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Pathways for leapfrogging to reconcile development and climate change imperatives in Africa

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1. Introduction

The linkages between energy, poverty, development, and climate change are clear, yet the identification of pathways that provide an integrated approach to addressing these linkages remains open. Continuing business as usual is likely to lead to a world where energy access will be far from universal, quality of life will not be improved for the poor citizens in the global South (particularly in sub-Saharan Africa), and climate change mitigation will be negligible. Modern, clean, secure and affordable energy is a crucial input for mitigating poverty, securing prosperous livelihoods, building vibrant industries to diversify national economies, and connecting the continent through trade and cooperation. Energy is indeed a fundamental prerequisite for development and a

Abstract

A just energy transition toward low carbon emissions pathways is increasingly a priority not only to cope with the adverse impacts of climate change but also for achieving more sustainable economic and social development of the African continent. Fortunately, to optimize its energy mix for development according to sustainability criteria, Africa can take advantage of a rapid energy transition, thanks to its huge and largely untapped renewable energy potential and its abundance of a less polluting fossil fuel, namely, natural gas. Moreover, the fact that most of the infrastructure for energy systems in Africa is not yet built, particularly in sub-Saharan countries, offers these countries a good opportunity for leapfrogging. This Policy Brief explores guiding principles and pathways for a low carbon energy transition, including leapfrogging opportunities, energy system design and social innovation.

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Une transition énergétique juste vers des filières à faibles émissions de carbone est de plus en plus une priorité, non seulement pour faire face aux effets néfastes du changement climatique, mais aussi pour favoriser un développement économique et social plus durable du continent africain. Afin d'élargir sa palette énergétique dans l'optique d'un développement répondant à des critères de durabilité, l'Afrique peut, pour parvenir à une transition énergétique rapide, s'appuyer sur le potentiel énorme dont elle dispose en matière d'énergie renouvelable, potentiel qui reste largement inexploité, et sur ses réserves abondantes en gaz naturel, un combustible fossile parmi les moins polluants. Le fait que la plupart des infrastructures des systèmes énergétiques en Afrique ne sont pas encore construites, en particulier dans les pays subsahariens, offre par ailleurs à ces pays une bonne occasion de faire un véritable bond en avant. La présente note de synthèse examine les principes directeurs et la voie à suivre pour favoriser la transition vers des sources d'énergie à faible émission de carbone et aborde notamment la question des technologies permettant de sauter des étapes de développement, de la conception des systèmes énergétiques et de l'innovation sociale.

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Una transición energética justa hacia trayectorias de desarrollo con bajas emisiones de carbono cada vez es más prioritaria no solo para hacer frente a los efectos negativos del cambio climático, sino también para alcanzar un desarrollo social y económico más sostenible del continente africano. Afortunadamente, para optimizar su conjunto de fuentes energéticas en favor del desarrollo con arreglo a criterios de sostenibilidad, África puede beneficiarse de una rápida transición energética, gracias a su enorme potencial en gran parte sin explotar en el ámbito de las energías renovables, y a su abundancia de un combustible fósil menos contaminante, a saber, el gas natural. Además, el hecho de que la mayoría de la infraestructura para sistemas energéticos en África no esté construida aún, especialmente en países de África Subsahariana, ofrece a estos países una buena oportunidad para dar el salto tecnológico. En este informe de políticas se examinan los principios rectores y las trayectorias relativos a una nueva transición energética hacia un futuro de bajas emisiones de carbono, entre ellos las posibilidades de salto tecnológico, el diseño de sistemas energéticos y la innovación social.

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key requirement for the well-being of human society (AFREC, 2019; Goldemberg, 1998). Achieving this goal requires a rapid and just energy transition in the continent, to foster meaningful development and reduce inequality in a sustainable manner, compatible with climate imperatives. The energy transition is indeed more and more becoming a critical requirement for our societies in the context of multiple crises, climate change (IPCC, 2018; IPCC, 2014). Energy transition is a gradual and complex process that allows humanity to move from a material and social order based on a fossil fuels energy system to a material and social order based on a renewable energy system (Smil, 2010; Lavelle, 2015; Davidsson, 2015).

In order to achieve such an objective, Africa must undergo a fundamental shift in its energy system, from dominant centralized fossil fuel-based energy systems to, increasingly, integration of decentralized/ distributed clean renewable energy systems, where adequate, at scales to meet all energy needs. Indeed, distributed electricity generation is a fast-growing feature of modern electricity systems (IRENA, 2017; IRENA, 2018; IRENA, 2019; Sweeney, 2018). In Africa, we are witnessing a combination of both centralized grid-connected and decentralized off-grid renewable energy deployment. Centralized power plants are being operated on a large scale in countries such as Morocco, with its Ouarzazate Concentrated Solar Power Station, and also on an average scale in many other countries on the continent where utility-scale grid-connected systems larger than 10 MW are being developed. By contrast, decentralized off-grid renewable energy systems are being deployed in remote and low-density population areas where grid-based options and/or stand-alone diesel generators are not cost-effective. Such off-grid solutions offer opportunities for jumpstarting clean electricity access (IEA, 2019a).

