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Sustainable Energy for Africa

Brussels, 23-25 October 2017

Guest Editors: Georges Van Goethem & Bernard Mairy

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Avenue Circulaire 3
B-1180 Bruxelles (Belgique)

Ringlaan 3
B-1180 Brussel (België)

☎ (02)790.39.02
E-mail: contact_raos@kaowarsom.be
Website: http://www.kaowarsom.be

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Opening Speech

by

Carole Maman[*]

This is my great privilege and honour to represent the Minister of Development Cooperation, Digital Agenda and Telecommunications, Alexander de Croo, and to open this conference organized by the Royal Academy for Overseas Sciences of Belgium around the theme of “Sustainable Energy for Africa”. The organization of such an ambitious conference deserves a lot of credit — a very timely subject that is at the core of African perspectives, more than thirty high-profile speakers coming from all horizons, a wide audience from the academic world but also the industrial and business world. Belgium can be very proud of organizing such a large event that not only contributes to the influence of Belgian research but also to improved communication among academics in Europe and Africa. I would therefore like to thank wholeheartedly and congratulate the Royal Academy for Overseas Sciences of Belgium and in particular its Chairman, Professor Georges Van Goethem, and its Permanent Secretary, Professor Philippe Goyens, for setting up this event.

As the Chief Investment Officer of BIO — the Belgian Investment Company for Developing Countries — my take on the subject of sustainable energy in Africa is the one of an “investor”. As some of you may know, BIO is the main player of the Belgian Cooperation in terms of support of the private sector through investment. We invest in the financial sector, in agribusiness, in SMEs and in infrastructure across Africa, Latin America and Asia. For the past three or four years, we have seen a surge of public private partnership projects in renewable energy in Africa and of new initiatives to improve access to electricity for all. Over the past couple of years, we participated along with other development agencies in the financing of various hydro, solar, wind, geothermal projects across the three continents and supported the set-up of new developers, particularly in Africa and Asia. On a yearly basis, we invest fifty to sixty million euros in renewable energy.

Coming from an investor perspective, there are three observations I would like to share with you:

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[*] Chief Investment Officer, BIO – Belgian Investment Company for Developing Countries, rue des Petits Carmes 24A, B-1000 Brussels (Belgium).

— First, maybe stating the obvious, the development of sustainable energy is a key piece in supporting an inclusive development of Africa and in addressing the challenges faced by the continent.
— Secondly, I can share the good news that these projects are on the rise as a result of the conjunction of favourable factors: improved public policy, reduced investment costs, new support from development agencies, new distribution channels. There is a wind of opportunity blowing in the sector to an extent I had never experienced before.
— My third and last observation is that development agencies are still clearly needed as many challenges still lie ahead of us in terms of public policy, of public investments and of private participation in the development of the sector in a situation where African population is growing fast, climate change causes a significant risk on the economy and natural resources get depleted.

On my first observation relative to the central role of sustainable energy in the development of the continent, I would like to bring to the table some key facts that will be certainly repeated over the coming three days:

— Six hundred and twenty million Africans lack access to electricity and this number is still growing. Two thirds of Africans, often in rural areas, lack access to these basic services: turning the light on and using electrical appliances including mobile phones, radios, TVs, computers. This obviously has an impact on human development, including on education and on integration of Africans in the global community.
— Four out of five sub-Saharan Africans use biomass to cook, including charcoal or collected wood with drastic consequences on health and nature depletion. It is estimated that up to nine hundred thousand Africans die every year as a consequence of poor quality of air at home.
— One hundred fifty is the average ranking of sub-Saharan Africa in the Doing Business report for getting electricity. Over one hundred ninety countries listing, it means that African countries are at the bottom. The majority of businesses in Africa need to rely on generator as their alternative energy supply... or sometimes their main energy supply. How can African enterprises expect to compete on international markets or against imports when they lack access to cheap and reliable sources of energy?
— Eighteen percent of merchandise imports in Africa are for oil and gas imports: oil-importing African countries suffer from their dependency on oil price and need to use their scarce hard currency resources for energy imports.
— Last but not least, Africa has also been identified as one of the most vulnerable regions as far as climate change is concerned with drastic consequences on agriculture, quality of life and population migration.

To sum up, lack of reliable access to energy plagues the population and the African economies and prevents Africa from competing successfully on international markets. The continent will also be terribly affected by climate change. How can sustainable energy help address these issues?

- First, because there are vast untapped sustainable resources in Africa: for instance, there are 1750 GW of capacity for hydro on the continent, 90 % of which is untapped; massive geothermal resources lie in the Rift Valley, there is high radiation sun almost everywhere, wind along the coasts and high potential for development of sustainable forest as well as biomass.
- In addition, contrary to oil and gas or coal, the wind, water, steam and sun are free.
- Of course renewable projects have high upfront costs. However, another good news for the continent is that these upfront costs have significantly gone down especially for sun and wind plants which allow to compete with oil and even coal plants.
- Another advantage is that most of these projects can be quickly carried out and therefore respond to the sense of urgency in terms of energy needs: for instance, a 100 MW solar project takes only a year to start generating electricity, the same for wind fields.
- Renewable sources of energy are also significantly decarbonized leading to reduce carbon emissions compared to conventional energy.
- Last, mini-grids and off-grid solutions help address access to energy of remote areas for one third of the price of oil generators.

Let me now come to my second observation: sustainable projects are on the rise in Africa. This is happening now.

Nearly all African countries in which BIO intervene have now set some objectives in terms of renewable energy production. The G7 countries have also committed to support the deployment of 10 GW of new capacity by 2020 bringing the total of renewable energy generation to 50 GW. Let me cite some of the projects that are currently being deployed:

- Hydro projects: at BIO, we see many projects being developed in Ethiopia, Uganda, Ivory Coast and Kenya without mentioning Inga in DRC.
- Wind projects in Kenya, Morocco, South Africa.
- Geothermal projects in Kenya, Ethiopia and possibly Uganda.
- Sustainable forestry projects in South and East Africa.
- Methane extraction from Lake Kivu for electrification: a project in which BIO participated.
- I would also like to point out the remarkable evolution of solar industry on the back of lower cost of production, more efficient solar panels and high levels of solar radiation. What started in South Africa, then Morocco, is now being rolled over in Rwanda, Senegal, Namibia, Burkina Faso, Benin, Zambia and soon Ethiopia. “Solar Home Systems” are also being sold on a pay-and-go basis continent wide to help households shift from diesel and candles

> to electricity with all the benefits you can fathom in terms of health improvement and education. Industries, supermarkets are increasingly turning to solar panels to lower the electricity cost and reduce dependency on the grid and on diesel generators.

Turning to my third observation, I would like to underline that the recent surge of sustainable projects is the result of political will from African leaders as well as world leaders, but also of the support from development agencies. A lot remains to be done and we, development agencies whether multilateral or bilateral, need to collaborate tightly to respond to the challenges faced in increasing energy access.

Challenges come first from the governments that need to define the policy and objectives and might need advice on priorities knowing that their budget is limited. Public budget needs to be used wisely, in particular to renovate and expand the grid… We need to avoid such situation as in Lake Turkana where a brand new 300 MW wind project is still not connected. One should also point to the poor state of the grid network that results often in large electricity losses and in instability. Pushing the agenda on regional interconnections could also significantly improve energy access and distribution. With an adequate interconnection in East Africa, much of the power shortage could be solved.

Challenges also come from the support of private sector involvement: while many governments have started implementing projects to accommodate private investors by delivering concessions, agreeing on feed-in-tariff and extending public guarantees for payment, some countries still lag behind. For instance, Tanzania has recently failed on its “Power Purchase Agreement” creating a devastating effect for all investors.

On top of this, electricity utility companies suffer from poor financial standing as prices fail to reflect supply costs and they need to rely on public subsidies. This lack of funding is a drag on long-term investment plan whether for grid or power generation and lead to privilege short-term solutions such as oil imports. A close to market electricity price remains the condition to invest in and to improve energy access. There is, however, a political cost as Ivory Coast recently experienced, as there is a time lag between the moment prices increase and the moment the end-users experience the improvement.

We, development agencies, have a role to play in supporting policy-makers in the countries, in helping public institutions define and implement a coherent and comprehensive strategy. We also have a role in ensuring that the strategy takes into account the potential impacts of the projects on the welfare of the local population and on the environment and to mitigate as much as possible all negative impacts. We finally have a role in building the human capacity in the host countries to accompany the development of sustainable energy through education and through academic cooperation.

When the policy-maker is clear about the objectives pursued and takes a long-term view, when the utility agencies have the skills and finance required, the private sector does accept to take its share of the risk and to develop projects sensible to the countries and their population. That is where the Belgian Cooperation collaborating both with public entities and civil society through Enabel (the Belgian development agency) and with private players through BIO can play an active role.

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African Universities and Science Diplomacy in favour of Alternative Sources of Energy

by

Wail Benjelloun*

Keywords. — COP22; Climate Change; African Universities; Science Diplomacy; Social Responsibility.

Summary. — The 22nd session of the Conference of the Parties (COP 22) to the UNFCCC (United Nations Framework Convention on Climate Change) took place on November 7-18, 2016 in Marrakesh, Morocco. During this session, parties considered preparations for entry into force of the Paris Agreement (COP21, 2015). Being the continent most threatened by climate change, this is an important event for Africa; and in fact, Africa is one of the three main themes around which this year's COP will revolve; the other two being agriculture and adaptation. Through an important science diplomacy initiative, African universities, led by the Conference of Moroccan University Presidents, played an important role in ensuring funds, raising awareness, and in lobbying for alternate sources of energy.

Introduction

The 22nd Conference of the Parties signatory to the Kyoto Treaty (COP22) was held in Marrakesh, Morocco, from 7 to 18 November 2016. During the previous meeting held in Paris in 2015 (COP21) important commitments were made by the participating countries to attain objectives meant to reduce gas emissions to bring down global temperature. In addition, the conference expressed support for developing countries as they face the consequences of global warming.

In Marrakesh, the 22nd summit was thus considered Africa's Summit. Africa is in fact one of the world regions most affected by global warming and climate change but it is also one of the world least polluting regions. African countries have participated in the COP summits in good faith, committing themselves to contribute to the set objectives. Their major concern has been assistance with infrastructure and capacity building to mitigate the effects of global warming.

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* Former President UNIMED (Mediterranean Universities Union), Corso Vittorio Emanuele II 244, 00186 Rome (Italy).

Science Diplomacy and the Conference of Moroccan University Presidents

As the summit was being prepared in Morocco, a wide spectrum of NGOs were involved through calls by the national committee for the organization of parallel events in what became known as the Green Zone, an area where a rich combination of governmental and non-governmental organizations managed stands, lectures, discussion groups and other activities around the summit topics. Moroccan universities contributed to this rich exchange through a unified exhibit area under the auspices of the Conference of Moroccan University Presidents (CPUM).

The Conference of University Presidents had noted early in the organizational phases that the Paris Summit, important as it was, had indeed called on university expertise in many of its deliberations but nevertheless was not characterized by a significant presence of universities. In its preparations for the event the CPUM therefore concluded that the issue of climate change was important, that universities, especially in Africa, must play an important role in the search for solutions and mitigation actions. In this they were joined by the Hassan II Academy for Science and Technology, a prestigious forum for national and international scientists in all fields of science. The Union of Mediterranean Universities was solicited early on to encourage its member and associated universities to participate actively in Marrakesh. It was also recognized that a healthy earth is in fact a human right, to be nurtured and protected and thus a strong initiative of the National Council on Human Rights. In conjunction with COP22, a summit of African university leaders was planned, to discuss climate change matters and to work on two impactful documents:

- A joint declaration in the name of all African universities to be presented at the United Nations blue zone;
- A roadmap to support research in Africa on climate change and sustainable development.

Through a coordinated effort, all three organizations worked to ensure the participation of a maximum number of African and other developing countries, from areas particularly vulnerable to climate change. Also attending were international universities with a history of cooperation with African counterparts in the areas of research and capacity building. African national academies of science, which include in their membership some of the continent's finest researchers, contributed both expertise and funds for the meeting.

Nearly one hundred university leaders, and directors of research academies met in Marrakesh at the invitation of the Conference of Moroccan University Presidents and the Hassan II Academy for Science and Technology. The event was sponsored by UNIMED along with several other international organizations. Most of the participants were from Africa, with several presidents from other continents. The principal objective was to convey to COP22 negotiators scientific information concerning climate change in Africa and to lobby for political and policy support for the adoption of mitigation measures.

Thanks to the international contacts of the CPUM, partner institutions including the conferences of university presidents from France, Spain and Portugal, the *Agence universitaire pour la Francophonie* (AUF), the *Institut de Recherche pour le Développement* (IRD) and others also contributed to the effort to marshal the continent's academics. This mobilization by the Moroccan university system constituted a new approach to science diplomacy (Fedoroff 2009), relying on the significance of the space occupied by the university in the national social fabric to raise funds for an activity of continental importance. In working with international universities and organizations, the CPUM was able to convey the concerns of the continent, to encourage the sharing of technologies and expertise, and to raise additional financial support. By successfully gathering an array of the leaders of Africa's most important institutions of higher learning, the CPUM guaranteed the presence of science in COP22 and reinforced the place of scientific research as a tool in mitigating climate change and in developing alternative sources of energy.

The Role of African Universities in Addressing Climate Change

The meeting also considered the role of universities in addressing climate change, with reference to education, training, research and social responsibility and the setting of a climate research agenda for Africa. The second day of the African universities meeting was devoted to mitigation, adaptation and resilience to climate change in Africa: role of science, technology and continental cooperation.

It became clear from the discussions that African countries must prioritize adaptation and mitigation strategies if current growth is to be sustained. In 2012, 70 % of major global droughts occurred in Africa, affecting more than sixty million people. The fact that Africa relies so heavily on rain-dependent subsistence agriculture means that rainfall variability (drought or flooding) can seriously hamper GDP growth. Therefore, Africa must work to make its voice heard in international fora, adopt mitigation measures to decrease deforestation and opt for alternative sources of energy (the Moroccan wind and solar programme was commended). It must also empower the poor through the adoption of appropriate social safety nets.

At the end of their deliberations, participants in this summit adopted a Joint Official Declaration of African Academies of Science and Presidents-Rectors of African Universities recommending actions to be undertaken in the academic and scientific areas to face the challenges of climate change in Africa. The declaration insisted on the necessity for the United Nations, for decision-makers in the developed world and for international organizations to set up a special fund to financially support initiatives that need to be implemented in Africa, including support for research.

The conference constituted an opportunity to engage in science diplomacy: using science lobbying to influence policies where scientific research is a lead provider of information and knowledge. The CPUM lobbied for, and successfully generated funding from the Moroccan government, Moroccan universities, the Moroccan Organization for Human Rights, the Hassan II Academy, as well as from international agencies.

Being the continent most threatened by climate change, this was an important event for Africa; and in fact Africa is one of the three main themes around which this year's COP revolved; the other two being agriculture and adaptation. Participating scientists raised the alarm that climate change could worsen current trends in resource depletion and reduce river flow, therefore decreasing hydroelectricity production and industrial productivity. Indeed, if current trends worsen, pollution management, sanitation systems, waste disposal, water supply, public health and infrastructure projects could become more costly.

Researchers present at the conference recommended priority areas for research, including:

- Energy economy in universities;
- The use of renewable resources, such as wind, hydropower, biomass and geothermal energy; the use of combined technologies;
- Determination of the effects of various new technologies on climate change;
- Integration of concentrated solar power with conventional natural gas-fired power plants for an integrated solar combined cycle system;
- New energy solutions to pump water and develop agriculture;
- Greater awareness of civil society in order to modify consumer behaviour;
- Differential use of resources, treated wastewater for toilet flushing and gardening;
- Adoption of energy-efficient technologies in desalination;
- Development of integrated-system approaches to specific economic and consumer demands;
- Development of nearly zero waste and nearly zero energy in buildings and industry: agro-industries, building sector, tourism, fishery, energy,…;
- Integration between greenhouses and exploitation of specific biomass and waste.

These research topics and actions focus on the importance of transdisciplinary innovation for industry, agriculture, and households. Since African universities are responsible for more than 80 % of scientific research production, the sharing of collective expertise becomes a valuable multiplier of the quality of the continent's research production. A special recommendation was made to provide funds for inter-African university research on alternate sources of energy, supporting the exchange of specialists and the mobility of young researchers. Additionally, African universities, through their contacts and cooperation with international universities and research institutions, are best placed to advance climate change and alternative energy research activities on the continent.

The Marrakesh proclamation, adopted by the heads of state and of government at the end of COP22, included these recommendations, calling for an increase in funding, in mobility and in access, together with an improvement in technological capacity building for Africa as well as the transfer of technology from developed to developing countries.

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The Main Challenges for Financing Sustainable Energy in Africa. Lessons from the Past and New Opportunities for PPP, viewed from a European Point of View

by

Paul Frix[*]

1. Context

Access to energy is a critical enabler for economic, sustainable and inclusive development, particularly in the fields of education, health, enterprises and jobs creation. However, because of little installed capacity, at least six hundred million people in Africa have today no access to electricity. Even those connected to the main grids experience frequent blackouts, which request costly domestic generators. The public utilities in the sector often face undercapitalization, poor management, inappropriate tariff collection, financial difficulties and insufficient maintenance. According to the African Development Bank (AfDB), annual power consumption in sub-Saharan Africa per capita is 181 kWh (kilowatt hours), compared with 6,500 kWh in Europe and more than double that in the USA.

