could prove crucial (Energy Sector Management Assistance Program, World Bank 2014).

2.5.3 Managing Air Pollution from the Energy Sector

As plans for coal become concrete, the main concern of SSA policy makers should not be so much on greenhouse gases—which they arguably have the right to emit, and which impact would nevertheless be lower than that of western countries—but on particulates. According to a recent estimate, air pollution from coal fired generation causes 2,200 deaths annually in South Africa and costs the government 2.37 billion dollars per year (Holland 2017).

Another important contributor to air pollution is transport. The sector is driving the demand of oil in SSA, however as of today environmental regulation on vehicles is basically inexistent in most countries. Only Nigeria and South Africa adopted Euro 2 emissions standards, and a limit on the age of imported vehicles has been imposed in a handful of countries only (International Energy Agency 2014). More could be done, also thinking in terms of urban planning. The direction is already set by several African NDCs[3] that mention plans to scale up mass transportation (e.g. buses, trains), the acquisition of hybrid vehicles for public transport, and the potential use of bio-fuels (Chap. 4) (UN Economic Commission for Africa 2016).

To be clear, the issue of air pollution goes beyond coal power production and oil-based transport. Although very difficult to quantify given the lack of emission inventories, estimates of deaths by air pollution indicate that the threat comes from a variety of sources. In contrast to western countries where air pollution comes largely

[3]National Determined Contributions to reduce greenhouse gas emissions and adapt to the impact of climate change, submitted to UN Framework Convention on Climate Change (UNFCCC) by the signatories of the Paris Agreement on Climate (2015).

(circa 50%) from vehicle emissions, in SSA solid biomass and waste burning are probably the biggest factors (the latter being particularly hard to quantify because of the unknown chemical composition of emissions from composite waste).

Since 1990, while the number of premature deaths related to unsafe water, lack of sanitation facilities, and malnutrition have been declining in SSA, those related to indoor and ambient air pollution have increased (Roy 2016). This highlights the importance of tackling the problem from multiple sides, including the capillary, uncontrolled use of solid biomass.

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