2. Development, poverty eradication and energy transition

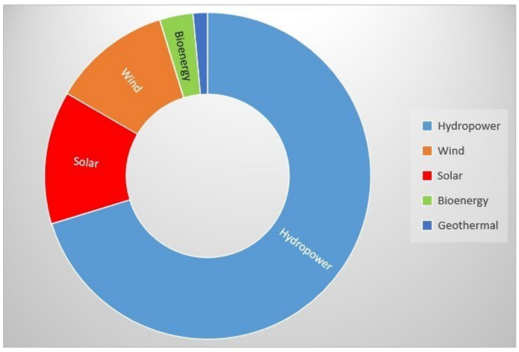
For many decades, economic growth was closely correlated with energy supply, particularly from fossil fuels, including coal, oil and gas. This poses four challenges to sustainability, as made clear in the Global Energy Assessment Report (GEA, 2012): soaring greenhouse gas emissions; decreasing energy security; air pollution at the local and regional levels, with implications for health; and lack of universal and affordable access to energy services. Historically, and even currently, energy systems are dominated by fossil fuels, and centralized electricity systems are the main sources of the carbon dioxide emissions causing human induced global warming. Furthermore, most sub-Saharan African countries are characterized by a heavy reliance on traditional and non-efficient biomass, particularly to meet household energy needs for cooking. The energy-poverty-development nexus has many consequences, including economic costs, health risks, environmental degradation, gender divisions, and irregulated and poorly managed urbanization (Sokona *et al.*, 2012; Casillas and Kammen, 2010). Analysis of the environmental impacts of extensive use of biomass also points to ecological damage such as reduced soil productivity and forest degradation (Behrens *et al.*, 2012; IPCC, 2019).

However, since the 1990s there has been a growing push for a paradigm shift, with a focus on energy access, poverty eradication and sustainable development, together with an emphasis on greenhouse gas mitigation in response to climate change. The continuing expansion of renewable energy is part of a major, accelerating trend in the global energy sector (Gürtler *et al.*, 2019). Identifying pathways for social and economic development that are sensitive to environmental concerns and climate change imperatives is increasingly a key priority worldwide (IPCC, 2014; IPCC, 2018). Such challenges require a worldwide decarbonized economy (IPCC, 2018). The decarbonization requires energy transitions that are well known to be very complex and is a far more complicated challenge. Indeed, Grin *et al.* (2010) and Smith *et al.* (2010) argue that transitions are processes characterized by i) co-evolution of technological change, consumption behavior and the institutional reforms that are required to embed the new technologies in society; ii) multi-actor processes that engage actors in unpredictable ways from all sectors (public, private and non-profit); iii) long-term processes, often 40-50 years, with distinct internal phases (from initiation to maturation); and iv) the reconfiguration of the institutional and organizational structures and systems of society.

While the transitions to a decarbonized economy will be a massive and enduring undertaking, Africa has many advantages. The continent possesses a huge untapped renewable energy potential, estimated at 350 GW for hydropower, 110 GW for wind, 15 GW for geothermal, 1000 GW for solar (African Development Bank *et al.*, 2017; Hafner *et al.*, 2018), and, according to IRENA (2014), a potential 520 GWh/yr of bioenergy. The renewable energy potential is unevenly spread among African countries. Although solar and, to a lesser, wind energy might be harnessed in most African countries, geothermal potential is mainly located in Eastern Africa.

This situation offers African countries a huge opportunity for rapid leapfrogging to new energy systems (Goldemberg, 1998; Lovins *et al.*, 2019), as most of the needed energy infrastructure in the continent is not yet built. Africa's leapfrogging over expensive landline telephone infrastructure to directly investing in mobile technologies provides a well-known and documented example (Noordeh, 2017). Noordeh's argument also applies to renewable energy, giving developing countries the choice to "leapfrog" over heavy investment in carbon-intensive forms of energy (i.e. coal and other fossil fuels) and instead make large-scale investments into renewable forms of energy. Such leapfrogging is being facilitated by innovations in power sector technology such as battery storage, grid automation, and smartphone-linked energy saving and control devices that are advancing at a pace that has surprised developers and adopters alike (Clark *et al.*, 2017). However, for effective energy leapfrogging some basics should already be in place, such as adequate invest-

Fig. 1: Renewable installed electricity capacity in Africa in 2018



In 2018, the total renewable installed electricity capacity is estimated at 46251 MW, with hydroelectricity accounting for more than 70 percent of the total. Wind and solar combined accounted for a quarter of renewable energy capacity. (Source: IRENA energy database)

Source: IRENA energy database

ments in energy infrastructure; governance, enabling policy, and energy regulatory frameworks; a skilled workforce to take advantage of new job opportunities. While renewable energy systems offer tremendous potential for leapfrogging, their deployment needs to follow a clear least-cost planning and investment agenda. There seems to be throughout the continent an *ad hoc* development of renewable energy projects, with increasing numbers of public-private partnerships that do not necessarily take into consideration grid integration criteria. In addition, as argued by Swilling and Annecke (2014), leapfrogging is not a given and will depend entirely on whether the capacity of innovation exists and whether, in turn, an appropriate set of institutional arrangements are in place to incentivize and harness innovations that demonstrate economically viable "leapfrog" technologies. While innovations are largely technological, they also embrace strong institutional and relational dimensions.