According to UNEP (2017), the African continent, with 16 % of the world current population, has the world lowest per capita energy consumption. It consumes about 3.3 % of global primary energy, mostly oil (42 % of its total energy consumption) followed by gas (28 %), coal (22 %), hydro (6 %), other renewable energy (1 %), nuclear (1 %).

It is foreseen that in 2100, Africans could represent 40 % of the world population. Under the joint pressure of demography, urbanization and economic growth the electricity needs will explode in the coming decennia (Barroux 2017).

Fortunately, the energy sources of the continent are extremely important and diverse, combining traditional and renewable energy (Barroux 2017, IEA 2014).

The potential of clean energy is particularly huge. The continent has well over 10 TW (terawatts) of solar potential, 350 GW (gigawatts) of hydroelectric, 100 GW of geothermal (*Africa's Pulse* 2018, Okosi 2017). The mounting international common awareness about the climatic dangers of global warming and the need to react at world level, combined with rapid and affordable technological pro-

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[*] Honorary Director-General Belgian Development Cooperation and CDE/CDI, Counsellor CBL-ACP, PROPADEV SPRL.

gress in clean energy production and distribution, management and communication tools (ICT), should logically allow Africa a leapfrog in its development process. With appropriate policies and support, the continent should be in a position to base mainly the future of its economic development on a post-carbon model using various types of sustainable and renewable energy, central and interconnected grids as well as decentralized and off-grid solutions in electricity production and distribution. In complement to this, progress and innovation in energy efficiency and conservation will also play a decisive role (Ladler 2017).

2. The False Dilemma: Decentralized Approaches versus Big Projects

Centralized and decentralized approaches are complementary but require different types of financing, process and actors.

The development of centralized grids and their interconnection at national and regional levels through "power pools" has a critical role to play in the development of regional integration, industrialization, trade and market structuration. The investments required are huge and need careful preparation, long-term views, coherent regional cooperation and very often deep institutional and regulatory reforms. By contrast decentralized approaches through mini-grids, smart grids or off-grid solutions are by far less expensive and allow affordable energy access to populations in rural and isolated regions, giving them easier, and more efficient access to education, health care and telecommunication and well-being. In recent years, progress in decentralized technologies has been impressive and makes them, in particular concerning solar and wind energy sources, the most competitive solutions to reach the ambitious objective of "Electricity for all" in 2030 promoted by the UN Sustainable Development Goals and various other international initiatives. The collapse in solar photovoltaic (PV) panel prices — which have fallen by 80 % since the end of 2009, according to the International Renewable Energy Agency (IRENA 2018) — provides Africa with a unique opportunity to bridge the power deficit using one of Africa's most abundant natural resources: sunlight.

Today, renewable energy from solar and wind sources for example, has reached a stage where it is now competitive compared to traditional power sources in many types of situations and allows very decentralized approaches.

2.1. Centralized Grids, Power Pools and Regional Integration

The hydroelectricity potential of Africa is particularly huge and still largely untapped.

Big dams and huge hydroelectric projects have generally bad reputation at the level of NGOs. Those projects are generally very expensive, complex and require long and careful preparation and implementation periods. Their final impact on local populations and environment may be more or less damageable. They may also be prone to corruption and bad governance. Their financing needs are very important and particularly risky. They require various types of risk mitigation mechanisms at local and international level. In addition, this type of project is generally not well adapted to respond to the needs of rural and remote areas where a large majority of the population of sub-Saharan Africa can still be found (Huet & Boiteau 2017).

However, well-conceived and managed properly, those projects have, as already mentioned, a strategic role to play to boost and structure the continent development, economic diversification, industrialization and market integrations.

The spots, countries and regions having a decisive comparative advantage to develop this type of big projects and kick off their own industrialization and regional integration process are (fig. 1):

- — The DRC with a global exploitable potential of 100 GW of which 44 % located on the sole Inga site;
- — Ethiopia (12 GW);
- — Mozambique and Zambia with 10 GW;
- — Guinea (6 GW) in Western Africa.

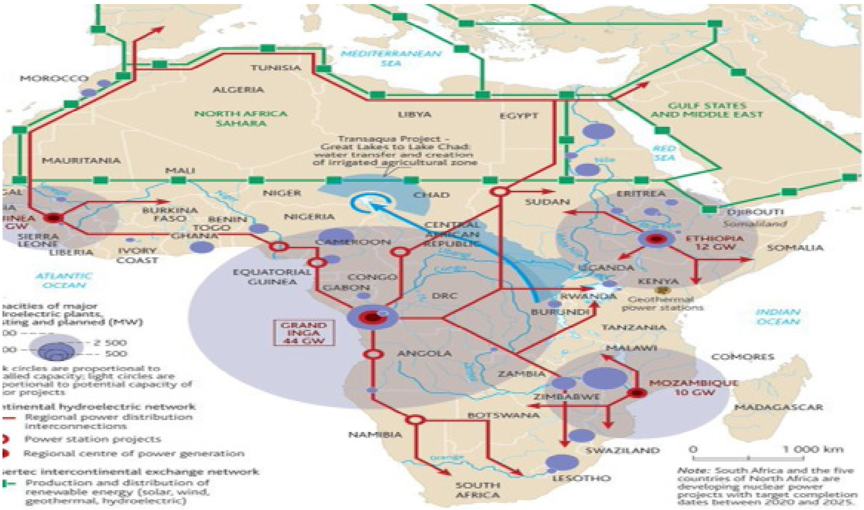


Fig. 1. — Countries and regions where big hydroelectric projects can take place.

In the introduction to its 2017 edition, the Atlas of Africa Energy Resources, published jointly by the AfDB, the ICA (Infrastructure Consortium for Africa), the Sustainable Energy Fund for Africa and the UN Environment Program (UNEP 2017), considers that:

- Regional energy integration, due to the small size of much of the economies of African countries, is extremely important to attract investments, for the security of energy supply and mix, and to reduce the cost of doing business (economies of scale) and costs to consumers;
- Regional energy generation provides an optimal economic solution to generating and using energy, because energy is produced where it is most economical and supported, and is provided where it is most highly needed;
- Power pools are also important because power trade is an indicator of energy integration; power pools themselves are, along with transport infrastructures and ICT (Information and Communication Technologies), key drivers of regional integration;
- There is high political commitment to regional energy markets;
- Regional energy integration through power pools is a prerequisite for sustainable development.

The main power pools in Africa are:

- The EAPP for Eastern Africa (eleven countries);
- The WAPP for Western Africa (fourteen countries);
- The SAPP for Southern Africa (eleven countries);
- The CAPP for Central Africa (ten countries);
- The COMELEC (five Maghrebian countries).

One characterizing feature of electrical grids in Africa is their isolation. The formation of regional energy trading pools should help stabilize energy markets, but requires building up costly transmission line infrastructures between countries. The choices made have not only a direct impact on the interregional trade of energy but may also exert an important structuring role on the location and spatial repartitions of the activities in the countries and regions concerned (Frix 2015, 2016). The potential, efficiency and type of development of numerous economic basins and corridors of the continent depend on a combination of efficient transportation and communication systems and on the type, cost and reliability of the energy supply. Type of industrialization and ecosystem of services are deeply influenced by this kind of factor. Concerted strategies and choices at national and regional levels are required to deliver optimal results, win-win solutions, and to diminish the risks of important possible environmental and social negative effects.

According to experts consulted by Wikipedia, the resources needed for grid integration would be at least nineteen billion US$ annually. Investment in improving regional energy trade would save an estimated five billion US$ annually in emergency generation costs, yielding a 22 % rate of return. If the theoretical global and mutual advantages of grid integration are obvious, the strategic options concerning the volume and choice of investments, partners, localization of investment, transmission lines, tariff strategies, governance regulatory and business environment existing at regional levels are critical to determine who and where will be the main winners (if any) (Frix 2015, 2016).

Illustrative of this are the extraordinary capacities, opportunities, challenges and risks presented by the development of the Inga site on the Congo river in the Lower Congo Province.

2.2. The Emblematic Inga Case (Frix 2016, Misser 2013)

2.2.1. Points of View

The points of view concerning this project are contrasted.

Generally NGOs consider this project as ruinous, a dangerous utopia, detrimental for the environment and a potential white elephant (*cf.* research and articles published by the "International Rivers Association").

The cost of the first two dams built in 1972 and 1982 and the transport line of 1,700 km constructed to link Inga to the copper mines of the Katanga Province in response to a political will of president Mobutu, contributed to more than 50 % of the external debt of the country and to the outbreak of a financial crisis from the 1980s to 2010. Due to poor management, lack of maintenance of the power plants and transport lines to Kinshasa and Katanga and also the non-realization of the vital complementary infrastructures — a deep-sea port in Banana to allow the development of industries in the Lower Congo Province, those first two and relatively modest realizations may be considered as white elephants and globally as a failure.

By contrast a large number of experts and economists consider that:

- With Inga the DRC has one of the most important potentials of clean and renewable energy in the world located on a single geographical site, which can be equipped progressively, and step by step. This should allow, if the project is well conceived, implemented and properly managed, the production of the cheapest electricity for industrial and general use in the world.
- Well used and valued, this clean energy, which is renewable, abundant and among the cheapest in the world, will be essential not only for the development and diversification of the DRC economy but also for a significant part of the African continent. It is regarded by NEPAD and ADB as the one, if not the greatest, integrative project of the continent.
- Compared to what happens with most of the big dams in the world, the environmental damage produced by the development of Inga will be minimal (*e.g.*, the retention basin for the final development stages of "Grand Inga high fall" will remain very small and will cause very limited displacement of population and very little environmental damage).
- It will make economic development less dependent on fossil fuels and reduce consumption of charcoal in large urban centres, such as Kinshasa. The pro-

ject will slow down further deforestation in Central Africa and have, in the end, a substantial positive ecological balance.

Although already identified and studied during the colonial period, the implementation of the Inga project, after the country's independence in 1960, suffered from numerous rivalries, avatars and vicissitudes. The history of Inga is something of a thriller and was described brilliantly by François Misser in his book on the Inga saga (Misser 2013). An updating of the developments that occurred since then has been made by the same author in No. 87 of *Conjoncture Congolaise* published by the CREAC and the Royal Museum for Central Africa in 2016. With the global awareness of the dangers of global warming, the value of Inga potential has gained, in recent years, a new dimension that makes it today undoubtedly the most important sustainable economic resource available for the DRC and Central Africa future development.

The hydroelectric potential of the DRC is estimated to ± 100,000 MW (megawatts), ± 44,000 of which concentrated on the site of Inga in Lower Congo, 225 km southwest of Kinshasa and 150 km from the mouth of the Congo river. The 56,000 MW remaining are scattered over several dozens of hydraulic sites unevenly distributed across the country. By owning 13 % of global hydropower potential, the DRC ranks third in the world after Russia and China. It should be noted, however, that the capacity installed in the 1970s and 1980s on the site (Inga I and Inga II) is quite low. It amounts to 1,774 MW, representing only 4 % of the total potential of the site. Furthermore, because of lack of maintenance and slow international rehabilitation programmes, this ability was used, until recently, at only 40 % of its capacity.

In DR Congo, population access to electricity is still extremely low (around 10 to 15 % compared to an average of 35 % for the continent). In rural areas this rate hardly exceeds 1-2 %.

Paradoxically, the development of Inga will only very partially remedy this situation as the electricity produced has logically to be used in priority in large urban cities such as Kinshasa or Lubumbashi and before all for industrial and mining activities in the country and elsewhere on the continent. The access to electricity in most of the territory will mainly be ensured by decentralized production units and by other projects, involving the development of medium, small and micro hydro plants, solar, wind or the use of local biomass.

2.2.2. Key Issues

If rationally and progressively implemented, the Inga site should be able to produce a large quantity of renewable clean energy, the cheapest in the world.

The impact it will have on the DRC and the rest of Africa will depend heavily on strategic options and tariff policies that will be performed at local, subregional, continental and sectoral levels. These strategic tariff policies will determine who will in the end benefit from decisive comparative advantages to have clean, abundant, renewable and very cheap energy (ex-factory cost of kWh is estimated at $ 0.03 cent). A neutral arbitration based on comparative studies between strategic interests in the medium and long term of the DRC and those of potential external partners would be necessary.

If Inga is a potentially wonderful asset, it has in fact the disadvantage of being internationally coveted as well by equipment suppliers and contractors as by potential customers. This, combined with weak local governance, exposes the country to vulnerability and has induced for the last few years many changes in the technical and strategic options (Misser 2013).

Choices were also made difficult, because of a lack of updated comparative studies on the advantages and disadvantages of the various possible development scenarios at continental and regional levels.

Are missing or are in need of complementary investigations to assess:

- The most adequate tariff policies and strategies to be followed at national, sectoral and regional levels to maximize the impact of Inga's development in Congo, Central, Southern and Western Africa.
- Conditions of the interconnections of the various African networks and comparative advantages created by other large hydroelectric projects planned on the continent (see fig. 1).
- How to ensure the mobilization of required funding and a fair distribution of risks at international level. For your information, investment costs required for the first (Inga 3BC) of the seven new stages planned for the Grand Inga were evaluated initially at around twelve billion US$, including the interconnections associated with the full 4,800 MW project. For the most part, the final cost will depend on the transmission lines across the country, which will be required in the strategic and geographical options that will be finally selected.
- Amongst African partners who are the most interested in the development of Inga, we can find the member states of the Power Pool of Central Africa: Nigeria, Egypt and especially South Africa. The latter, still heavily dependent on coal, a very polluting energy source, has been eyeing the enormous potential of clean, renewable energy from Inga for fifteen years. In the first decade of the 21st century, South Africa was the spearhead of the project called "Westcor", which created an international "offshore" company controlled by consuming countries of Southern Africa and where DR Congo was very minor. Unrealistic implementation conditions of Inga 3 and abandonment by BHP Billiton of its important aluminium smelter project in Moanda led to the dissolution of the consortium.

2.2.3. Recent Evolutions

On legal, technical and policy grounds very different from the former Westcor Inga 3 project, the new Inga 3 project named “INGA III low-fall” has been relaunched at the beginning of this decade, jointly by the DRC and South Africa.

This is the first of seven steps now planned to implement the “Grand Inga”. It involves the flooding of the Bundi dry valley with the construction of a large dam at its outfall.

The potential electrical power to install as part of this first phase of “Grand Inga” is 4,800 MW, of which 2,300 will be redeemed by the DRC to meet the growing needs of large urban centres and mining companies and 2,500 to South Africa.

A special treaty was signed between the two countries. It was ratified in 2015 by the Congolese parliament. It recognizes the ownership and sovereignty of the DRC on the Inga site and its leadership in the process of promotion, development and implementation of the project through a National Agency for Development and Promotion of Inga (ADEPI/DRC).

The competences of this agency range from production to the sale of electricity and to the construction of transport lines. Since its creation, the new agency has been placed under the direct authority of the presidency of the Republic of Congo. ADEPI is expected to enjoy a technical support provided by the World Bank. Alongside the agency, two commissions were set up:

— A joint ministerial commission;
— A joint permanent technical commission.

For further developments of the “Grand Inga” project, priority is given to the needs of the DRC while South Africa is given a right of first refusal on at least 20 % of the new capacity that will be created at later stages. In addition, the DRC may not grant to its other external customers more favourable rates than those offered to South Africa.

Following a “call for interest”, three international consortia were first shortlisted to carry out the project, including a European (Spanish) consortium, a Korean consortium associated with the Canadian company SNC Lavalin and a Chinese consortium led by the company that constructed the Three Gorges Dam (22.5 GW).

The final selection of the successful bidder is still underway. To be noted in the meantime the withdrawal of the Korean consortium. Only two groups remain then in the race: one led by the Chinese companies Three Gorges and Sanhydro and the other one, the European Spanish consortium. More recently in 2017 the Congolese authorities asked the two consortia to merge their offer.

The beginning of the works was planned for 2017 but this deadline is no longer realistic.

2.2.4. Outlook for Belgian and European Companies

After being involved in Inga I and II issues in the 1970s and 1980s, Europe and especially Belgium have been marginally interested in the development of Inga for nearly thirty years. However, as a consequence of problems of gas supply from Russia via Ukraine, Europe became aware of the vulnerability of its supply sources.

This led to the development of an energy partnership with Africa. This partnership aims at security and diversification of European supplies and integration of the energy factor in the development cooperation policies as well as the fight against global warming.

In this context, it would be logical and necessary that the energy sector and in particular the Inga issue feature prominently in the National and Regional Indicative Programmes of the eleventh European Development Fund (EDF). They should be considered as key elements for the success of the regional integration and economic diversification planned in the framework of the Economic Partnership Agreements in Central Africa (EPAs), which include the DRC.

If they want to run the risk of being marginalized in the context of a project of the magnitude of Grand Inga, whose achievements will take several decades and profoundly change the geography and the economic dynamics of Africa, the Belgian, Luxembourg and European companies should build alliances and join together in consortia of complementary businesses of different sizes.

It is a necessity to be truly competitive at European level to develop new forms of Public-Private Partnerships (PPPs) and provide varied ranges of complementary products and services such as training, standard definitions and mechanisms for certification or risk spreading to better withstand competition from increasingly strong new partners like China, India, Korea and Brazil.

Belgium, Luxembourg and the European Union should feel concerned in priority with the “Grand Inga project” and its subsequent development as ports, economic corridors, basins and special economic zones.

In addition to its active role in achieving the Inga I and 2 plants, Belgium was involved in the 1970s, through the Tractionel company (now Tractebel Engie), in technical studies for a deep-water port at Banana in the Congo estuary. This essential complement to Inga II has never seen the light because of the debt crisis of the 1980s that prevented funding.

Today, Luxembourg and Belgium could and should act at European level as champions to:

- Include the development of the Grand Inga and its sub-projects, which include the deep-water Banana port and the economic corridors that must be developed to Kinshasa and then to Brazzaville – Pointe-Noire and Luanda, among the flagship projects of the Euro-African energy partnership, post-COP21;

- Develop new PPPs adapted to the development and funding of unusual scale and long-term projects such as the present one, including a deep-water port at Banana and developing economic corridors between Banana and Kinshasa or between Luanda and Pointe-Noire, passing by in Soyo and Banana;
- Facilitate the participation of European companies in such projects and programmes in partnership with local companies with a focus on regional integration in Africa.

For Europe, this is a unique opportunity to again become an important and active partner in one of the most promising projects for development in the DRC, the integration of Central Africa and the future of the African continent.

It is also important to restimulate companies, universities as well as Belgian, Luxembourg and European engineering offices to participate in the large and lengthy process whose developments will be spread over at least twenty-five years. The projects and the complementary investment in infrastructures of transport, communications and services requested will mobilize tens of billions of euros. They require the establishment of innovative public/private partnerships and involve many sectors and sub-sectors

3. Financial Needs, PPPs and Role of ODA (Official Development Aid)

3.1. Objectives and Resources Needed

The resources needed to implement the seventh goal of the SDG (Sustainable Development Goals), the UN initiative “SE4All” (Sustainable Energy for All) and the resolution of the COP21 in Paris in 2015, are enormous.

As a reminder, the seventh SDG goal aims namely at:

- Ensuring universal access to affordable, reliable, sustainable and modern energy services for all by 2030;
- Increasing substantially the share of renewable energy;
- Doubling the rate of improvement in energy efficiency.

The “SE4All” initiative, a multi-stakeholder partnership between governments, the private sector and civil society launched by the UN Secretary-General in 2011, has three interlinked objectives to be achieved by 2030:

- Ensuring universal access to modern energy services;
- Doubling the global rate of improvement in energy efficiency;
- Doubling the share of renewable energy in the global energy mix.

The World Bank estimated in 2011 that sub-Saharan Africa needed to add 8 GW of new generation capacity each year, but an average of only 1-2 GW has been achieved.

According to a 2015 McKinsey report, “it would take US$ 490bn to generate power and US$ 345 bd for transmission and distribution to meet the needs of the SSA region in the next 15 years” (Castellano *et al.* 2015).

According to the AfDB, it could cost sixty billion US$ per year to achieve its target of providing universal electricity access by 2025. Power deficit and the reliance on backup solutions is a huge burden to all the sectors. Loss of growth rate per year, because of lack of sufficient and competitive energy, is estimated up to 2 %.

In line with the SDG goal 7 and international commitment subscribed at the COP21 in Paris in 2015, various initiatives have emerged to help Africa develop clean and sustainable energy and access to electricity for all.

Today, these initiatives are numerous and their number tends to increase and become impressive. They are often complementary to each other and convergent but it is not always the case, because of insufficient coordination and harmonization of the approaches.

The first ten-year implementation plan of the African Union “Agenda 2063”, approved in 2015 in Addis Ababa, has among its objectives:

- Raising by at least 10 % the share of renewable energy (wind, solar, hydro, bio and geothermal) in total energy production;
- Reducing by at least 20 % the proportion of fossil fuel in total energy production;
- Increasing by at least 50 % electricity generation and distribution.

Among other initiatives to mention:

- The Africa Power vision (APV) based on the PIDA (Programme of Infrastructure Development in Africa) managed by the AfDB (NEPAD 2015).
- The AREI (African Renewable Energy Initiative), launched in 2015. It is led by the African Union’s Commission, the New Partnership for Africa’s Development (NEPAD)’s Agency, the African Group of Negotiators, the African Development Bank, the UN Environment Programme (UNEP), and the International Renewable Energy Agency (IRENA). According to its promotors, “AREI is a transformative, Africa-owned and Africa-led inclusive effort to accelerate and scale up the harnessing of the continent’s huge renewable energy potential. Under the mandate of the African Union and endorsed by African Heads of State and Government on Climate Change (CAHOSCC), the Initiative is set to achieve at least 10 GW of new and additional renewable energy generation capacity on the continent by 2020, and mobilize the African potential to generate at least 300 GW by 2030”. The AREI has already obtained the support of several investors, who promised to provide ten billion US$ by 2020 to reach that objective (AREI 2017).
- Recently, the AfDB launched a “New Deal on Energy in Africa” (NDEA) (AfDB 2017) whose target is universal access to electricity for all in Africa

by 2025. To achieve this the AfDB believes that 160 GW of new on-grid and some seventy-five million off-grid connections will be needed through a mix of conventional and renewable resources in the next few years.

— The Board of Directors of the African Development Bank (AfDB) has approved a financing package of one hundred million US$, comprising fifty million equity and fifty million convertible senior loan, to seed the Facility for Energy Inclusion (FEI), a pan-African renewable energy debt fund (AfDB 2017). The investment is expected to catalyze energy access for an estimated three million people. This initiative is rooted on the Bank's New Deal on Energy for Africa and increasing global recognition on the importance of energy access for all in Africa.

FEI will focus on providing senior and mezzanine debt to off-grid, mini-grid and small-scale Independent Power Producers (IPPs), *i.e.* projects with total cost under thirty million US$. The Fund will provide hard and local currency financing.

The Bank's approval opens the door to a formal fund-raising process, which seeks to raise up to four hundred million US$ in additional investment from like-minded Development Finance Institutions (DFIs), private investors and commercial banks. In preparation for this, the AfDB has namely held informal discussions with potential investors from UK, USA, Germany, Japan, and South Africa. In July 2017 a Japan Africa Energy Initiative was launched. A few others are being prepared or envisaged.

The AfDB is playing an increasingly important and federative role of numerous initiatives in the field of energy and sustainable development. It is today a key institution for the real appropriation by Africa of its priorities and development strategies.

3.2. How to Promote and Finance New PPPs?

The IRENA report published in 2016 and named "Unlocking Renewable Energy Investment: The Role of Risk Mitigation and Structured Finance" gives a broad view not only of the renewable energy opportunities but also of the risks involved and the kind of enabling environment, instruments and policies needed to promote and facilitate access to capital and mitigate financial risks (Wuester *et al.* 2016). To create favourable conditions and boost existing opportunities, the development of appropriate PPPs combining private and public resources is particularly needed in Africa.

Centralized as well as decentralized approaches in the field of renewable energy need to be supported by PPPs through guarantee schemes and blending mechanisms if we want the development of clean and renewable energy in Africa to reach a decisive stage in the next few years.

If coherent institutional, legal and regulatory reforms are generally needed locally or regionally to accelerate the process, it is at the level of medium-sized and large projects that the situation and challenges are the most complex.

Big projects and particularly big dams:

- Are more complex and difficult to design and implement;
- Are very expensive and risky, what requires the setting-up of efficient risk mitigation mechanisms;
- Need a coherent and predictable economic, fiscal and legal environment;
- Involve many different partners at the implementation, financing and management levels which request careful preparation and the setting of special vehicles or arrangements (*e.g.*, BOT or DBOT…) (World Bank PPPLRC);
- Get more exposed to bad governance and conflicts of interest;
- Are liable in some cases to have important negative impacts on the local environment and on the financial and social stability of the countries concerned;
- Might trigger international conflicts concerning, for example, the access to water for the downstream countries.

Project risk can take multiple forms.

According to IRENA (Wuester *et al.* 2016), this includes namely political and regulatory risk, counterparty, grid and transmission link risk, currency, liquidity and refinancing risk, as well as resource risk.

Policy makers, financial institutions and investors can draw from a strong toolkit that can help overcome these barriers, mitigate investment risk and improve access to capital for renewable projects.

The following options constitute a portfolio of measures, instruments and tools to be used in combination:

- Enabling policies create stable and predictable investment environments, and help overcome barriers and ensure predictable project revenue streams.
- Technical assistance and grant funding can be critical early on in the project lifecycle when preparing the ground for investment. They foster project development and strengthen documentation. Targeted non-financial interventions can play a facilitating role and help take projects forward to full investment maturity.
- Debt-based instruments, such as on-lending and co-lending structures, can help local finance institutions overcome key barriers, especially limited access to capital and low experience in lending to renewable energy projects.

The most common PPP approaches for the realization of big projects led by the public authorities in developing countries are concessions, BOT and DBOT (World Bank PPPLRC).

Precise definition and detailed information on those approaches are given on the site “PPPLRC” (Public-Private Partnerships Legal Resource Center) of the World Bank.

Concessions, Build-Operate-Transfer (BOT) projects, and Design-Build-Operate-Transfer (DBOT) projects are types of public-private partnerships that are output focused. BOT and DBOT projects typically involve significant design and construction as well as long-term operations, for new build (greenfield) or projects involving significant refurbishment and extension (brownfield). The site gives definitions of each type of agreement, as well as key features and examples of each. The page also includes links to checklists, toolkits, and sector-specific PPP information.

3.3. Contractual Structures

Figure 2 shows the contractual structure of a typical BOT project or concession, including the lending agreements, the shareholders’ agreement between the project company shareholders and the subcontracts of the operating contract and the construction contract, which will typically be between the project company and a member of the project company consortium.

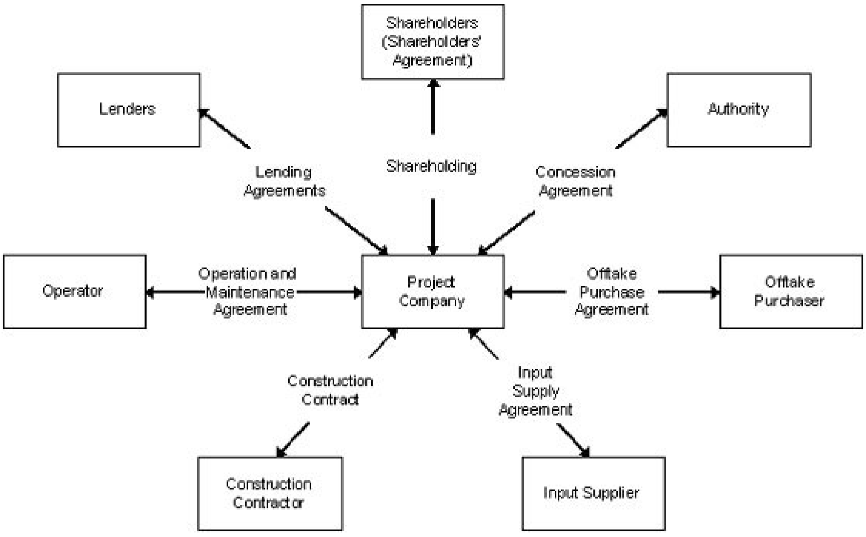


Fig. 2. — Contractual structure of a typical BOT project or concession.

Each project will involve some variation of this contractual structure depending on its particular requirements: not all BOT projects will require a guaranteed supply of input, therefore a fuel/input supply agreement may not be necessary.

The payment stream may occur in part or completely through tariffs from the general public, rather than from an offtake purchaser (fig. 3).

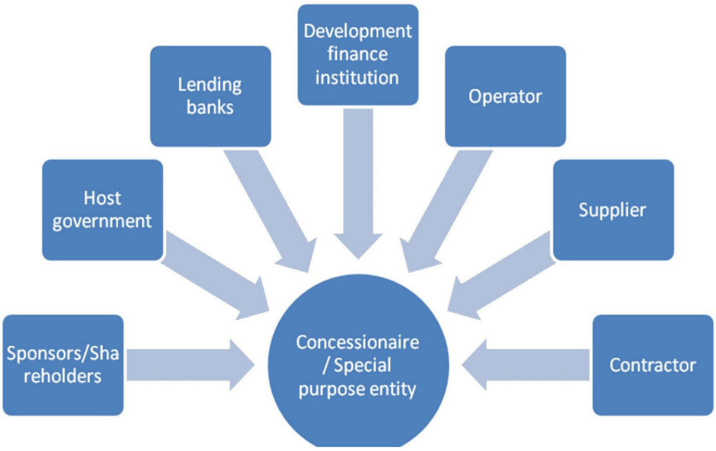


Fig. 3. — Example of payment stream.

3.4. The Use of Guarantees

Based on data from sixteen institutions, IRENA analysed guarantee issuance and use in renewable energy investment. The results show that:

- The use of guarantee in the sector remains fairly limited (0 to 13 % of the portfolio; 4 % on average);
- Guarantee has been used mainly to support larger-scale projects.

The main mechanisms used to reduce and share risks are:

- Government guarantee;
- Political risk insurance;
- Partial risk guarantee;
- Export credit guarantee;
- Various currency and liquidity risk mitigation instruments;
- Collaterals.

At multilateral level, it is worth mentioning the Multilateral Investment Guarantee Agency (MIGA) and several regional guarantee funds involving the World Bank, AfDB Regional Dev Banks, European Investment Bank (EIB) and various Development Finance Institutions (DFIs).

To mobilize more easily private sector financing and investment, different mechanisms have indeed been set up to reduce the risk of private investors/financiers are used to. Three classes of financing and risk associated are generally distinguished:

- Class C: first lost share.
- Class B: mezzanine loans or shares that rank senior to the C share portion (Class B). They are generally contributed by DFIs.
- Class A: share that ranks senior to the other two share classes.

The financial structure of such projects can also be presented this way:

- Senior debt (the least risky level);
- Subordinated debt;
- Hybrid instruments;
- Preferred equity;
- Common equity (the riskier level).

Placed in the middle of the capital stack subordinated debt and hybrid instruments can have unique characteristics that public institutions can use to reduce the cost of capital and to mobilize private capital in renewable energy investment.

Bonification of interest and Technical Assistance (T.A.) facilities adjacent to the capital structure are more and more often available to investees to help entrepreneurs to better design, build up and implement their project and to governments to define coherent strategies under institutional, legal and harmonized conditions.

More and more African states are in a position of issuing public green bonds to finance projects: it is namely the case for Ethiopia, Kenya, South Africa,… Sovereign funds, pension funds and insurance companies, and private investment funds and private foundations, such as those of Bill and Melinda Gates or Warren Buffett, can also play an important role, once efficient risk mitigation schemes have been set up.

At the other end of the spectrum, crowd funding and blending solutions with ODA (Official Development Assistance) may also be encouraged for decentralized approaches.

To be noted the booming of green bonds issuance. Even if they represent only 1.5 % of the total, the share of green bonds, according to HSBC (Hong Kong & Shanghai Banking Corporation) estimations, could climb within ten years to 5 or 10 % of the market (tab. 1).

Table 1

The largest issuers of green bonds to date (amounts, categories and countries): The French state, EDF and Engie are among the top ten (State of the Market 2017, Climate Bonds Initiative, HSBC)

Largest issuers to date	Amount	Issuer type	Country
EIB	$22.6 bn	Development Bank	Supranational
KfW	$12.8 bn	Development Bank	Supranational
World Bank	$10.6 bn	Development Bank	Supranational
SPD Bank	$7.6 bn	Commercial Bank	China
Republic of France	$7.6 bn	Sovereign	France
Iberdrola	$5.6 bn	Corporate	Spain
TenneT Holdings	$5.5 bn	Corporate	Netherlands
EDF	$5.3 bn	Corporate	France
IFC	$5.3 bn	Development Bank	Supranational
Engle	$5.1 bn	Corporate	France

3.4.1. What about using Local Assets as Collateral?

The local and international financial sector may also ask promoters or local governments to provide various types of collateral as guarantees to their loans. For fifteen years, China has massively used this type of guarantee at state level to develop infrastructures in Africa and facilitate its access and investments in mines, energy, agro, agroforestry and industry, deep-sea ports and ESZ (Economic Special Zones).

Such an approach under the form of a “Debt-Projects Swap” was suggested in the late 1990s and early 2000s at Belgian level by Paul Frix, director-general at the Department of Foreign Affairs and Development Cooperation and permanent delegate of Belgium to the OECD DAC (Development Assistance Committee), to solve positively the DRC external debt problem. The proposal was to convert a large chunk of the Congolese external debt into an international investment fund for the reconstruction and development of DR Congo (FIRC). The concept was examined and validated by Prof. Berlague of KU Leuven and Prof. Venan Kinzonzi of DRC. It was discussed in workshops at the OECD level but was not, at the time, sufficiently in line with the dominant mood which gave priority after decades of very painful and inappropriate structural adjustment programmes to the debt cancellation of 90 % of the eligible HIPCs (Highly Indebted Poor Countries). However, the system had been successfully tested on modest scale by the Belgian Cooperation and the credit insurance company “Ducroire” (today Credendo) in Bolivia and Guatemala. Since then, countries like France have used this type of mechanism to finance social and development programmes in post-HIPC beneficiary countries (Frix 2003).

3.5. For Long, the ODA Concept and Role should have been Adapted and Modernized

On the same occasion the need was also felt to review the DAC concept of ODA, which is based on the net flux of public resources from OECD countries towards developing countries, not really taking into account the final results of the operation financed. In such a system the reimbursement of a public ODA loan for a successful public utility (*e.g.*, a hydropower project) should be accounted as a reduction of the ODA performances of the lender country. Reversely, the non-reimbursement of ODA loans for a failed project (white elephant) will be registered as full ODA and in case of debt cancellation, possibly accounted twice by certain unscrupulous OECD countries.