3. Renewable and conventional energy potential and prospects for large-scale deployment

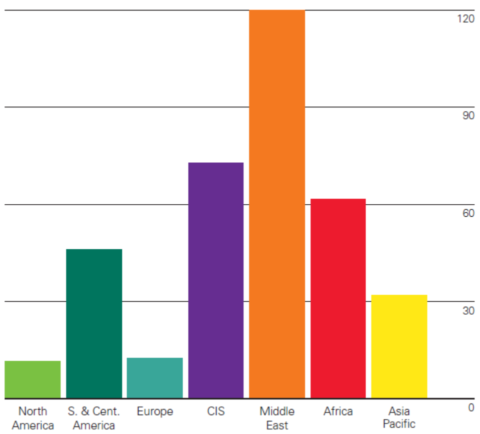
Renewable energy sources are abundant, widely available, and increasingly cost-effective (GEA, 2012; IPCC, 2011; REN21, 2018) (see Fig. 1). Fortunately, Africa is endowed not only with substantial potential renewable energy sources but also with fossil fuels, particularly natural gas, that, for a period, may facilitate the rapid energy transition to renewables while limiting greenhouse gas emissions.

The continent has the highest solar energy potential in the world, but has installed only 5 gigawatts of solar PV (Photovoltaics), less than 1 percent of the global installed capacity (IEA, 2019a). The same applies to Africa's hydroelectricity potential. For instance, potential hydroelectric power in the Democratic Republic of Congo is estimated at 100 GW, of which only 2 percent are tapped (Gnassou, 2019). Apart from conventional hydropower, only a tiny fraction of renewable energy is currently tapped in Africa. Fossils fuels will therefore be required during the transition period, all the more so given that renewable energy is intermittent and energy storage technologies are not yet sufficiently mature to allow large-scale cost-effective storage.

Natural gas is very likely the best fossil fuel option to meet Africa's domestic energy consumption needs and to limit the growth of greenhouse gas emissions, in particular carbon dioxide, as it is the least polluting fossil fuel. Proven natural gas reserves in Africa are much larger than African oil reserves but they are, to a large extent, untapped[1] (see Fig. 2) and much of the natural gas currently produced is exported to other continents.

Large-scale deployment of renewable energy and natural gas is paramount for modernizing energy systems to overcome the challenges Africa is currently facing, along with the associated infrastructure (transportation network, manufacturing capacity, etc.), the enabling environ-

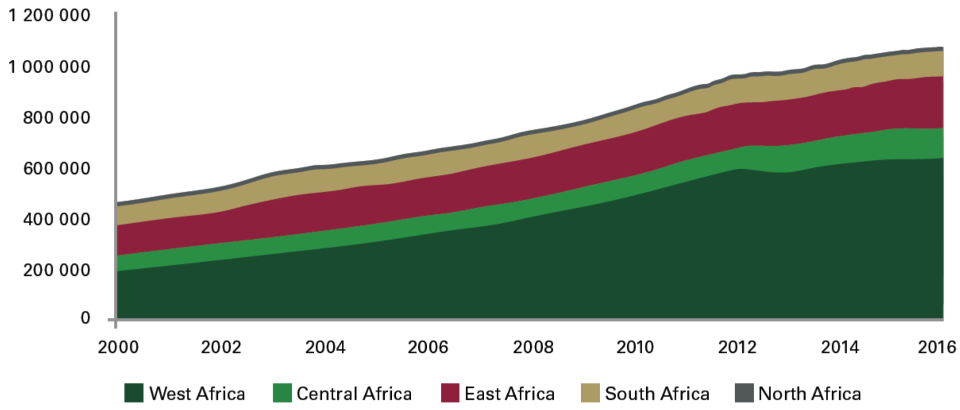
Fig. 2: Life expectancy of natural gas reserves in Africa and other regions in 2017 (years)



Africa accounted for only 3.3 percent of global primary natural gas consumption in 2018, of which 68% takes place in Algeria and Egypt. However, the continent holds 7.1 percent of the world's proven natural gas reserves, with a life expectancy, as measured by the ratio of reserves to production, totalling over 60 years (BP, 2019).

Source: BP, Statistical Review of World Energy, 2019

Fig. 3: Africa's firewood production by region 2000-2016 in ktons



Source: AFREC, 2018 key energy statistics

ment, including regulation, and the research and development that are needed in order to achieve this.

4. Continental disparities and reliance on traditional fuels for basic energy needs

The African continent is still characterized by sharp differences between the energy systems of North and sub-Saharan Africa. Indeed, most sub-Saharan countries still rely heavily on traditional and inefficient biomass fuels to meet their domestic energy needs for cooking and some productive activities. Moreover, Africa is the only continent which has been experiencing a growth in firewood and charcoal consumption (see Fig. 3).

Traditional biomass for energy (firewood and charcoal) is the main source of energy in rural areas in sub-Saharan Africa but biomass, particularly charcoal, is also used on a large scale in many urban areas in sub-Saharan Africa. Firewood and charcoal are widely used for cooking, with widespread use of inefficient stoves and other cooking devices resulting in serious health consequences due to indoor air pollution, which disproportionately affect women and children (Rehfuess, 2006). In sub-Saharan Africa, it is estimated that cooking with polluting fuels and stoves was linked to almost half a million premature deaths in 2018 (IEA, 2019a). Increased access to cleaner cooking solutions - such as improved firewood, charcoal or other modern bioenergies,[2] or liquefied petroleum gas stoves, fan-forced gasifier stoves, or new generation electric stoves - will allow for dramatic reductions in the negative impacts that result from widespread biomass fuel cooking in sub-Saharan Africa.

5. Inefficiencies and gaps in electricity production and distribution

Today, Africa relies heavily on fossil fuels (oil, natural gas, and coal) for its electricity generation and domestic energy consumption. Furthermore, for many African countries, development models are highly dependent on hydrocarbon revenues (IEA, 2019a; UNU-INRA, 2019). However, continued reliance on fossil fuels, particularly oil, creates significant vulnerabilities to external shocks, such as sharp price fluctuations, for these countries and for the continent. This is particularly true in light of rapid decarbonization, first, of the electricity sector and, then, of all sectors in the longer term. According to BP, African countries are currently endowed with 7.1 percent of the world's gas reserves and 7.2 percent of the world's oil reserves (BP, 2019). With the worldwide decarbonization of the economy that has been prompted by the escalating climate crisis and a rapidly shrinking carbon budget, there could be little or no room for fossil fuel extraction or emissions within just a few decades. This may drastically reduce revenues from hydrocarbon exports. More importantly, the growing risk of stranded assets[3] presents a very real threat for Africa, particularly oil-producing countries (UNU-INRA, 2019). This situation poses a critical dilemma for the continent, with almost a new fossil fuel discovery being made every year, in the context of a dire need to resolve Africa's dramatic energy poverty and huge inequality. In 2018, according to Oil Change International, nearly 60 percent of public finance for energy supply in Africa went to fossil fuels, while a much smaller proportion of 18 percent went to projects on renewable sources of energy. With the increasing push to respond to climate change, policy makers are facing the choice of whether to invest in new fossil fuel infrastructure to provide energy access and boost exports or to follow paths toward innovative low-emissions energy development.

There is also a significant deficit in electricity supply and reliability across the continent, and particularly in sub-Saharan Africa, scarce and unpredictable power supplies, combined with high electricity tariffs, resulting in high production and transaction costs as well as a lack of competitiveness for businesses (Brew-Hammond, 2010; Pachauri *et al.*, 2012), thus constraining industrialization, development of businesses and economic activities (Bazilian *et al.*, 2012). Even when electricity is available, the reliability of service is a major issue, particularly for the productive sectors (Tenenbaum *et al.*, 2014). The proportion of firms without access to reliable electricity in sub-Saharan Africa is higher than in any other region

(AFD and World Bank, 2019). This results in a substantial amount of inefficient and expensive on-site self-generation of electricity from fossil fuels in industrial, commercial, and even residential sectors. Many enterprises resort to backup facilities, mainly diesel generators, thus increasing both costs and greenhouse gas emissions. According to the World Bank, 53.2 percent of the businesses in sub-Saharan Africa own or share a diesel generator, in comparison to 38.2 percent in the Middle East and North Africa and only 17.2 percent in Europe and Central Asia (AFD and World Bank, 2019) (see Fig. 4).

Electrification has followed a centralized supply-oriented model, in which the utility, whether government-owned or private, generates and distributes electricity through the grid to customers who can afford to pay high connection costs (Shahsiah, 2017). This approach can also create brittle power systems that expose the economies and businesses to a number of risks along the power supply chain, ranging from inadequate distribution infrastructure creating fault and power outages to fuel supply shortages limiting generation. This model also requires a relatively large investment in power plants, transmission and distribution infrastructures, but leaves out many potential customers in both productive and domestic sectors. Indeed, in sub-Saharan Africa the distribution lines only reach end users that are clustered in specific regions or those who can afford the expensive electricity costs. Centralized systems remain both underdeveloped and insufficient in energy distribution, and often suffer from outdated infrastructure. To achieve the Sustainable Development Goals (SDGs), it is time to look past a top-down power grid approach, and find a bottom-up approach that focuses on demand and incorporates renewable energy.

6. Insufficient regional integration

Energy trade within Africa remains marginal, reflecting the low rate of Africa's economic integration (World Bank, 2019; African Development Bank, 2019). However, there are signs of positive change such as the trend toward power pools in all five African regions. Power pools have contributed to increasing access and improving electricity supply. This trend could be scaled up to interconnect all African countries where viable and cost effective. It could thus provide greater access, mainly through electricity networks, and ensure that Africa's energy resources and potential resources (renewables, and natural gas where applicable during the transition) primarily benefit the economy of the continent and its population.

7. Capacity constraints

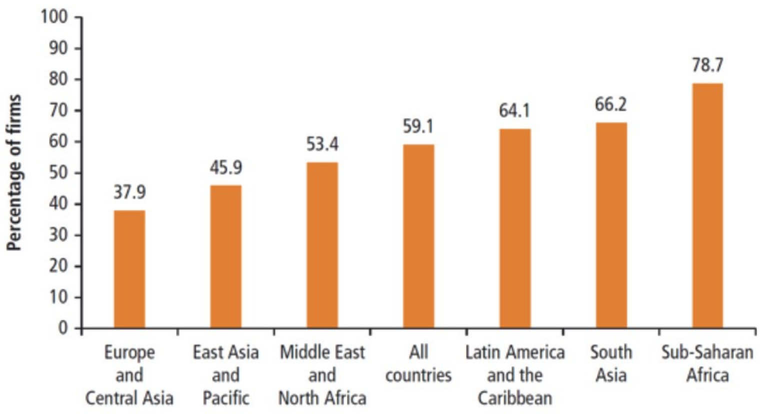
Institutional and administrative capacity remains limited and is a fundamental bottleneck to enabling the actions required in all other areas. A critical number of Africans have extensive knowledge and ample capacity to understand their socio-economic, cultural and ecological contexts, but they are dispersed and sometimes not embedded in suitable institutions, a situation which necessitates general reliance on individual consultants. Therefore, capacity must be understood in terms of capacity mobilization (including area-specific local and traditional knowledge) as much as capacity development. Parallel to capacity mobilization and institution-building, Africa needs to embark on long-term efforts to foster a new generation of practitioners and scholars who are well networked and motivated to serve their continent. These capacities are greatly needed in order to invest in jumpstarting Africa's just energy transition, which will take time and will require increasing numbers of highly skilled people. Any serious energy transition program therefore requires a long-term strategic plan for capacity building and mobilization. The following section outlines key elements of pathways for a just transition.