Today nearly everybody recognizes the need to adapt the ODA concept to the need to better involve the private sector, local and foreign, in the process of a sustainable and inclusive development. ODA may play, through appropriate modalities of blending and technical assistance, a catalytic role in the orientation of local and regional development and in the mobilization of resources at local and international levels.

3.6. European Approaches

The EU cooperation in the field of energy in Africa has already a long history behind it and has been very diverse and relatively important all along the Yaoundé, Lomé and Cotonou agreements. The support has been channelled mainly through the "Energy Facility" financed by the European Development Fund and managed by DG Dev, and the "Investment" and "Infrastructure" facilities located at the EIB.

3.6.1. The "EU-Africa Energy Partnership"

Among the tools and channels getting already the support of the EU to be mentioned: the "EU-Africa Energy Partnership", which is one of the eight partnerships of the Joint EU-Africa Strategy (JEAS) launched during the Lisbonne Summit in December 2007, the UN "Energy4All" Programme, the IRENA and AREI.

Over the past decades, the EU and Africa have developed a stronger and more political partnership. The objective is to raise the relationship with Africa to a higher strategical level. In this framework, the energy partnership aims to develop common vision and options but up to now, compared for instance with Chinese initiatives, concrete results may appear limited.

In the future, the volume of EU financing should gradually and substantially increase and diversify through new blending mechanisms, green bonds, impact loans, multi-stakeholders' initiatives, new programmes as "Electrifi" and the European External Investment Plan for Africa (EEIP).

The fifth Africa EU summit in November 2017 was a critical opportunity to develop the Africa-EU-Partnership, particularly in the strategic fields of investment promotion in clean energy, and energy efficiency.

3.6.2. The New Blending Facility "Electrifi"

The focus of "Electrifi", which will be managed by FMO (Entrepreneurial Development Bank, the Netherlands), is on addressing the electricity needs of populations living in rural undeserved areas and areas affected by unreliable power supply. Electrifi encourage the adoption of decentralized and renewable energy solutions.

It will supply development finance, debt, quasi-equity, equity and guarantee but not concessional loans and other low-cost capital.

In equity, Electrifi will provide 50 % of the equity portion of the project, which should be approximatively 30 % of total project size. Electrifi will support early stage development projects providing grant and seed capital for the structuring of feasible and bankable projects. Grant will be converted into subordinated debt when reaching project milestones.

- Debt mezzanine: loans up to 12.5 % of total projects;
- Size of investment: 500 K-10 M€.

The objective is to catalyze other investments by investing in riskier projects and taking riskier position in the capital structure and/or offering more flexible repayment terms than other investors.

Electrifi is funded by the European Commission and "Power Africa" with an initial amount of EUR 115 M, 75 M of which by the EU.

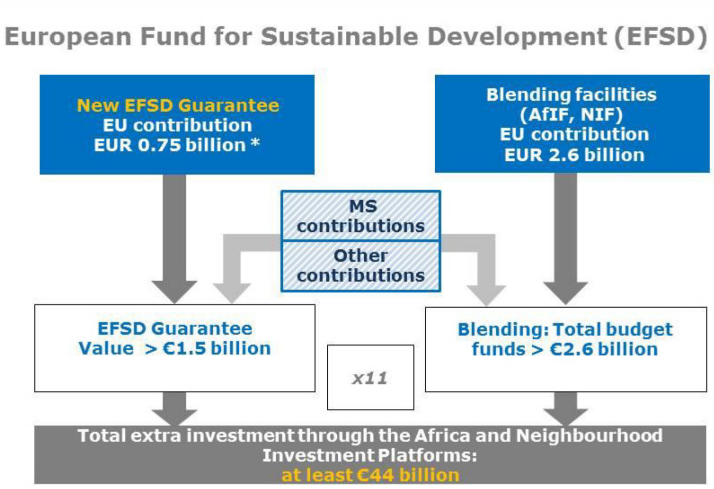
The EIB is the main instrument of Europe to support infrastructure and energy projects. Sustainable energy is a key priority for the EIB in Africa. Almost a quarter of recent EIB operations in sub-Saharan Africa, and over a third of recent operations in North Africa, are in support of the energy sector. The EIB offers both finance and technical assistance for projects which help meet Africa's need for accessible and efficiently-used energy, whilst developing the continent's considerable renewable energy potential (EIB 2016).

The EIB has provided over two billion euros of annual financing to Africa mainly, up to now, through the "Infrastucture Facility" and the "Investment Facility".

In the future and in collaboration with other DFIs, the EIB should continue to be the pivotal instrument for the promotion of investment and economic partnership in Africa.

3.6.3. The EEIP for Africa

The EEIP (European External Investment Plan) is built according to the model of the Juncker Plan at European level (fig. 4).



* Plus a EUR 0.75 billion contingent liability.

Fig. 4. — New partnership framework. External investment plan (*source*: EU Commission, DG for International Cooperation and Development: Presentation of the EEIP).

According to its initiators, it should generate massive EU investments in Africa. It is expected that it should progressively be able to:

— Leverage forty-four billion euros of investments. The investment vehicle will be based on a €1.5 billion budget from the EU and €1,85 billion from the European Development Fund. It will be supported by a structured dialogue with the European and African private sector under a "Sustainable Business for Africa" (SB4A) platform. Synergies will be sought with similar national initiatives by EU member states and at multilateral level, in particular with the G20 "Compact with Africa".

— Tackle the root cause of migration through the promotion of sustainable projects providing jobs for young generations.

— Support Africa's digital agenda, focusing on the deployment of e-governance services, initiatives and investments that facilitate the development of agribusiness through access to and use of market, climate and environmental data, and on the development of open digital research environment to foster skills and knowledge.

The EEIP will be based on three pillars supposed to work in synergy (fig. 5):

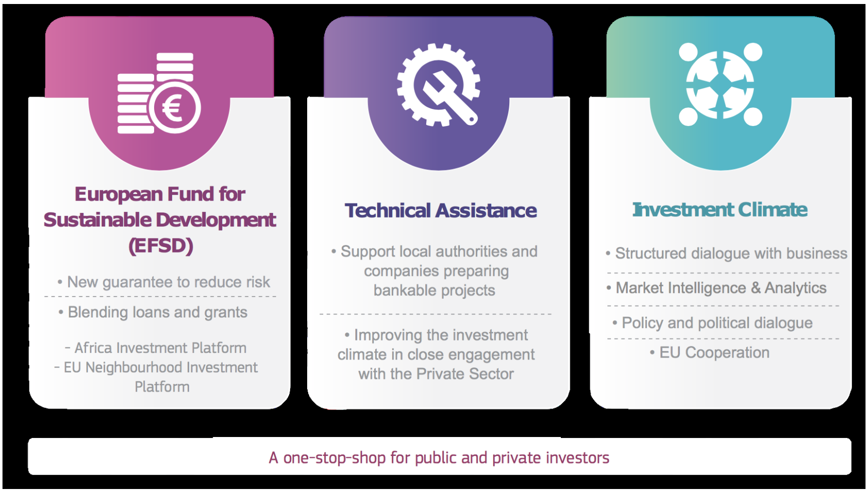


Fig. 5. — The three pillars on which the EEIP will be based.

- EFSD (European Fund for Sustainable Development) offering a full range of new mechanisms: guarantees, blending facilities and other forms of risk mitigation mechanisms aiming at:
  - leveraging additional financing;
  - crowding in private investment.

  The EFSD guarantee will be mainly managed through thematic and geographic “investment windows”; renewable energy will be one of the thematic approaches.
- T.A. (Technical Assistance) for the preparation and launching of projects.
- Investment Climate for political and policy dialogue for economic reforms helping local and regional authorities to design coherent strategies, institutional and regulatory reforms.

A digital one-stop-shop/web portal will give a single and simple entry point for partners investors and private sector.

The process will be supervised by:

- A strategic board giving the general orientations and composed of the EU Commission, EU member states and observers;
- An operational board with the participation of the EU-EDFIs (European Development Finance Institutions);
- A secretariat, managed by the EU Commission.

ESFD Main Characteristics:

1. The EFSD will be the main instrument of the EEIP. It will be composed of two regional investment platforms, which will support investments and increase access to financing, primarily in Africa and the European neighborhood. It will do so by supplying financing capacity in the form of grants, guarantees and other financial instruments, including blending, with the total foreseen budget of 3.35 billion euro, with a potential to mobilize up to 44 billion euro of investments. Its management will be ensured by the European Commission in close cooperation with the European Investment Bank.
2. The fund will operate as a “one-stop shop” to receive financing proposals from financial institutions and public or private investors and deliver a wide range of financial support to eligible investments.
3. The regulation also establishes an EFSD guarantee and a guarantee fund. This will allow the EU to provide guarantees to eligible counterparts for specific financing and investment operations. The EFSD guarantee fund will constitute a liquidity cushion from which eligible counterparts would be paid in the event of a call on the EFSD guarantee. Resources for this fund will come from the general budget of the EU, voluntary contributions from member states, returns on invested resources of EFSD guarantee fund, amounts recovered from defaulting debtors and any other payments received by the EU as part of the guarantee agreements.

4. Main Conclusions

- Thanks to its enormous potential in renewable energy and the technology revolution underway, “emerging Africa” is virtually in a position to leapfrog dirty energies to base mainly the future of its economic development upon clean, cheap and renewable energy.
- The needs for investments in the clean energy sector in Africa are enormous and request peace and stability, coherent policies, favourable business environment, and involvement of the private sector, namely through appropriate PPPs capable of mitigating risks and able to mobilize domestic, regional and international resources.
- Big hydropower projects and decentralized approaches are complementary but require specific tools and approaches to be financed, implemented and managed.
- Domestic and foreign resources can be mobilized through EDFIs, green bonds, sovereign funds, private investment funds, insurance companies, pri-

vate foundations, crowd-funding schemes thanks to various blending and guarantee schemes.

- International (multi, bi and regional) initiatives, in line with the SDGs and commitments subscribed at the COP21 in Paris to develop clean energy in Africa, are currently burgeoning but their real degree of complementarity, convergence, additionality and impact is sometimes difficult to assess.
- The same observation can be made at the level of the EU which, in parallel with the actions conducted under the EU-ACP framework and the Cotonou Agreement, has developed a specific political and economic partnership with Africa (JEAS), namely in the field of energy with the "Africa-EU Energy Partnership".
- Confronted with the migration problems and the competition with China concerning Africa's development, Europe intends to develop new PPPs to encourage private investment in Africa, namely through the EEIP for Africa based on the Juncker investment plan's model.
- If the intentions appear excellent, the envisaged modalities of implementation of the EEIP for Africa still look relatively complex and bureaucratic whereas an efficient permanent mechanism of dialogue with the private sector at European and African levels has still to be properly fixed.
- Despite a long and diversified experience of cooperation with Africa and a real desire to introduce a sustainable energy dimension in all domains of its cooperation with Africa, the EU still experiences certain difficulties to be really proactive, pragmatic and sufficiently reactive to seize strategic opportunities such as the ones offered by the development of the Inga site or the main economic corridors and basins that will structure the landscape of the regional integration in Africa in the future.
- One of the key challenges will also be to ensure sufficient mobilization of the resources needed at private and public levels without triggering a new unbearable spiral of external debt as it was the case in the 1970s and 1980s. From this point of view the merits of "Debts-Project Swaps" may in certain cases be a possible alternative to debt cancellation. To limit the risk of non-reimbursement of its loans in the infrastructure sector in Africa, "Infrastructures-Real Assets Swaps" have been developed by China since the beginning of this century. This helped China mobilize sufficient resources to become, in 2017, the first external direct investment provider in the African continent before the EU and the USA (*cf.* the 2017 report of the *Financial Times* on investment in Africa).
- In its own interest and if it wishes to really remain one of the important partners of "emerging Africa", the EU, with its member states, has to rapidly develop long-term visions and coherent, dynamic, proactive approaches in the field of PPPs.
- Risk lowering for private investment and the partial redefinition of the public aid concept and role at the level of the OECD/DAC could also be key factors

to allow the EU to contribute efficiently to the rapid emergence of a post-carbon economy in Africa.

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Sustainable Energy Mix for Africa and MENA Region Countries

by

Mustafa El Tayeb* & Idris Eisa El Tayeb**

Keywords. — Renewables; Fossil Fuels; Nuclear Energy; African and MENA Region Countries.

Summary. — This paper reviews the current applications of energy technologies from renewables, fossil fuels and nuclear energy in specific African and MENA (Middle East and North Africa) region countries. The results indicate that Africa is rich in many energy resources but poor in energy availablity, supply and most of the energy resources are not yet fully utilized. Most people in sub-Saharan regions face severe energy poverty and extreme supply shortages. The low availability of energy services hampers the economic development of the countries in the region. North-African, other MENA (Gulf) countries and South Africa are major exceptions with significant higher levels of electrification and overall energy consumption. Meeting the current and future energy demand is the major challenge to all African and some MENA region countries. This paper highlights some successful stories in specific countries. The last chapter focuses on the necessary policy, strategies and the transformations needed in the energy sector structures, legal framework, and financial challenges that lead to implement optimal and sustainable energy mix programmes (of renewables, fossil fuels and nuclear) for African and MENA region countries.

ABBREVIATIONS

EIA	Environmental Impact Assessment
GCC	Gulf Cooperation Council
GHG	Greenhouse Gas
GWe	Gigawatt electrical
HEU	High-Enriched Uranium
IAEA	International Atomic Energy Agency
INIR	Integrated Nuclear Infrastructure Review
IPP	Independent Power Producer
IRP	Integrated Resources Plan
IUEC	International Uranium Enrichment Centre
LEU	Low-Enriched Uranium
Mt	Megatonnes

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* Member of the Academy; president of The Future University, P.O. Box 10553, Khartoum (Sudan).

** Department of Microbiology and Immunology, Faculty of Medicine, University of Khartoum, P.O. Box 102, Khartoum (Sudan).

MW	Megawatt
NECSA	Nuclear Energy Corporation of South Africa
NIP	National Infrastructure Plan
NNEECC	National Nuclear Energy Executive Coordination Committee
NNR	National Nuclear Regulator
NPC	South-African Council for the Non-Proliferation of Weapons of Mass Destruction
NPT	Treaty for the Non-Proliferation of Nuclear Weapons
PBMR	Pebble Bed Modular Reactor
PWR	Pressurized Water Reactor
RES	Renewable Energy Sources
Safari-1	South-African Fundamental Atomic Installation
tU	tonnes Uranium
TWh	Terrawatt hours
ZAR	South-African Rand

1. Introduction

Most people in sub-Saharan Africa face severe energy poverty. The low availability of energy services hampers the economic progress and development of the countries in the sub-Saharan region. North-African, Gulf countries and South Africa are major exceptions with significant higher levels of electrification and overall energy consumption. Meeting the current and future energy demand poses a major challenge in all African countries.

Africa's energy sector is poorly developed. For most people, energy is not accessible, unreliable and unaffordable. The total grid capacity of about 158 GW in 2012 (IEA 2014) is less than Germany's power generation. Smart sustainable mixed systems of energy resources is the wayout for Africa's critical energy situation in order to grow in phase with the world.

Currently more than 50 % of African people have no access to power on daily basis. The current conventional grids of the countries will not meet the massive growing demand. So, private sector involvement, small-scale energy projects and renewable energy technologies must be developed to help fill the shortfall. This implies that African countries' governments must create enabling policies and encouragement to allow private sectors to spur growth in the power sector.

The inclusion of independent private sector power producers in the national African countries grids can rapidly step up and improve the energy supply level.

Africa's economy is growing at unprecedented speed. One of the core challenges as African countries continue to grow and develop is energy: meeting rising demand for power, transport and other uses in a way that is economically sustainable and safeguards livelihood. Economic growth, changing lifestyles and the need for reliable modern energy access are expected to require energy supply to be at least doubled by 2030 according to Africa 2030 Energy Plan. For electricity it might even have to triple.

Africa and MENA region are rich in renewable energy sources, and the time is right for sound planning to ensure a right and sustainable energy mix programme for the countries. Decisions made today will shape the continent's energy use of decades to come.

2. Renewable Energies Potential, Technologies and Constraints

Africa 2030 renewable energy programme is part of IRENA's global RE map 2030 analysis, which outlines a roadmap to double the share of renewables in the world energy mix within the next fifteen years. It is based on a country-by-country assessment of energy supply, demand, renewable energy potential, and practical technology choices for households, industry, transport and power sectors. The results are shown for the five African regions.

Africa 2030 analysis has identified modern renewable technology options across sectors, across countries, collectively contributing to meet 22 % of Africa's total final energy consumption (TFEC) by 2030, which is more than a fourfold increase from 5 % in 2013. The key modern renewable energy technologies with the highest deployment potentials for Africa are: hydropower, modern biomass technologies, solar energy, wind energy, and geothermal energy.

If the RE plan 2030 options are implemented, then the share of renewables in the generation mix could grow to 50 % by 2030; hydropower and wind capacity could reach 100 GW capacity each; solar capacity will be over 90 GW. For the power sector the above-mentioned would be an overall tenfold renewable energy capacity increase from 2013 levels. And it would result in a reduction of 310 Mt of carbon dioxide (Mt CO_2) in emissions by 2030 when compared to the baseline. In all regions of Africa except the north, hydropower will continue to play an important role. Northern, Eastern and Southern Africa can all generate power from wind energy. While concentrated solar power (CSP) matters specifically in North Africa, geothermal sources are available in East Africa. Solar photovoltaics (PV) will suit very well northern and southern regions of Africa. This transformation would require on average seventy billion US$ per year of investment between 2015 and 2030 (EE map 2030).

Whilst the power sector is the most visible candidate for an energy transformation, opportunities in the heating and transport sectors are also significant. A complete overhaul of Africa's energy supply will require increased renewable energy penetration across the three sectors, and would provide enormous socio-economic benefits. One of the main ones would be the reduced reliance on the traditional use of biomass — typically foraged wood in inefficient cookstoves.

Modernizing biomass use is not only beneficial for the economy but it will also improve human health (Sudan case) and release women and children from foraging to find enough supply of firewood. RE map 2030 has identified options (modern biomass use) that reduce the use of traditional cookstoves by more than 60 % by 2030 (compared to 2013).

Modern renewables also offer great potential in empowering local communities. These resources can be harnessed locally at a small scale, contributing to rural development and electrification without the cost of extending national grids to remote places (case of Kenya and Sudan).

2.1. Role of Renewable Energy Technologies

Renewable energy accounted for about 16 % globally of final energy consumption in 2010 and about 50 % of new electricity generation capacity. Recently, renewable energy has gained attention in Africa for several reasons:

- The high volatility, increasing prices of fossil fuels, especially oil, and the high cost of grid extension;
- There is a growing demand for energy in the region, and renewable energy systems offer cost-effective options to provide off-grid energy supplies to isolated and remote areas;
- Fossil fuels are a major source of GHG emissions;
- Africa has a large potential for developing its substantial renewable energy resources, which include hydropower, biomass, solar, wind, and geothermal energy.

2.2. Renewable Energy Offers Gulf Countries a Proven, Home-grown Path to Reducing CO_2 Emissions

The six GCC countries are in the top 14 per capita emitters of carbon dioxide in the world; renewables offer a financially viable way to change that. There is also growing pressure to protect the Gulf's fragile environment.

Solar power generation fits very well with demand patterns where air conditioning dominates the electricity demand curve, particularly in the GCC. Growing a renewable energy industry in the Gulf will move the world closer to realizing the potential of renewable energy as a fuel source.

In the coming decades, MENA countries will continue to grapple with how to meet the rapidly-growing demand for electricity. Demand in the region is expected to continue to grow by around 6 % over the next ten years (RE map 2030), which is double the expected world average rate. To solve the growing energy demand problem in the region, reforming domestic energy prices is the most economic way, to slow the growth in domestic demand and improve energy efficiency.

Large-scale renewable energy systems could help diversify energy supplies, reduce energy imports, and help mitigate climate change at local and global levels.

Small-scale renewable energy is useful in off-grid applications and stand-alone systems. These aim to increase access to modern energy in areas that are too far from the grid.

3. Prospects and Constraints of Fossil Fuel Technologies

Fossil fuels are the major sources of revenue for the oil and gas producing countries in Africa, accounting for 50-80 % of government revenues in these countries.

Oil exports account for about 80 % of government revenues in Nigeria and Angola while natural gas exports account for about 60 % of revenues in Algeria.

Africa’s large fossil fuel reserves provide important opportunities to improve access to energy, accelerate economic growth, and reduce poverty (tab. 1).

Table 1
Fossil fuel reserves in Africa

Energy type	Reserves	Regional distribution
Crude oil	132.1 billion barrels	Northern Africa: 53.2 % Western Africa: 28.2 % Central Africa: 16.9 % Other Africa: 1.7 %
Natural gas	14.7 trillion m^3	Northern Africa: 55.8 % Western Africa: 36.1 % Other Africa: 8.2 %
Coal	31,696 billion tonnes	Southern Africa: 95.2 % Eastern Africa: 1.6 % Other Africa: 3.2 %

The proven crude oil reserves in Africa are increasing. They have increased from 58.7 billion barrels in 1990 to 132.1 billion barrels in 2010. The recent increases in crude oil prices have made it more economic to explore and develop ‘marginal’ deposits.

Europe and China are currently the main partners for Africa. It is now evident that China has turned to Africa to meet its increasing fossil fuels accounting for about 82 % of total electricity generation, of which 41 % is supplied by coal and 28 % by natural gas (figs. 1, 2).

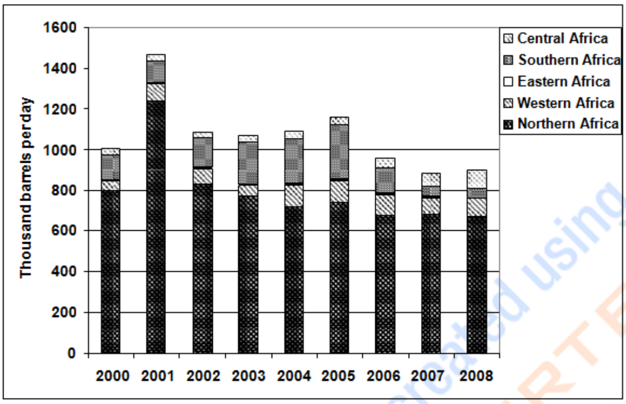

Fig. 1. — Share of exports of refined petroleum products per region in 2000-2007.

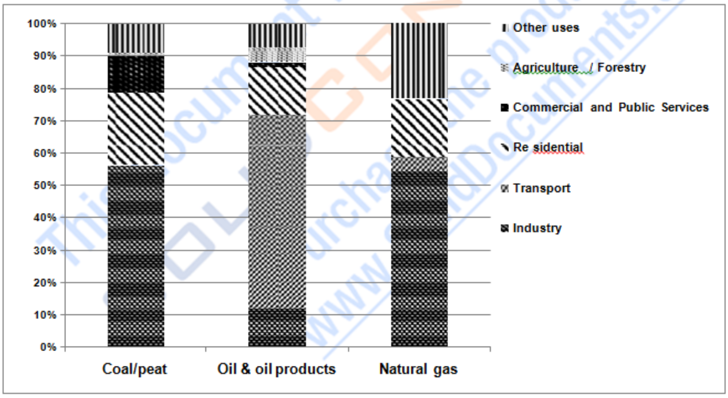

Fig. 2. — Sectorial consumption of fossil fuels in 2008.

4. Nuclear Energy Technologies Applications, Prospects and Constraints

4.1. INTRODUCTION

Nuclear power today is used only in a small part of Africa's energy supply, but its contribution will grow in the future. This section elaborates on challenges associated with expanding nuclear electricity production in Africa, on possible ways forward, and on the range of assistance that the International Atomic Energy Agency can provide. For all its member states, the agency can assist in building national capabilities in overall energy analysis, energy strategy and development & training.

For countries wishing to pursue a nuclear power programme, it assists in planning, evaluating options and infrastructure development. Finally it assists at the stage of deployment and subsequent operations. For near-term progress in Africa, it will be necessary to bridge the gap between the economies of scale that favour large nuclear plants and the smaller electrical grids and capital capabilities of many African countries.

Possibilities are, first, new small- and medium-size reactor designs and, secondly, integration of electricity grids among neighbouring countries. Of the four hundred and forty nuclear power plants operating around the world today, only two are in Africa: Koeberg-1 and Koeberg-2 in South Africa.

The South African government has announced its intention to expand nuclear energy as part of the country's total energy mix. Its proposal is to build a 'fleet' of six new nuclear power stations, together expected to add 9,600 MW to South Africa's power generation capacity, by 2020.

As a major emitter of GHG, largely generated by its coal-fired power stations, South Africa has undertaken to reduce its carbon emissions by 34 % in 2020 and 42 % by 2025.

South African public opinion on the nuclear future is influenced by factors mainly related to concerns about the cost, security and safety of nuclear energy.

4.2. MENA Region Nuclear Energy Programme

Several MENA countries have announced plans to embrace nuclear power as part of their future energy mix. The United Arab Emirates (UAE) is ahead of its peers in building the first Arab nuclear power plant and becoming the first country in twenty-seven years to start constructing its first reactor. As these countries seek to meet their growing energy needs, they are forced to weigh the highly-contested costs and benefits of nuclear power. Over the next decade, new nuclear power plants are scheduled to be operational throughout the MENA region (tab. 2).

Table 2

Future nuclear reactors in some Arab countries

Country	Capacity	Expected date of production
UAE nuclear units	5.6 GW	First unit: 2017 Final unit: 2020
Saudi Arabia (1 unit)	17 GW	First unit: 2022 Final unit: 2032
Jordan	2,000 MW	By 2023
Egypt (4 units)	1,200*4 MW	Over the next twelve years
Morocco, Tunisia, Algeria	Research reactors since 1990	Under assessment
Kuwait, Oman, Qatar	Cancelled their programmes	

Transformations needed in MENA region for the nuclear energy programme call for:

— Motivation;
— Global overview;
— Capacity of the country grid;
— Economic cost;
— Subsidies;
— Social cost;
— Decommissioning;
— Waste;
— Water;
— Institution and domestic reform.

4.3. PROSPECTS OR BENEFITS OF NUCLEAR ENERGY TECHNOLOGIES

It is true that nuclear energy is a superior source of electricity generation compared to fossil fuels in terms of climate impact. Nuclear energy's superiority stems from the fact that it does not depend on the availability of sun or wind, which are intermittent, or water, which is constrained.

Scale is another advantage: one power plant can produce enough electricity to light half of a country. In Slovenia, for instance, only one operating nuclear reactor supplies approximately 40 % of the country's total electricity needs.

The cost of electricity generation, once the initial investment cost has been amortized, is very competitive with other sources of energy.

Compared to other energy sources used for electricity production, nuclear power plants use moderate amounts of water and minimal land per amount of electricity produced.

5. Some of the Successful Projects in Specific Countries

Here are some examples of successful projects taken from Kenya, Morocco, South Africa, Egypt and Sudan (figs. 5-11).

Fig. 5. — Improved cook stoves in Kenya.

Fig. 6. — Wind Farms, Kenya.

Fig. 7. — Successful projects in Morocco.

Fig. 8. — Solar PV and solar concentrators’ plants, Morocco.

Fig. 9. — Successful projects in South Africa.

Fig. 10. — Solar concentrators, South Africa.

Fig. 11. — Wind farm, South Africa.

The largest successful wind farm in the world is in Egypt. The Gulf El Zayt wind farm has a capacity of 200 MW, containing one hundred turbines of 2 MW each (fig. 12). The farm produces 800 GWh/yr, enough for five thousand families.

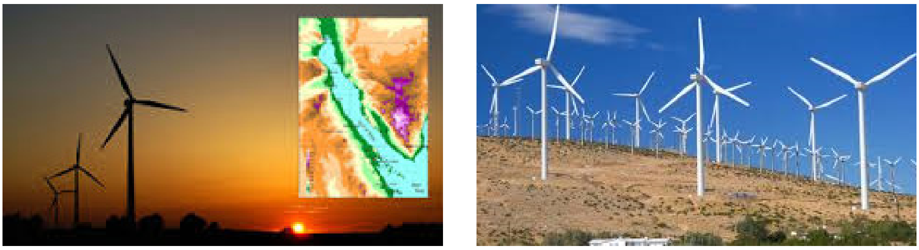

Fig. 12. — Gulf El Zayt wind farm, Egypt.

Among successful projects of small-scale renewable energy systems in Sudan, let's mention solar PV systems applied for the following: solar dryers, solar pumps, SHS, solar fridges, solar street lights, etc. (figs. 13-15).

Fig. 13. — Solar dryers, Sudan.

Fig. 14. — Solar street lights, Sudan.

Fig. 15. — Solar pumps, Sudan.

Improved cook stoves are nearly similar to those in Kenya with improvement to suit the local tradition and conditions. The improved stove is known as El Surour, disseminated all over the country, and manufactured from local material, using local skills (fig. 16).

Fig. 16. — Improved cook stoves, Sudan.

Solar evaporators is a famous success project, using solar heat to evaporate salted water. The concentration of salted water is of more than 5,000 ppm, in a Gaah village in the west of Sudan about 600 km from Khartoum. The project was initiated by UNDP (United Nations Development Programme) in 1995. The work was performed completely by women in the village, using firewood to boil the salted water for more than two hundred years. Currently they are using simple solar evaporators and this has resulted positively to the environment and women health (fig. 17).

Fig. 17. — Solar evaporators, Sudan.

6. Recommendation of Sustainable Energy Mix Programme for Africa and MENA region

Policies, strategies and transformations are needed at the national and regional levels of electric grids and energy sectors of the countries for implementing a successful optimal energy mix programme of renewables, fossil fuels and nuclear energies. The involvement of independent private sector power producers in the national African countries' grids is essential; it can rapidly step up and improve the capacities of poor energy supply in most of the countries.

Renewable energy systems could be employed in the form of large- or small-scale systems for electricity generation, heating, mechanical power, and other applications.

The short-term programme would consider the implementation of projects that have proven track records and that maximize the use of local resources, expertise and available grant finance. Some of the mentioned barriers to RES development could also be addressed in the short-term programme. Typical projects that could be implemented under the short-term programme would include the following:

- Biomass-based cogeneration;
- Geothermal energy;
- small-scale renewables (improved cook stoves and kilns, solar dryers, solar water heaters, wind pumps, small hydro).

The long-term programme would build on success from the near-term fast track programme to develop medium- and long-term initiatives. It would rely largely on ongoing and planned energy sector reforms to establish an enabling environment that would attract bilateral/multilateral as well as private finance for major investments in both national and regional RES projects. Examples of such projects include:

- Large-scale wind power projects;
- Large-scale urban waste-to-energy projects;
- Long-term capacity building and training, policy and financing;
- Climate change assessment programmes.

Large-scale renewable energy systems are usually connected to a grid and thus are normally financed through public funds (*i.e.*, national budgets).

Small-scale renewable energy is usually used in off-grid applications and standalone systems. These aim to increase access to modern energy in areas that are too far from the grid or that are too costly to connect to it.

6.1. Facts to be Considered in Renewable Energies

Regardless of the increasing urban drift, the population in Africa is still mostly rural (59.6 % in 2011) and the access of population to electricity is still limited to 22.7 %.

Sub-Saharan Africa is in an especially difficult situation, with 99.6 % of population without access to electricity living in this group of countries.

Network infrastructures (electricity grids and roads), particularly in sub-Saharan Africa, are still underdeveloped and there is a general lack of detailed data on their deployment and expansion plans.

In such a situation, renewable energies, some of which showing a very interesting potential, are requested to play different roles in Northern Africa and sub-Saharan regions. In Northern Africa, renewable energies have to compete with cheap and sometimes heavily subsidized fossil fuel predominance in a usually mature infrastructure context. On the contrary, in sub-Saharan areas, the main challenge faced by renewable energies in this context consists in pushing energy production towards an increased sustainability. Well-managed wood-fuel sources can be sustainable, but growing demand for fuel wood and charcoal, in particular due to urbanization, currently causes a net loss of wood resources.

Finally, the fact that, compared to the rest of the world, there is a general shortage of energy-related information in Africa has to be reminded. This lack of information is even more apparent for renewable energies and the large uncertainties caused by such a scattered validated information availability should be kept in mind whenever the potential for the different energy options are compared.

In this context future research lines could focus on the following issues:

- Data gaps coverage: investigation and analysis are needed to obtain harmonized and consistent data and statistics for the African continent.
- Resource assessment: for some energy sources (*e.g.* biomass) a systematic resource assessment taking into consideration availability, exploitability and sustainability of potential energy has not been developed. In the case of biomass, such an assessment should consider the traditional four Fs (food, feed, fiber, fuel) approach to competing uses with in addition an ongoing growth of chemistry and biomaterials, also considering biomass from the three main categories of forest, agriculture and waste.
- Climate change: known to have mid- and long-term effects on renewable energy resources availability as it is expected to affect directly or indirectly (*e.g.*, through changing precipitation patterns) most of the physical variables at the basis of renewable energy availability.

6.2. Fossil Fuel Technologies Applications

Today, the bulk of energy needed for many applications in Africa is largely met by fossil fuels. These resources account for about 50 % of the total primary energy supply and one third of energy consumption (excluding the contribution to electricity generation) on the continent. Over 80 % of the electricity generated across Africa is from fossil fuels.

These energy resources are also a major source of export earnings for the major oil- and gas-producing and -exporting countries in Africa, including Nigeria and Angola. Despite having huge energy resources, the continent is faced with enormous challenges.

6.3. Nuclear Energy Technologies Applications

As stated earlier, the only African country with nuclear power plants is South Africa, whose plants have been installed this year. So, by now, South Africa has gained valuable theoretical and practical experience. In their IRP energy plan for 2010-2030, they are planning to build more modified modern nuclear reactors of about 9.5 GW, based on the following criteria:

- National position on nuclear power;
- Nuclear safety;
- Management;

- Legislation;
- Funding and financing;
- Safeguards, regulatory framework;
- Radiation protection;
- Electrical grid;
- Resource development;
- Stakeholder involvement;
- Siting and support facilities;
- Environmental protection;
- Emergency planning;
- Security and physical protection;
- Nuclear fuel cycle and radioactive waste;
- Industrial involvement and procurement structures.

As far as the future nuclear programmes of the MENA region are concerned, the IAE (*Institut d'administration des entreprises*) reported about UAE's nuclear power plants and stated that: "the UAE's experience with developing a national nuclear infrastructure and its establishment of a regulatory framework and system has been impressive".