8. Guiding principles and pathways to Africa's energy transition

Guiding principles

Several landmark regional and international agreements already exist that address the many energy challenges that Africa faces (UNU-INRA, 2019). Agenda 2063, the Paris

Fig. 4: Proportion of firms without access to reliable electricity (%)



Source: AFD and World Bank, Electricity Access in Sub-Saharan Africa, Uptake, Reliability, and Complementary Factors for Economic Impact, 2019

Agreement, the SDGs, the Africa Renewable Energy Initiative, and the Least Developed Countries Renewable Energy and Energy Efficiency Initiative for Sustainable Development all point to a set of key principles to overcome the challenges identified. Africa's just energy transition should be guided by the following overarching principles:

- *African leadership and ownership in setting the energy for development agenda, with clear policies for the short, medium, and long term;*
- *Mobilizing the continent's own energy resources particularly renewable energy resources, complemented during the transition by natural gas;*
- *Leapfrogging to the best available, smart, modern, distributed renewable energy systems that enable a transition toward low to zero carbon energy futures in line with the Paris Agreement on climate change, the SDGs and national development objectives; and*
- *Moving from natural resource-based economies to more complex and diversified value chains and improved terms of trade with other continents.*

<u>Energy transition pathways and key strategic objectives</u>

There is an urgent need for a fundamental global shift in energy systems, from centralized fossil fuel-based systems to increasingly decentralized/distributed renewable energy systems at scales to suit every energy need (IPCC, 2011; IPCC, 2018). Limited energy infrastructure and populations spread over vast areas and still largely rural are no longer a major constraint on energy access. Africa has unmatched renewable energy availability, and the technologies required to utilize this energy can be scaled up to meet every need and installed wherever energy is needed. Furthermore, Africa can largely avoid the costly lock-in of centralized electricity generation systems in areas previously without electricity and upgrade existing systems to create energy security (McCulloch *et al.*, 2017). Fortunately, the sharp and continuous fall in price of solar and wind energy systems, combined with similar trends in battery storage, provides the incentive and momentum to accelerate actions on the ground. In addition, the flexibility and speed of solar installation technologies further ensure that there is a good match of scale, suitability and response to the urgent need for them.

Africa's enormous renewable energy potential offers a tremendous opportunity to orient the continent's energy systems towards decentralized, distributed renewable energy sources to power the continent's development aspirations. Using a combination of technological, social, and engineering innovations, there are varieties of new delivery models in the power sector that offer a transformation not only in access to power, but also in ownership and control at the local level. Renewable energy sources, in particular solar, are remarkably diverse and flexible, offering the generation of electricity on a large spectrum from solar lanterns, solar home systems, stand-alone mechanical equipment requiring power, and micro/mini-grids, to larger grids with 24/7 reliable on-demand power. Power generation can be as small as a few watts to as large as hundreds of megawatts. This flexibility, modularity, and scalability make it possible to install a wide range of renewable energy systems in a short period of time for a variety of end uses at various locations simultaneously. Renewable energy technologies can provide adapted energy services across society: from very isolated rural locations to peri-urban areas and big cities, matching design with the availability of financial resources and energy service requirements (Kirubi *et al.*, 2009). Such an approach provides the opportunity to leapfrog straight to better-designed, more efficient, sustainable power systems.

The opportunity to transform energy systems from supply-side and centralized to demand-side and decentralized is an opportunity to leave behind the legacy of carbon-intensive energy. In order to address Africa's current energy challenges and successfully leapfrog straight to renewable energy, the following key strategic objectives need to be met, taking into consideration the guiding principles above:

- Energy infrastructure for economic and social development

Energy infrastructure expansion is urgently needed to drive economic growth and social development across sectors (Davidson and Sokona, 2002; Eberhard *et al.*, 2016). An important example is agriculture, which is a major contributor to gross domestic product (GDP), employment and exports, and the basis for livelihoods and wellbeing among the many small-scale farmers on the continent. However, agricultural productivity in Africa remains very low, as much due to continued dependence on low efficiency inputs, such as human and animal energy, as to a lack of modern energy and infrastructure along the value chain (e.g. storage, processing, and transportation to markets) (World Bank, 2017).

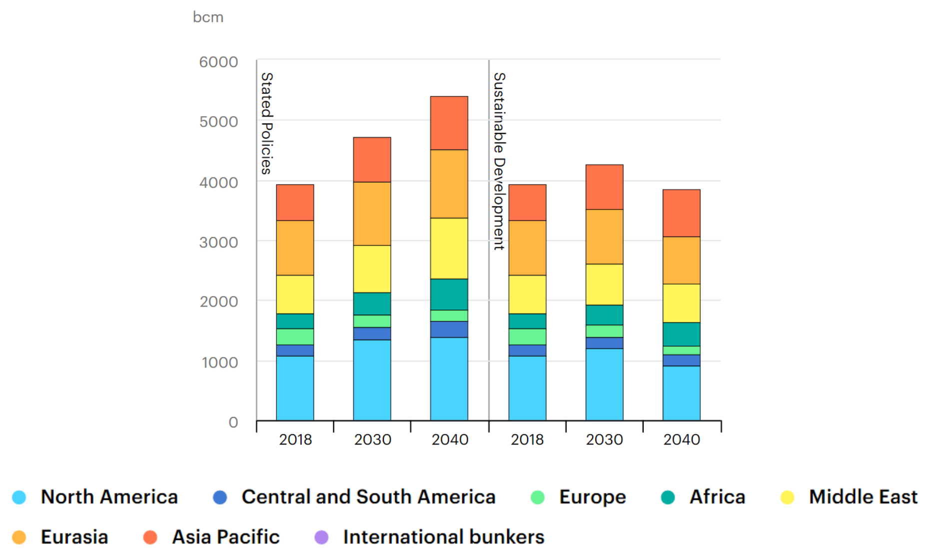
Expansion of access to energy must be achieved in line with Africa's development aspirations as encompassed by Agenda 2063 and the SDGs, as well as with global climate mitigation aims, in ways that maximize synergies while minimizing trade-offs. To achieve this goal there is a need to rapidly increase infrastructure for production and use of renewable energy sources such as solar, wind, modern bioenergy, hydropower, and geothermal, to ensure a sustainable energy mix compatible in the medium to long term with a fully decarbonized energy system.

Such a just transition is a massive undertaking, but Africa has many advantages, particularly given that the bulk of the energy infrastructure is not yet built, and the fact that, while renewable energy systems such as wind farms and utility-scale solar power plants can be land intensive, this is often less of a constraint in most African countries than in more densely populated regions of the world.

- Integrated regional and intercontinental energy systems

Lack of integration has been identified as one of the key

Fig. 5: Natural gas demand scenarios by region, 2018-2040 (bcm)



Source: IEA, World Energy Outlook, 2019

challenges in Africa's sustainable development. Energy, particularly regional and intercontinental natural gas and electricity networks, may be key drivers in Africa's increased integration. Currently, the deficits in Africa's electricity infrastructure are resulting in increased production and transaction costs, reduced business competitiveness, and negative impacts on the prospect of foreign direct investment flows to the continent. This is hindering the rate of economic and social development throughout Africa.

African energy development can follow a new model across several dimensions simultaneously. On one hand, **cross-border electricity trade** coupled with market development should dramatically reduce average electricity prices for all African countries and increase the share of renewables and energy security for the whole continent. On the other hand, **distributed electricity systems** that have already benefitted parts of the population will provide further benefits by expanding interconnections that allow enhanced balancing, load sharing and access to new markets.

Africa's energy transition is a long process which requires the optimization of a renewable-fossil fuel mix to mitigate greenhouse gas emissions and eventually achieve full decarbonization. **Natural gas**, as noted, is the least polluting and hence most appropriate fossil fuel option to contribute to meeting Africa's domestic energy needs during Africa's energy transition period. Compared with renewables, natural gas may currently be cost-effective, particularly for high temperature heat for industry and for heating buildings. An analysis of natural gas consumption in developed economies where infrastructure is well developed shows that natural gas represents a large share of industrial consumption (IEA, 2019b; APERC, 2002). However, with regard to the African continent, natural gas has not so far played a major role in energy development outside North Africa. Indeed, the share of natural gas in the energy mix in sub-Saharan Africa (less than 5 percent in 2018) is one of the lowest in the world (IEA, 2019a). According to the IEA Stated Policies Scenario, gas demand in sub-Saharan Africa will triple to over 100 billion cubic metres (bcm) by 2040 (IEA, 2019a; see Fig. 5).

Furthermore, long term sustainability scenarios for the period 2019-2050 show that a significant amount will be invested in the natural gas sector. Under this scenario, US $240 billion should be invested compared with just US $20 billion for coal during the same period (IEA, 2019c). Recent natural gas discoveries in the continent could fit well with Africa's push for industrial growth and its need for reliable electricity supply. For instance, the combined natural gas reserves of emerging producers in East Africa (Mozambique and Tanzania) are impressive, with up to 7 cubic tera-meter (IEA, 2019a).

Development of the continent's natural gas resources could help to strengthen the continent's economic integration, provide a modern source of energy for productive activities and electricity generation and increase access to modern fuels for Africa's population. For instance, the Trans-Saharan Gas Pipeline, a priority project for the Program for Infrastructure Development in Africa (PIDA), is set to link sub-Saharan Africa with North Africa and would offer opportunities to access supplies of natural gas for transit countries. Developing gas infrastructure will be a major challenge in many areas, however, given small market sizes. Apart from long-distance pipelines to supply large-scale power plants, companies are increasingly looking at reaching industrial and commercial customers via small-scale liquefied natural gas (LNG) delivery or through distribution networks around industrial hubs (IEA, 2019a).

Countries will also need to consider risks of stranded assets and implications of rapidly falling costs of renewables, though. Indeed, with the rapidly falling costs of renewable energy and storage solutions, renewables are rapidly and increasingly being deployed for electricity supply. It will be an important strategic consideration for African countries to determine to what extent it makes sense to unlock Africa's natural gas potential and enhance interconnections of African countries through gas pipeline networks during the transition period towards full decarbonization in line with the Paris Agreement.