Some MENA governments are full of praise for nuclear power and this is encouraging. As stated by UAE Nuclear Energy Corporation: "Nuclear energy is the right choice for the UAE because it is a safe, clean and proven technology, it's commercially viable, and it delivers significant volumes of base-load electricity".

7. Conclusions and Recommendations

- African countries support renewable technologies, which are seen as the most economic option;
- Africa is rich in renewable energy sources, such as solar, wind, biomass, hydro and geothermal energies;
- Africa 2030 renewable energy programme is part of IRENA's global RE map 2030 analysis, which outlines a roadmap to double the share of renewables in the world energy mix by 2030.

Nuclear energy technologies applications have the following prospects and constraints:

- The construction, operation and maintenance of nuclear reactors require massive investments;
- Saudi Arabia's planned nuclear power reactors come at an estimated cost of \$80 billion;
- UAE's nuclear power has an estimated cost of \$20 billion;

- Egypt, Jordan and Morocco are planning the construction of nuclear reactors and nuclear plants;
- Decommissioning: the IEA estimates that two hundred currently operating reactors will be retired by 2040, at a cost exceeding $100 billion.

To improve the energy situation in Africa we recommend the following multi-pronged strategy:

- A short-term programme (one-five years) intended to implement low-risk and low-cost near-term initiatives;
- A long-term programme (ten-fifteen years) built around major renewable energy sector initiatives.

The short-term programme would include:

- Biomass-based cogeneration;
- Geothermal energy;
- Small-scale renewables (improved cook stoves and kilns, solar dryers, solar water heaters, wind pumps, small hydro).

The long-term programme would include:

- Medium- and large-scale wind power projects;
- Medium- and large-scale solar projects;
- Large-scale urban waste-to-energy projects;
- Long-term capacity building and training, policy and financing programmes.

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Sustainable Energy Transition: An Operations Research Perspective

by

Per Joakim Agrell[*], Ignacio Andrés Aravena Solís[**]
& Anthony Papavasiliou[*]

Keywords. — African Power Grid; Operations Research; Renewable Energy Transition; Smart Grids.

Summary. — As an interdisciplinary domain that is positioned at the interface of engineering, mathematics and economics, operations research offers a ubiquitous set of methodologies for comprehensively addressing the engineering, institutional and economic challenges that result from the transition to sustainable energy systems. With its unique renewable energy potential, Africa is ideally positioned for a sustainable energy transition, and can be expected to be confronted with an array of challenges that have already emerged in numerous US and European systems. These challenges relate to electric power supply provision at all scales of the supply chain, from the individual household to the community up to the national scale. We provide a discussion of how operations research can be used as a decision-making tool for addressing such challenges from a holistic systems point of view, which accounts for both renewable resources and conventional resources. For a concrete demonstration of the application of operations research, we provide a demonstration on the optimal management of storage for storing solar power supply in Burkina Faso, which was conducted in collaboration with Tractebel-Engie.

1. Introduction

Historically, access to electricity has been pivotal for improving living conditions and increasing productivity in growing economies. Most countries have followed essentially the same path to achieve global electricity access since the 1900s [see, for instance, the parallel between USA (Tuttle *et al.* 2016) and India (Central Electricity Authority 2016)]. This path consists of three steps:

— Building isolated networks;
— Interconnecting these networks to improve their efficiency and reliability;
— Building larger and more efficient power plants to meet the demand of the interconnected grid.

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[*] Center for Operations Research and Econometrics (CORE), UCLouvain, Voie du Roman Pays 34 – L1.03.01, B-1348 Louvain-la-Neuve (Belgium).

[**] Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA 94550 (USA).

The increasing awareness of human-made climate change alongside advances in communications over the last twenty years have motivated a fourth development step in mature networks: the transition of power systems towards renewable energy supply and smart grids. Growing economies without a mature power grid have the opportunity of skipping the historical development steps and leapfrog towards renewable energy and smart grids directly. This will allow growing economies to harness the environmental benefits of supplying their growing demand for electricity using renewable energy resources and to avoid investing in infrastructure that will have to be retired when transiting to renewable energy later on, as is currently the case of coal power plants in Germany (Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety 2016).

In this white paper, we present an operations research perspective on the transition towards renewable energy and smart grids for growing economies, with a focus on the case of Africa. Our vision is to use operations research for facilitating this transition by developing planning and operation decision tools for future power grids. The document is organized as follows. Section 2 presents power systems under the current and future paradigms, and analyses the current state of power grids in Africa. Section 3 introduces operations research and outlines applications of operations research in power systems. Section 4 presents an application of operations research for managing a solar power plant and storage units in Burkina Faso. Section 5 concludes this document and provides directions for future development.

2. Power Systems

Electricity plays a key role in modern life, powering virtually every household appliance, every governmental, production and healthcare facility, sanitary service, communication network, etc. In all these applications, we tend to understand electricity as a commodity with high reliability and relatively low cost. Power systems, nevertheless, are currently undergoing a major transformation due to the incorporation of renewable energy resources, smart devices and communication technologies, which will change the way we use and understand electricity. In order to better elaborate on the implications of this transformation, we briefly summarize the characteristics of current and future power grids, and the current state of power systems in Africa, with special attention to the challenges and opportunities that this transformation presents to the continent.

2.1. Traditional Power Systems

The outline of a traditional power system consists of three main levels, schematically presented in figure 1: (*i*) large central electricity generators, (*ii*) a high-voltage transmission grid connecting electricity generation and demand nodes, and (*iii*) a low-voltage distribution grid to which most consumers are connected (Fang *et al.* 2012).

High-voltage transmission grids are typically highly meshed, providing several paths for electricity to arrive at distribution centres. Lines in the high-voltage grid typically experience bidirectional flows (*e.g.,* energy can flow from terminal 1 to terminal 2 or vice-versa) because of multiple production facilities installed throughout the grid and laws governing power flows. Low-voltage distribution grids, on the other hand, are typically radial and distribution lines present flows in a single direction: towards consumers.

Production scheduling in traditional power systems considers consumers as passive agents, *i.e.* their demand is simply forecasted in an aggregated and assumed inelastic way. In real time, the system is managed centrally by a system operator that continuously monitors the system status, and uses production and transmission control actions to ensure reliable operations while meeting the demand.

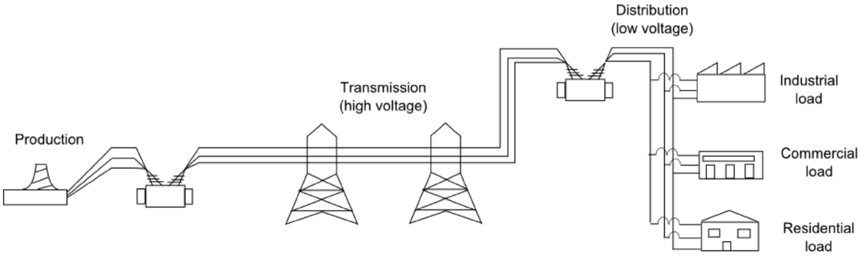

Fig. 1. — Conventional power systems, characterized by a unidirectional flow of energy.

2.2. Future Power Systems: Smart Grids

Smart grids incorporate distributed generation (wind and solar PV), smart appliances and a communication layer that covers each element of the grid (Fang *et al.* 2012). We can still distinguish between production, high-voltage transmission network and low-voltage distribution network. However, the flows of energy and information might go in any direction (fig. 2).

The most important difference between traditional and future power grids occurs at the distribution level. In future power grids consumers will inject energy into the grid, react to system conditions, interact with other consumers and distributed generation. In other words, consumers will become prosumers, increasing the number of active players in the energy market from a couple of hundreds to millions. Depending on renewable energy availability, distributed generation and active consumers might even coordinate locally and operate in isolation from the rest of the grid forming micro-grids (Lasseter 2002).

Production scheduling and real-time operations must consider both the effect of distributed generation and active consumers. These problems, then, become intractable at a centralized level for future power systems due to the number of variables that would have to be managed simultaneously. Instead, these problems will be solved at a distributed level (Fang *et al.* 2012), using techniques from distributed optimization and distributed control.

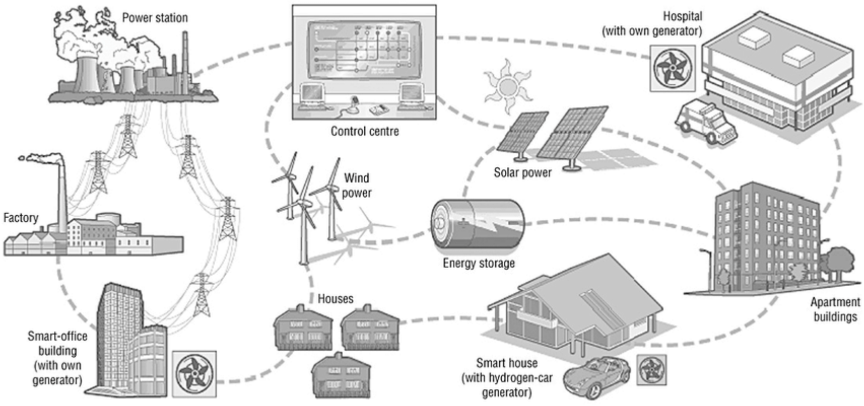

Fig. 2. — The future energy grid (*The Economist* 2004), characterized by a bidirectional flow of energy and information.

2.3. Power Systems in Africa: Challenges and Opportunities

Africa is currently facing a significant energy access gap. At present, more than six hundred million Africans are without access to energy, and this figure is set to increase as population grows on the continent. The capacity generation need for 100 % access of energy in Africa will amount to 600 GW in 2030, whereas the existing projections for power generation capacity deployment are planned to approximately 220 GW by 2030.

Despite the remaining access gap, several countries have interconnected their power networks (Arderne 2017), placing power systems in most African countries between the first and second steps of development, while renewable energy sources are already the most economically competitive form of technology for the continent. There is a clear need and opportunity for Africa to leapfrog towards a renewable energy powered future with access for all citizens. Leapfrogging means avoiding that the African continent be locked into dirty, centralized fossil fuels, and instead jumping to the smart, distributed renewable energy systems of the future (Lucas *et al.* 2017).

In response to this opportunity, the African Renewable Energy Initiative (AREI) was ratified in a joint statement by Canada, France, Germany, Italy, Japan, United States of America, United Kingdom, EU and Sweden on 7 December 2015 (and later joined by the Netherlands), with the goal of mobilizing at least ten billion US$ cumulatively from 2015 until 2020. The specific goals of the AREI are:

- To help achieve sustainable development, enhance human well-being, and support sound economic development by ensuring universal access to sufficient amounts of clean, appropriate and affordable energy for all Africans by 2030;
- To help African countries leapfrog towards renewable energy systems that support their low-carbon development strategies while enhancing economic and energy security.

The first phase of the AREI is set for 2016-2020 and aims at achieving the deployment of 10 GW of renewable power generating capacity by 2020. The second phase spans 2020-2030 and aims at deploying a further 300 GW, which would cover the energy access gap of Africa. Closing this energy access gap would contribute to well-being, thriving local economies, boosting agriculture, medium-size enterprises and productive sectors, creating jobs, improving health, reducing emissions, enhancing energy security, and achieving sustainable development goals.

3. Operations Research in Power Systems

Operations research encompasses a wide range of mathematical methods for making planning and operational decisions for real-world applications. The decision process is modelled as an optimization problem, which can be written as:

$$\min_{x} f(x), \text{ subject to } x \in X$$

where x is the decision vector, X is the feasible set, *i.e.* the set containing all possible decisions, and $f(x)$ is the objective function, *i.e.* a quantity depending on x which we want to minimize. For instance, consider the problem of shopping at a minimum cost in a supermarket: x would correspond to the quantities bought of each good, X to the shopping list and $f(x)$ to the cost in your bill.

Optimization issues can encode a very wide range of decision problems and, as a consequence, optimization issues appear in widely different domains, such as circuit design and economic theory (Boyd & Vandenberghe 2004). This flexibility allows operations research to take a holistic view at decision-making, while still incorporating specific field knowledge in the formulation of optimization issues.

3.1. A Brief History of Operations Research

Although optimization issues date back to the time of Newton, operations research as a discipline on its own started with the simplex method by G. Dantzig in 1947 (developed while working for the US Army Air Force during World War II).

This method allowed for the first time to solve linear optimization issues (issues where $f(\chi)$ is a linear function and X is a convex polyhedron). The discipline since then has branched into several subfields, out of which combinatorial optimization and convex optimization have been the most prevalent in power systems applications.

Combinatorial optimization deals with problems where the set X is discrete (for instance, the natural numbers). These problems arise often in practice, when making decisions between a limited number of options. This subfield started with the study of the travelling salesman problem by a group of researchers who included Dantzig himself (Cook 2010). The development of combinatorial optimization oscillated between two ideas to solve combinatorial problems. On the one hand, we have cutting-plane methods, which start with a larger set containing X and gradually introduce additional restrictions until the solution falls into X. These methods were originally used by Dantzig for specific problems and were later generalized by L. Gomory in 1958. On the other hand, we have branch-and-bound methods, which work by enumerating the points in X in a smart manner. These methods were also initially investigated by Dantzig, but their first full version was developed by W. L. Eastman in 1958. Further developments in this subfield include the conception of the polyhedral theory in the 1970s and the discovery of the equivalence between optimization in polytopes and separation of points from polytopes in the 1980s. Current solvers for combinatorial problems work by a combination of heuristics, cutting-plane and branch-and-bound methods, commonly referred to as branch-and-cut algorithms.

Convex optimization deals with problems where the set X is convex (for instance, a sphere) and $\mathrm{f}(\chi)$ is a convex function (for instance, a parabola). Problems of this type often appear when making decisions restricted by the laws of physics. The history of convex optimization is, roughly speaking, the history of interior-point methods (Boyd & Vandenberghe 2004). These are methods that iteratively move from one point in the interior of X to another, while minimizing the objective function. Early interior-point methods were developed in the 1960s and 1970s by A. Fiacco, G. McCormick, I. Dikin and others. However, these methods did not offer guarantees on the number of iterations that will be necessary to get to a solution. The first polynomial-time interior-point methods for a subclass of convex problems (*e.g.*, linear problems) was put forward by N. Karmakar in 1984, while polynomial-time interior-point methods for convex nonlinear problems were developed in the 1990s by Y. Nesterov and A. Nemirovski.

3.2. Long-term and Short-term Optimization Problems in Power Systems

Applications of operations research to power systems operations have been proposed since at least the 1960s (see, for instance, the PhD thesis of L. Garver in 1961). Nevertheless, it was not until computers became available to utilities that these applications started to be implemented by system operators. Nowadays, operations research plays a key role in power system operations both in the long term and short term, saving up to billions with new advances being incorporated into practice (Carlson *et al.* 2012).

Long-term optimization models for power systems are used by system operators to make decisions that impact the system over the course of several years or months. They involve expansion planning decisions, major maintenance coordination (major maintenance of thermal power plants can take a couple of months), hydrothermal coordination, *i.e.* the problem of planning the use of large reservoirs alongside thermal units to supply the system, among others. Hydrothermal coordination is in fact one of the most notorious applications of operations research in power systems. The difficulty of this issue arises from the fact that it needs to be solved by using a long enough horizon to model the cycle of the reservoir (typically a couple of years). Water inflow depends both on rainfall and ice melting, which are unpredictable beyond a couple of weeks. The solution to this problem is achieved by the Stochastic Dual Dynamic Programming (SDDP), a decomposition algorithm at the interface of optimization and simulation, proposed by Pereira & Pinto (1991). This specialized algorithm is the cornerstone of operations planning in hydrothermal systems such as Brazil and Chile.

Short-term optimization models are used both by system operators and utilities to determine how to schedule production/consumption a couple of days or hours in advance. These models are often referred to as unit commitment models. They involve deciding which units should be energized and how much power should be injected to the network over a certain horizon, in order to meet the demand while respecting the laws of physics governing power flows in the transmission system. Unit commitment models are combinatorial problems which were originally tackled by using Lagrangian relaxation, as proposed by Muckstadt & Koenig (1977), a fast method that provided approximate solutions. Advances in combinatorial optimization and the rapid increase in computing power allowed to switch from Lagrange relaxation to commercial implementations of the branch-and-cut algorithms in the early 2000s (Carlson *et al.* 2012). The later algorithm can provide exact solutions and it continues to be used until the present day.

3.3. Optimization Models and Algorithms for Future Power Systems

As previously mentioned, future power systems differ from current ones in that they incorporate significant amounts of renewable energy resources and active participation from agents connected at the distribution grid. Including these new elements into current optimization models leads in general to suboptimal decisions. This has been shown to be the case for expansion planning (Nweke *et al.* 2012) and for short-term scheduling (Tahanan *et al.* 2015), but it can be expected to occur at all decision levels. Therefore, in order to plan and operate future systems, it will be necessary to extend the optimization models for power grids (described in the previous section) and, also, to design specialized algorithms for solving these adapted models since currently available methods and software are unable to solve them in operationally acceptable time frames.

This development is critical for allowing Africa to leapfrog towards future power grids. Contrary to the transition in mature networks, where the existing infrastructure will soften its effects, leapfrogging will change African networks significantly over a short period of time, requiring to make decisions from the planning to the operational levels in a way that takes into account the new technologies to be incorporated into the grid.