- A new paradigm for household energy transition in sub-Saharan Africa

In sub-Saharan Africa, a key priority is a rapid transition away from firewood and charcoal to cleaner and renewable energy sources. It is estimated that 2.2 billion people will still be dependent on inefficient and polluting energy sources for cooking by 2030, mainly in Asia and Sub-Saharan Africa (IEA *et al*., 2019). It is also estimated that the burning of non-renewable biomass fuels alone generates 1 $GtCO_2$ per year (Bailis *et al*., 2015), i.e., approximately 3 percent of global fossil fuel emissions, estimated at 33.1 $GtCO_2$, in 2017 (IEA, 2018). A rapid transition on a large scale to cleaner options will not only limit greenhouse gas emissions given the low energy efficiency of the biomass value chain, but also contribute to reaching the target of universal access to modern fuels. Given that firewood - mainly in rural areas - and charcoal - in urban areas - are the predominant cooking fuels in most sub-Saharan countries, efforts in almost all African countries, and even worldwide, have been focused on the deployment of improved cookstoves and/or liquefied petroleum gas (LPG). As far as improved stoves are concerned, the dispersal of improved cookstoves has not kept up with population growth; increasing urbanization has led to denser emissions, and evidence suggests that health effects of improved stoves have not been as expected (Batchelor *et al*., 2019). With regard to LPG, some countries such as Senegal and Botswana have experienced a transition from charcoal to LPG in urban areas. However, this transition was spread over several decades and supported by subsidies which were eventually phased out.

New pathways for the transition in the energy sector may include electricity, thanks to the dramatic decrease in electricity prices from renewables and new technologies to cook with electricity. The feasibility of using solar photovoltaic panels to produce electricity for cooking in off-grid rural areas is being investigated technically to reduce the cost and power required for electric cooking (Batchelor *et al*., 2018). There are, however, other more technologically mature options for electric cooking, such as electric induction stoves, one of the most efficient cooking technologies available (Kastillo *et al*., 2017). For instance, the Ecuadorian Efficient Cooking Plan (ECP) for clean cooking aims to change three million LPG-based stoves to induction stoves. This technology may offer a leap forward in completely clean household alternatives for cooking (Goldemberg *et al*., 2018). Although electric cooking is an attractive option, it is not yet commercially viable. Phasing out traditional biomass for cooking in sub-Saharan Africa will require a combination of different fuels and technologies as well as communication strategies. In the short to medium term, LPG, and also natural gas in urban areas, are the most reliable, available and cost-effective options that can be deployed on a large-scale. Further technological progress in electric cooking and penetration of cheap renewables offer new options to meet cooking needs in sub-Saharan Africa.

- Climate change and decarbonization of the energy sector

While Africa only has a marginal historical responsibility for greenhouse gas emissions and is currently emitting less than 4 percent of global carbon dioxide emissions, climate change poses a huge threat to development in Africa, as the continent is particularly vulnerable to its adverse impacts and has limited capacity to withstand these impacts. It is a deep injustice that those least responsible for the problem are most vulnerable to its impacts (Winkler and Beaumont, 2010). The recent Special Report of the Intergovernmental Panel on Climate Change on Global Warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways clearly spelled out the need for decarbonization of the global economy starting with energy systems, and in particular the electricity sector (IPCC, 2018). Furthermore, almost all African countries have committed to reducing emissions through their Nationally Determined Contributions under the Paris Agreement.

According to IRENA, the deployment of renewable energy sources and energy efficiency, coupled with deep electrification of end uses, can provide over 90 percent of the reduction in energy-related carbon dioxide emissions needed to maintain a 2°C global warming limit (IRENA, 2018). Although most African countries have set ambitious targets for renewable energy, their share in electricity generation (apart from large hydro) is still below 5 percent. Energy intensity in Africa compared with high energy efficiency programs (e.g. for transport, buildings, industry, and energy) in other developing countries is still far below international standards. Depending on the region, tackling greenhouse gas emissions will imply different strategies compatible with social and economic development.

While coal is being used in only a few African countries, mainly in southern Africa, it is a major contributor to energy-related greenhouse gas emissions from the continent, with 32 percent of Africa's greenhouse gas emissions mainly coming from coal power plants. Indeed, coal is still a major energy source for electricity generation in several southern African countries, and particularly in South Africa, the highest emitter of carbon dioxide on the continent. Large-scale deployment of renewable energy (solar photovoltaic, wind and geothermal), along with natural gas, will dramatically limit coal's share for electricity generation. However, in order to reduce greenhouse gas emissions, the use of coal must also decrease in absolute terms. Encouragingly, African countries with a high share of coal for their electricity generation have already begun deployment of utility-scale renewable power plants and set ambitious targets for renewable energy deployment (African Development Bank *et al*., 2017).

- The Transport sector

It is important to tackle and engage in long-term planning across all sectors simultaneously, not just the energy sector, which is very often limited to the electricity sub-sector. Indeed, although **transport** accounts for over 30 percent of CO_2 emissions in Africa (see Fig. 6), there is no robust policy to curb these emissions.

In the short, medium and long term, modernizing urban and intercity public transport through the deployment of transport systems based on cleaner fuels (LPG, biogas, natural gas and, increasingly, electricity) offers major prospects for reducing greenhouse gas emissions and urban pollution and increasing the overall performance of African economies. In a few African countries, electrification of railways and urban transport systems as well as substitution of LPG for gasoline are already being carried out on a relatively large scale. Mass penetration of electric vehicles (EVs) may likely remain a long-term objective for Africa given the lack of infrastructure and the currently high initial investment costs for EVs. Nevertheless, EVs for collective transport (taxis, buses) for large cities only require a limited and quite centralized charging infrastructure. African countries also need to understand the significant trend in developed countries where there will be likely bans on light vehicles running on fossil fuels within the next couple of decades, if not before. This may revolutionize the system and rapidly lower costs. In light of the worldwide trend in the transport sector, it may be crucial for African countries to set very ambitious strategies for EV deployment despite currently high costs, so as to enable rapid leapfrogging. It may also be wise to develop industrial strategies towards increasing manufacturing of components for the EV value chain within Africa.

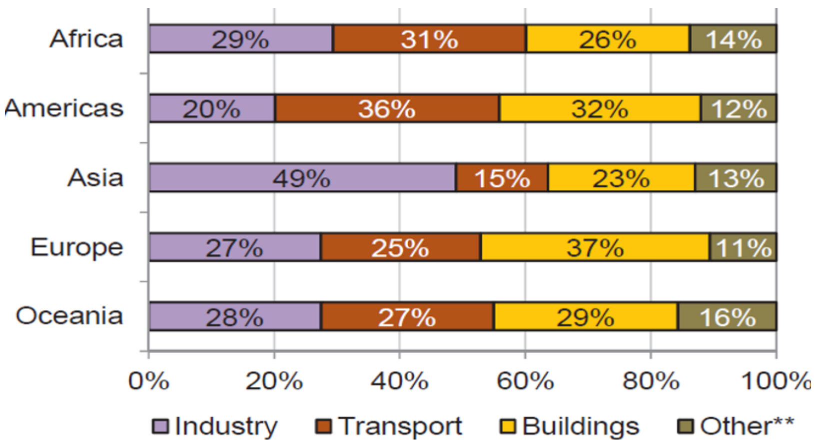
New technologies for transporting natural gas from source to demand points where distance and demand do not justify an investment in a gas pipeline are being developed and might be cost-effective. These technologies, known as virtual pipelines, allow for natural gas transportation in the form of compressed/liquefied natural gas using modules coupled to mobile platforms, which are transported by trucks, ferry boats, boats and/or rail platforms (Ikpeka and Ikiensikimama, 2016). With the use of virtual pipelines, it becomes feasible to provide clean fuel to households, replacing direct use of biomass (firewood and/or charcoal), produce fertilizers closer to agriculture clusters rather than only at large chemical plants located close to the LNG port terminals, and minimize gas flaring in oil production facilities and platforms (Ikpeka and Ikiensikimama, 2016). Several virtual LNG pipelines are planned or currently operated in North America, Europe, Australia and elsewhere.

9. Strengthening energy systems innovation and leveraging the potential of social innovation

To realize the full potential of renewable energy, innovative energy solutions tailored to local, national and continental conditions are needed. The Coalition for African Research and Innovation has identified two major barriers that need to be addressed, namely, inadequate allocation of resources to innovation, and the fragmented nature of available resources. Africa's share of global funding on research and development is only around 1 percent, and resource fragmentation severely limits any opportunities for collaboration (CARI, 2020).

A comprehensive continent-wide framework is clearly needed – one specifically designed to integrate currently dispersed renewable energy innovation resources into a more powerful source of innovative solutions that can

Fig. 6: CO_2 emissions from transport and other sectors in Africa and other continents relative to the continents' total CO_2 emissions in 2017 (%)



Source: IEA, CO2 emissions from fuel combustion, 2018 benefit cities, communities, public entities and businesses. Workers directly affected negatively by the changing priorities will need to be assured of a just transition, with establishment of rights and access to support for enabling re-orientation to other sectors - particularly the renewable energy sector with its tremendous opportunity for jobs creation.

The social and the technological dimensions of innovation are strongly interconnected and can hardly be separated from each other in explaining social change. The technology-centred paradigms currently shaping efforts at strengthening innovation systems in Africa need to give greater prominence to social innovation (Howaldt *et al.*, 2014). In addition to capturing the added value of such innovation as an autonomous field of action in its own right as a separate area in which efforts are needed, addressing this need would recognize the intimate links between the social and the technical sphere.

10. Conclusion: Jumpstarting the just energy transition

The largest share of the energy infrastructure and specific energy systems in Africa are yet to be built and the continent is not yet locked into any one energy option. In such fortunate circumstances, Africa has a tremendous opportunity to skip less efficient and more carbon -intensive technologies during the course of its development. Indeed, the continuously decreasing cost of high-efficiency, low-carbon technologies makes leapfrogging increasingly possible and allows for jointly tackling development and climate change imperatives in a sustainable and more equitable manner. However, the difficulty of such an undertaking is compounded by the imperative of carrying it out in accordance with certain requirements of social justice, a key condition for its success.

Given the right enabling conditions to nurture innovation, pursue power-system integration, decarbonize end-use sectors, and expand innovation beyond research and development, the continent will certainly leap ahead as a leader in decarbonized economies. The new and growing technological options must go hand in hand with holistic, innovative policy models and approaches to provide the efficient, reliable, affordable, and sustainable energy services required for the greater well-being of all Africans.

Endnotes:

[1] This ratio (reserves to production) shows the life expectancy of the reserves for a given period.

[2] Modern bioenergy technologies include liquid biofuels produced from bagasse and other plants; bio-refineries; biogas produced through anaerobic digestion of residues; wood pellet heating systems; and other technologies (IRENA).

[3] Stranded assets are assets that become devalued before the end of their economic lifetime or can no longer be monetized due to changes in policy or regulatory frameworks, market forces, societal or environmental conditions, disruptive innovation, or security issues.

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