A crucial problem to boost leapfrogging is to decide how to expand the transmission network. Given the currently underdeveloped transmission infrastructure in Africa, the decision of how to expand it will have major economic consequences and will be one that will extend for a lifetime of at least thirty to forty years. This is a notoriously difficult problem in power system planning, due to its combinatorial nature. For example, when faced with a project of installing one hundred new candidate lines, a decision-maker would need to examine 2^{100} different possible decisions — a prohibitively large number. At the same time, each mile of new transmission costs about one million US$ to build. The planning of the network needs to ensure that the system can withstand a variety of future scenarios of renewable supply and demand evolutions (*e.g.*, high renewable / high demand, high renewables / low demand, etc.). Finally, contingency constraints need to be satisfied, which ensure that the system can withstand the failure of any single element in the network. The resulting problem is extremely challenging from a computational standpoint and will require the development of specialized algorithms in order to be solved effectively.

Real-time operations represent, perhaps, the most important challenge of future power grids, due to the number of active agents interacting in the system. Current operation models will have to be extended to incorporate agents connected in the distribution grid. Coordination between these agents needs to respect the limitations imposed by the physics of power flows and quality of service standards of the distribution grid (voltage and current limits), none of which is considered by current operations models. While a model incorporating all these elements can be conceptually written, it would not be possible to solve such a model in a centralized manner because of its size: there are tens or hundreds of millions of variables and constraints, while computers can handle up to hundreds of thousands. The mere recollection of all the information to formulate this problem in a centralized manner can be an intractable task within operationally acceptable time frames. Instead, these problems would need to be formulated and solved in a distributed manner (LE CAM 2017), using the cloud to exchange information for coordinating the solution of the different pieces of the problem.

Models and algorithms for future power systems are an active area of research. Nevertheless, advances towards realistic applications and pilots are still rare. The technology in this area must therefore be further advanced, if African networks are to leapfrog towards the grids of the future.

4. Case Study: Scheduling Solar Energy Storage in Burkina Faso

The aggressive renewable energy integration agenda that Africa has embraced is exemplified by a number of large-scale renewable energy projects. In September 2017, Burkina Faso will be electrifying the largest solar installation of West Africa (Le Cam 2017), which is poised to cover 4 % of the country's national consumption once in place. These installations respond to the COP21 commitments of the country, which aim at sourcing 25-30 % of the national consumption from solar power by the horizon of 2025-2030. Senegal is following suit in the deployment of utility-scale solar power projects, with an objective of covering 20 % of its energy needs through renewable energy sources by 2017 (Maillard & Ndiaye 2016).

One of the major challenges in the incorporation of large shares of solar power into the grid is the management of its cyclical nature; in a solar-based power system there is excess supply during the day and shortage during the night. The solution to this problem so far, in countries like Germany, is to balance this excess and shortage of supply by using thermal generators (sometimes, via exports/imports from neighbouring countries). This solution not only is hardly environmentally friendly, but also infeasible for African countries where there is no installed spare capacity that can back up solar power plants. The envisioned solution for balancing solar power is the large-scale deployment of battery storage.

Battery storage is, however, more difficult to manage than thermal power plants. Present decisions will strongly affect the future state of the system, while the future availability of renewable supply and demand is uncertain. This problem is analogous to the problem of scheduling water reservoirs in hydrothermal power systems, which motivates the use of the Stochastic Dual Dynamic Programming (SDDP) algorithm in order to solve it (Pereira & Pinto 1991, Lemaréchal 2001).

4.1. The SDDP Algorithm

Stochastic Dual Dynamic Programming is an algorithm designed to solve multistage optimization problems under uncertainty. The algorithm is based on three core ideas: (*i*) it uses a lattice to encode uncertainty, (*ii*) it constructs policy functions for each stage based on approximations of future costs, and (*iii*) it obtains estimates of performance by simulation over the lattice.

The lattice allows to model an exponential number of uncertainty paths by only looking at a linearly growing number of nodes. In this application, the uncertain parameter is the net demand, which is encoded in a lattice as shown in figure 3. In this lattice, there are nine (3^2) possible paths for only six ($3 \cdot 2$) uncertain nodes. If we add one extra stage, there would be twnenty-seven (3^3) possible paths, for only nine ($3 \cdot 3$) uncertain nodes.

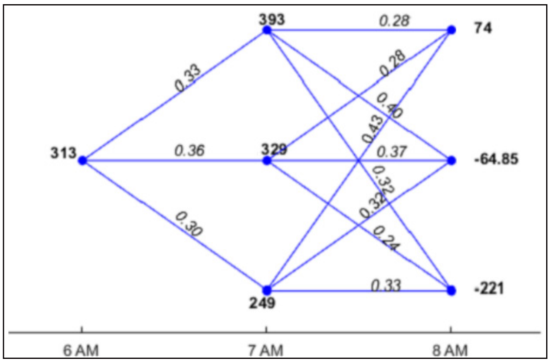

Fig. 3. — Lattice for net demand at sunrise, 6 to 8 am. Labels on each node indicate the net demand value. Labels on each edge indicate transition probabilities between its terminal nodes.

The SDDP algorithm constructs an optimal policy function for each stage iteratively, by solving the problem backwards stage-by-stage, starting from a desired end state (‘backward pass’). The desired end state is in turn determined at each iteration, by simulating forward stage-by-stage over a set of sampled paths, using the available policy functions to decide on the actions to take at each stage (‘forward pass’). Each simulation provides an estimate of the performance of the current policy functions, which is compared against bounds obtained from the backwards evaluation in order to decide on termination.

4.2. Numerical Results

The SDDP algorithm was tested in an instance of foreseen installation for Burkina Faso with 2,400 MW of solar capacity and battery banks totalling 5,000 MWh of storage capacity and 1,000 MW of power capacity, using a lattice with a four-day horizon (ninety-six stages) and ten nodes per stage, for a total of one thousand ninety-six uncertainty paths. The lattice was constructed using time series for demand and solar production for one year provided by Tractebel-Engie. The multistage stochastic problem was solved using the FAST Toolbox (Papavasiliou *et al.* 2018) with Gurobi as linear programming engine.

The policy functions constructed by SDDP were compared against a greedy policy function: charging the battery whenever there is excess supply and discharging it whenever there is shortage. The results of the SDDP policy and the greedy policy for a random uncertainty path are presented in figure 4. The demand is almost always met by both policies. Nevertheless, the SDDP policy manages to supply the demand without resorting to the thermal power plant, while the greedy policy utilizes the thermal power plant every day. Over the entire horizon, the SDDP policy achieves savings of 24 % with respect to the greedy policy.

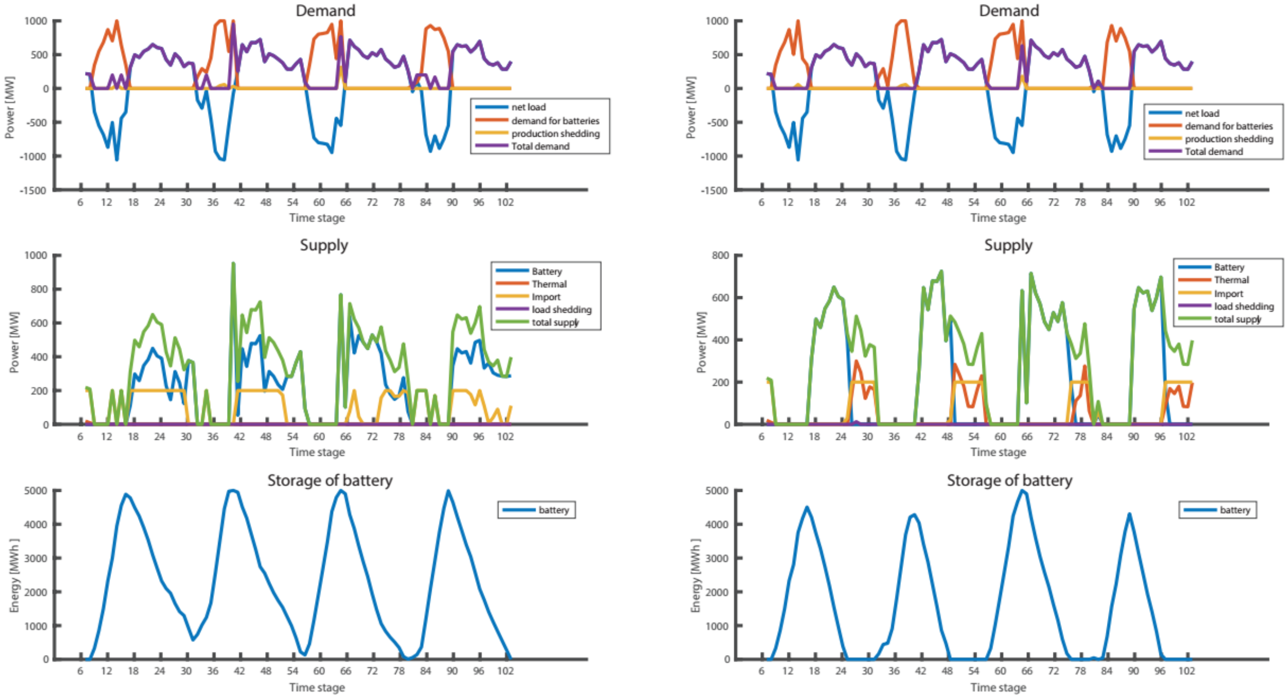

Fig. 4. — Simulation results for a random realization of uncertainty, using SDDP (left) and the greedy policy (right).

5. Conclusion

We have presented a summary of the challenges and opportunities for closing the energy access gap in Africa while simultaneously transitioning towards future power systems. Closing this energy access gap would contribute to well-being, thriving local economies, boosting agriculture, medium-size enterprises and productive sectors, creating jobs, improving health, reducing emissions, enhancing energy security, and achieving sustainable development goals.

It is our vision that operations research can be an enabling tool for this transition, helping to make optimal planning decisions and improving the efficiency and reliability of operations in future power grids.

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Tout ce que vous voulez savoir sur les énergies renouvelables en Afrique[*]

par

Pépin TCHOUATE HÉTEU[**]

La lutte contre le changement climatique implique de plus en plus le passage aux énergies renouvelables. Où en est l'Afrique? Pépin Tchouate Héteu, expert en énergie durable en Afrique, répond aux questions de Glo.be.

INTERVIEW

Environ 1,2 milliard de personnes dans le monde n'ont pas accès à l'électricité. Quelle est la situation en Afrique?

Six cent vingt millions d'Africains — soit environ 70 % de la population — n'ont pas accès à l'électricité, surtout en Afrique subsaharienne. D'ici 2030, ils pourraient être sept cent cinquante à huit cent cinquante millions. Les programmes conçus pour promouvoir l'accès à l'électricité doivent en tenir compte.

Quels sont les projets en matière d'énergie renouvelable en Afrique?

Les énergies renouvelables ont le vent en poupe. Au cours des dix dernières années, elles ont quadruplé. Cette tendance s'inscrit dans le cadre des objectifs ambitieux couverts par l'initiative africaine «Sustainable Energy for All». Toutefois, ces plans ne sont pas coordonnés. Certains États veulent doubler leur capacité, d'autres comme l'Ouganda et le Cameroun produisent déjà 90 % de leur électricité à partir de sources renouvelables, principalement de grandes centrales hydroélectriques.

En ce qui concerne l'énergie solaire et l'énergie éolienne, le potentiel est élevé, surtout en Afrique, mais leur utilisation reste limitée. Non seulement parce qu'elles sont imprévisibles, mais aussi en raison de la capacité du réseau. Afin de maintenir la stabilité de ce dernier, les sources d'énergie imprévisibles peuvent représenter au maximum 20 % de la capacité du réseau.

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[*] Interview réalisée par Chris Simoens, Glo.be pour un monde durable (11 décembre 2017) [https://www.glo-be.be/fr/articles/tout-ce-que-vous-voulez-savoir-sur-les-energies-renouvelables-en-afrique].

[**] Chargé de recherche École polytechnique de Louvain, rue Archimède 1, bte L6.11.01, B-1348 Louvain-la-Neuve (Belgique); directeur DEECC Consulting, rue J. Wauters 41, B-6230 Pont-à-Celles (Belgique).

Les énergies renouvelables en Afrique aujourd'hui sont les suivantes:

- Géothermie (chaleur issue du sol): pour la production d'électricité principalement en Afrique de l'Est (surtout au Kenya et en cours de développement en Éthiopie et en Érythrée).
- Hydroélectricité: presque partout avec un potentiel inexploité.
- Biomasse: principalement en Afrique centrale. Pas encore utilisée pour l'électricité, mais le potentiel est bien présent.
- Énergie solaire (photovoltaïque): omniprésente, mais avec un pic en Afrique de l'Est. Existe non seulement à grande échelle, mais aussi pour des systèmes domestiques plus petits.
- Énergie éolienne: principalement en Afrique du Nord (Égypte, Maroc, Éthiopie, Djibouti, entre autres).
- *Concentrated Solar Power* (CSP): focaliser les rayons du soleil avec des miroirs ou des lentilles. Énergie présente en Afrique du Sud, progressivement étendue à d'autres pays.

Mais les grandes centrales hydroélectriques sont cependant souvent controversées, n'est-ce pas? Des populations sont déplacées, ces installations ont un impact sur l'environnement et sur les niveaux d'eau des rivières dans les pays voisins. Prenons par exemple le barrage de la Renaissance sur le Nil bleu en Éthiopie.

Néanmoins, leur exploitation se poursuit. Le grand barrage Inga au Congo, par exemple, a un potentiel de 39 000 MW. Il pourrait fournir de l'électricité à plusieurs pays si les lignes à haute tension adéquates étaient construites. Cependant, les décideurs politiques devraient également tenir compte de l'impact sur les pays situés en aval; ce n'est pas suffisamment le cas pour le barrage Renaissance en Éthiopie. Ils sont peut-être conscients du problème, mais on constate un manque de coordination.

Quel est le potentiel des petites centrales hydroélectriques?

Les petites centrales hydroélectriques sont en nette augmentation mais ne permettent pas une production à grande échelle. Le Cameroun dispose de deux cent soixante-deux microsites hydroélectriques, chacun pouvant fournir entre 50 kW et 5 MW, soit 300 MW. En comparaison, le potentiel total de production d'hydroélectricité à grande échelle atteint 20 000 MW. La RD Congo possède également un énorme potentiel pour les petites centrales hydroélectriques, tout comme la Tanzanie.

Il est important de souligner que ces petites centrales sont bien adaptées à la production d'électricité hors réseau, c'est-à-dire indépendamment de celui-ci. Elles peuvent fournir de l'électricité aux villages isolés sans qu'ils soient raccordés au réseau (fig. 1). Sans ces centrales électriques locales, il faudrait certainement encore dix à vingt ans avant que les villages ne soient raccordés! De plus, l’électricité est moins chère puisque les lignes électriques vers ces villages isolés ne sont plus nécessaires. Cependant, les fonds sont souvent insuffisants.

Pourquoi?

Au cours des cinq dernières années, des entreprises essentiellement privées, y compris européennes, ont travaillé sur des solutions hors réseau, comme ENGIE et E.ON en Tanzanie.

Mais ces sociétés se heurtent à un obstacle majeur: les résidents des régions rurales préfèrent payer un peu plus cher pour leur électricité afin que cela devienne rentable pour les entreprises. Mais les décideurs politiques s’en tiennent à un prix égal — plus bas — dans tout le pays. Ce prix inférieur ne reflète toutefois pas le coût réel de l’installation hors réseau. Par conséquent, l’investissement n’intéresse plus le secteur privé.

Fig. 1. — Exemple de petite centrale hydroélectrique au Rwanda (© Shutterstock).

Quel type de biomasse les pays africains utilisent-ils?

La biomasse est constituée de déchets provenant des communes, de l’agriculture, de menuiseries, entre autres. Ce sont surtout les menuiseries éloignées, non raccordées au réseau, qui peuvent aujourd’hui produire leur propre électricité à partir de déchets de bois au lieu d’utiliser des générateurs diesel. Le basculement peut se produire si les déchets de bois deviennent économiquement intéressants pour elles en tant que source d’énergie.

Mais ces entreprises ont besoin de capitaux dont elles ne disposent pas. Cela me semble être une occasion unique pour les «tiers financeurs» qui peuvent louer l’unité électrique ou produire l’électricité contre paiement jusqu’à ce qu’elles rentrent dans leurs frais.

Le taillis est essentiellement renouvelable, mais en Afrique, il conduit à la déforestation. Quelle est la solution?

Le bois est en effet largement utilisé pour cuisiner, surtout à la campagne, et nos forêts en souffrent. Aujourd'hui, il existe des cuisinières qui nécessitent moins de bois ou de charbon de bois. À long terme, nous devons nous tourner vers d'autres technologies comme le biogaz obtenu, par exemple, par fermentation du fumier et des excréments, comme dans les prisons ougandaises. Le Sénégal et le Burkina Faso envisagent d'utiliser les déchets des abattoirs.

Le biogaz ne suffira cependant pas. Nous devrons passer au gaz propane, qui peut contribuer à la lutte contre la déforestation et la désertification. L'électricité est encore trop chère pour cuisiner, mais les fours solaires sont intéressants car ils focalisent la lumière du soleil. Espérons qu'ils soient utilisés beaucoup plus souvent à l'avenir.

Certains projets de construction de panneaux solaires sont en cours, mais l'expertise fait défaut pour les entretenir. Comment les pays africains peuvent-ils faire face à ce problème?

Pour la maintenance des panneaux solaires (fig. 2), nous avons en effet besoin d'experts: des techniciens, des personnes qui peuvent gérer les installations, mais aussi des fonctionnaires. Certains pays créent ou organisent des écoles d'ingénieurs, mais ces initiatives doivent s'intensifier.

Nous pourrions aussi obliger les entreprises qui construisent les centrales à les faire fonctionner pendant un certain temps. Jusqu'à présent, ces sociétés disparaissent à peine la centrale mise en place et n'assument donc aucune responsabilité quant à la qualité de l'installation. En les obligeant à gérer la centrale pendant un certain temps, ces sociétés devront assurer une meilleure qualité. Cela peut réduire les coûts de maintenance.

Fig. 2. — Panneaux solaires au Mozambique (© BTC/Dieter Telemans).

Pensez-vous que l'on évolue dans la bonne direction en matière d'énergies renouvelables?

La volonté est clairement présente, mais il nous manque encore des mesures concrètes pour aller dans cette direction. C'est probablement parce que les décideurs politiques ne cernent pas encore assez le problème. C'est pourquoi je soutiens la formation des fonctionnaires. Ils doivent replacer l'importance de l'électricité dans un contexte plus large, même si le prix de l'électricité hors réseau est plus élevé que celui en réseau. L'électricité réduira la propagation des maladies, améliorera l'éducation des enfants, encouragera les gens à entreprendre et stimulera l'économie locale.

Pour les ménages, l'absence d'électricité est donc beaucoup plus désavantageuse que le prix légèrement plus élevé de l'électricité produite par des micro-installations hors réseau. Nous devons trouver la bonne manière de transmettre ce message aux fonctionnaires. Si mon message ne passe pas, c'est que je ne l'ai pas encore bien expliqué.

Selon l'accord de Paris sur le climat, nous devrions cesser d'utiliser des combustibles fossiles d'ici 2050. Est-ce faisable en Afrique?

Certains pays peuvent y parvenir pour la production d'électricité, tandis que d'autres éprouveront de grandes difficultés.

L'énergie solaire et éolienne ne suffira certainement pas à elle seule, à moins que les possibilités de stockage de l'électricité ne deviennent fiables et abordables. Les pays qui possèdent également des ressources renouvelables, telles que la biomasse et l'hydroélectricité, sont plus susceptibles de s'affranchir des énergies fossiles d'ici 2050.

Mais les transports et l'agriculture continueront à utiliser des combustibles fossiles. Les voitures électriques impliquent de toute façon une production d'électricité très stable. Pour les transports publics, c'est envisageable, mais pas pour les voitures individuelles, à moins qu'elles ne deviennent abordables.

Regardez où nous en sommes aujourd'hui: la plupart d'entre nous utilisent des voitures d'occasion. Nous devrions établir un système de financement qui permette aux gens d'acheter des voitures neuves avec une plus grande efficacité. Cela réduirait l'utilisation des combustibles fossiles. Mais je n'envisage pas un basculement complet en faveur des voitures électriques en Afrique dans les trente prochaines années.

Que fait la Communauté internationale?

Elle offre de nombreuses possibilités de financement: la Banque mondiale, l'Union européenne, l'Agence des États-Unis pour le Développement international (USAID), l'Agence japonaise de Coopération internationale (JICA), des pays européens comme la Suède, l'Allemagne, la France et la Belgique (BTC, BIO, etc.), à la fois sous forme de dons et de prêts.

Où en est l'énergie nucléaire en Afrique?

L'Afrique du Sud a investi dans deux centrales nucléaires et prévoit d'en construire une troisième, pour un total de 1 300 MW. D'autres pays envisagent le nucléaire, mais cela reste controversé. La position des gouvernements africains, par exemple, reflète ce qui se passe en Europe: les centrales nucléaires sont démantelées et les déchets nucléaires constituent une importante préoccupation.

Les pays africains ne se lanceront donc pas tout de suite dans l'énergie nucléaire. Cependant, ils pourraient être séduits par des investisseurs qui leur garantiraient une électricité meilleur marché lorsqu'elle est produite par une centrale nucléaire plutôt que par une centrale conventionnelle. Cet argument n'est pourtant défendable qu'à court terme, les centrales nucléaires étant plus onéreuses à long terme.

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Inga: A Necessary Mega-Project that still needs to mature

by

François MISSER*

KEYWORDS. — Inga; Energy Highways; Three Gorges Corporation; Grand Inga Hydropower Project Treaty.

SUMMARY. — The Inga falls are the largest single hydropower site in the world with an estimated capacity of 40 to 44 GW. Such potential crucial in a continent which suffers from a huge power deficit has led engineers to design projects to export this capacity throughout the continent to the Aswan dam in Egypt, to South Africa and to Nigeria, via what they called the African Energy highways. The Inga 3 lower fall project, which is discussed in this paper, would be the first step towards Grand Inga, which in the author's opinion is necessary for Africa's economic future and the global environment. Yet, there are many hurdles on the implementation path owing to the magnitude of the project which makes its funding a challenging exercise. In fact, Africa's largest potential is located in one of the continent's most unstable and fragile states. This paper will present the project and its implications, and identify the challenges.

The Largest Single Hydropower Site in the World

The Democratic Republic of Congo (DRC) has been endowed with the largest hydropower site in the world, at the Inga Falls, 253 km south-west of Kinshasa. Its total potential of 40 to 44 GW accounts for about 40 % of the country's huge hydroelectric potential estimated at 100 GW.

This huge potential has been explored since 1885, namely by a Belgian geographer called Alphonse-Jules Wauters who already realized that the Inga falls could generate enough power for the neighbouring regions and countries. This considerable potential inspired a number of research works, already before Congo's independence in 1960. One of the most remarkable works was made by Pascal Geulette, member of the Royal Academy of Colonial Sciences (renamed Royal Academy for Overseas Sciences), who published a thesis on the subject titled "Considérations sur l'aménagement hydro-électrique du fleuve Congo à Inga" in 1955.

However, only a tiny share of the potential is being exploited with the construction of Inga 1 (351 MW) and Inga 2 (1,424 MW), which were completed in 1972 and in

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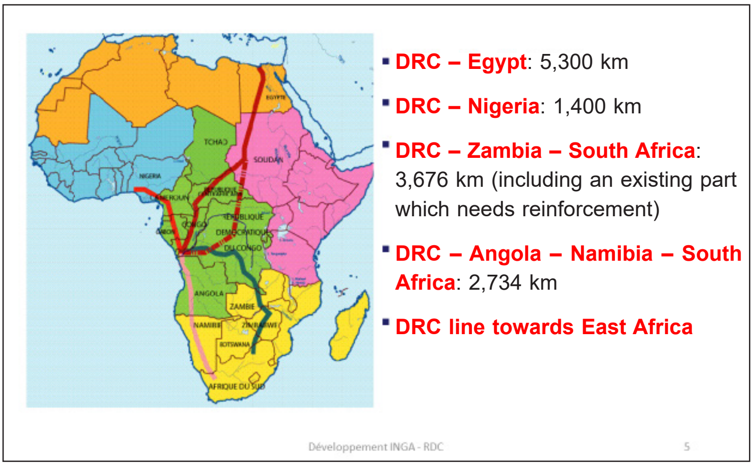
* Journalist, contributor to the UK-based *African Energy Bulletin* and to the yearbooks published by the Belgium-based Expertise Center for Central Africa (CREAC).

1982 respectively. Their combined generation power only represents 4.4 % of the site potential. Still, owing to the lack of maintenance during the Mobutu period (1970-1995), only half of the installed capacity was operational at the time of writing this paper.

The African Energy Highways

A number of engineers have been making plans on the development of the project and of its associated transmission lines. In 1993 and 1997, *Électricité de France International* (EDF) and Lahmeyer completed a prefeasibility study financed by the African Development Bank (AfDB) on the Energy Highways from Inga to the Aswan dam in Egypt, to South Africa and to Nigeria (fig. 1). Clearly, those engineers saw Inga as the gordian knot of Africa's energy development. Their vision was shared two decades later. During a presentation of the Inga 3 project, the Congolese Minister of Energy and Water Resources, Bruno Kapandji Kalala (2014), argued that the forecast energy deficit of Nigeria (19 GW), Egypt (46 GW) and South Africa (29 GW) by 2030 justified the development of Inga and that hopefully Nigeria should be able to import 2,600 MW from Inga by 2030 whereas Egypt and South Africa should by then be able to import 3,500 MW each.

There is no doubt that DRC's hydropower can be a game changer for the continent where it is badly needed, owing to the size of the demand. According to the French engineer Arnaud Rousselin (2014), from EDF, the demand of the West African Power Pool (WAPP) for 2030 is estimated at 40 GW, as against 103 GW for the East African Power Pool, 89 GW for the Southern African Power Pool and 15 GW for the Central African Power Pool (PEAC).



- **DRC – Egypt**: 5,300 km
- **DRC – Nigeria**: 1,400 km
- **DRC – Zambia – South Africa**: 3,676 km (including an existing part which needs reinforcement)
- **DRC – Angola – Namibia – South Africa**: 2,734 km
- **DRC line towards East Africa**

Développement INGA - RDC 5

Fig. 1. — Interconnection projects from Inga (*source*: SNEL annual report 2000).

The idea developed by EDF and Lahmeyer engineers was to build a third dam, much larger in a valley, the Mbundi valley, which runs parallel to the main course of the dam and the adjacent Nkokolo valley where the existing dams are located. Plans were to divert the largest part of the river flow into the Mbundi valley through an in-take canal and bring water to the turbines at the junction with the original riverbed, to generate something between 3,000 MW and 4,000 MW.

The development of the project was paralysed by the two Congolese wars of 1996-1997 and 1998-2003. But the debate resumed in 2003 at regional level. A new entity was created under the auspices of the Southern African Development Community (SADC), the Western Corridor. The plan was to bring power from a third dam on the Congo river, all the way down to South Africa via Angola and Namibia with a hook to Botswana. But the project did not materialize, mainly because the DRC, which hosts the site of Inga, was only given a 20 % stake in the company in charge of the project, which did not reflect the fact that it was bringing the largest contribution as host of the potential.

Inga 3 Lower Fall: The First Step of Grand Inga

A new study on the new project called ‘Inga 3 Lower fall’ was launched in 2008 by the AfDB and carried out by EDF and the Canadian consulting firm RSW, now absorbed by the American company AECOM. The study was concluded in 2013 and Inga 3 was defined as the first phase of the construction of Grand Inga (fig. 2, tab. 1).

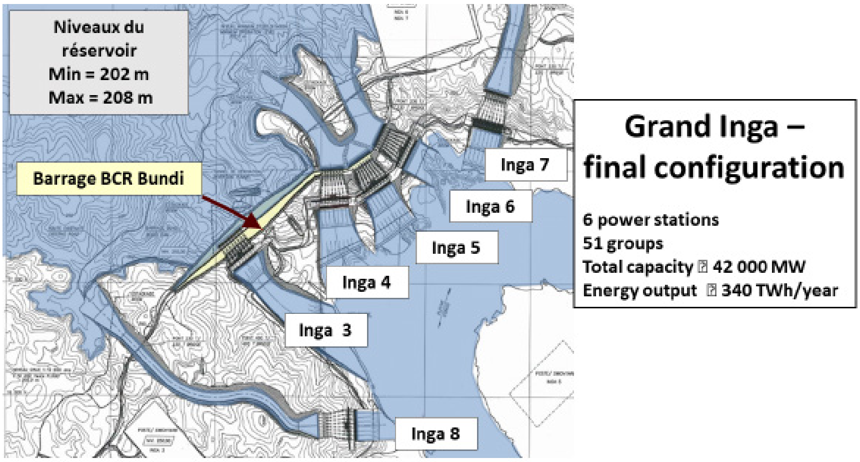


Fig. 2. — Phased development of Grand Inga (*source*: Rousselin 2014).

Table 1

Cumulated potential

Phase 1	Inga 3 Lower Fall	4,755 MW	4,755 MW
Phase 2	Inga 3 Higher Fall	3,030 MW	7,785 MW
Phase 3	Inga 4	7,180 MW	14,965 MW
Phase 4	Inga 5	6,970 MW	21,935 MW
Phase 5	Inga 6	6,680 MW	28,615 MW
Phase 6	Inga 7	6,700 MW	35,315 MW
Phase 7	Inga 8	6,740 MW	42,055 MW

Source: Department of Energy, Republic of South Africa (2014).

The Grand Inga International Treaty

The main challenge, however, for the Inga developers was to find an anchor client who could purchase a significant proportion of the energy produced by Inga 3 Lower Fall and whose solvency would attract financing for the project.

The anchor client that emerged was the South-African utility ESKOM. According to the Energy Department of South Africa (2014), the Grand Inga project is indeed of "strategic importance", since it could help reduce the carbon footprint, diversify energy risk, increase energy security and have a positive tariff impact.

On 30 October 2013, the Congolese and South African presidents, Joseph Kabila and Jacob Zuma, signed an international treaty for the development of Inga, which included a power sharing agreement. According to the Energy Department, the purpose was to develop an enabling framework linking both countries in the project and allowing them to jointly explore economically feasible options for its development. It namely provided for the establishment of an Inga Development Authority (ADEPI), a joint ministerial committee and a joint permanent technical committee to facilitate the development, the operation and the management of the project in the DRC through dealership.

The treaty included a commitment by South Africa to off-take 2,500 MW and 2,300 MW by the DRC which would be split between Katanga province and the mining industry (1,300 MW) and the national utility SNEL (1,000 MW). Moreover, the treaty also awarded a right of first refusal off-take, which implies that South Africa is guaranteed a minimum of 20 % of generated power equal to 9,540 MW and maximum of 13,060 MW from the phases, following Inga 3 Lower Fall.

The total cost of Inga 3 Lower Fall was then estimated at around U.S. $ 11 billion by the World Bank (2014). It included U.S. $ 2-3 billion of public investment for the intake, canal and dam, and approximately U.S. $ 6 billion of private investment for the powerhouse and the T-lines. The cost of the Southern African Power Pool (SAPP) transmission lines to South Africa, via Zambia and Zimbabwe, was estimated at U.S. $ 2.5 billion. According to the World Bank (2014), the total bill for Inga 3 Lower Fall could reach U.S. $ 14 billion including financial costs. A figure of U.S. $ 80 billion has circulated for the total cost of Grand Inga, including the transmission lines to Egypt, South Africa and Nigeria. However, according to an Oxford team of economists, the average cost of large dam projects is 96 % higher than estimated (LUNDE 2014).

The DRC Government decide to double Inga's Capacity

But all these projections about the Inga 3 Lower Fall were completely upset by the Congolese Agency for the Promotion and the Development of Inga (ADPI) in July 2017, with its announcement that the capacity of Inga 3 would be scaled up to 10,000 MW or 12,000 MW, which is more than the double of the initial projected capacity of 4,800 MW. ADPI's director, Bruno Kapandji, also announced that the two consortia which bided for Inga 3 would merge and submit a common offer in September 2017. "The national demand of electricity has raised considerably. In addition, such capacity increase will boost the competitivity in terms of costs. The DRC is facing a 3,000 MW deficit", he argued at the time to justify the decision to increase the capacity.

The first consortium, called *Groupement Chine d'Inga* is led by the Three Gorges Corporation and includes as well Sinohydro, the State Grid International Corporation, the Chanjiang Survey Planning Design and Research Corporation and the Dongfang Electric Corporation.

The second one is a Spanish-led consortium called *Groupement proInga* which includes *Actividades de Construcción y Servicios* (ACS), Eurofinsa, AEE Power, Andritz Hydro of Germany, Andrade Guttierez Engenheria SA of Brazil and… the China National Electric Engineering Corporation (CNEEC). At the same time, the ADPI announced that the Inga 3 project would only be finalised by 2024-2025 the soonest, four years later than expected.

The Inga Project is Necessary for Africa's Economic Future and the Global Environment

Despite its huge cost, the Inga project has been described as "the pearl of all projects" by the International Energy Agency's executive director and chairman of the World Economic Forum's Energy Advisory Board, Fatih Birol. The Inga project is a flagship project, not only for the DRC but for the whole of Africa. Inga is the largest hydropower site in the world, with a 40 GW potential, *i.e.* nearly the double of the world's largest operating hydropower project, the Three Gorges Project in China, which has an installed capacity of 22,500 MW.

There is no doubt that DRC's hydropower can be a game changer for the continent where it is badly needed, owing to the size of the demand.

In addition, Inga is a competitive project. According to the World Bank, Inga offers the world's lowest production cost with approximately three dollar-cents per kWh. Thereby it provides Congo with a considerable comparative advantage to attract investments and industries which could help transform its huge natural resources.

Inga can also deliver huge environmental services. Provided necessary investments are made to develop distribution networks and the use of electric cooking devices, it can be an alternative to charcoal, the main cause of deforestation and CO_2 emissions in Central Africa.

It can also help Southern Africa to increase the share of renewable energy in its energy mix and help substitute some of the generation capacity of the environment-damaging coal thermal plants. At the same time, Inga can be affected by climate change which could affect its generation capacity (Misser 2013). The most optimistic scenarios anticipate important fluctuations of rainfall in the Congo basin (Jones 2017).

Still Many Hurdles on the Implementation Path

According to a number of factors, the launch of the Inga 3 project has been delayed several times. In 2013, the government announced that the construction would start in October 2015. More than two years later, the date of the launch is not in sight.

This situation is partly due to the gigantic size of the project for which a pool of many financial resources is necessary. There is a need to harmonize strategies between the different stakeholders. At the same time, there are undeniably governance problems. The decision by the World Bank to withdraw from the project in July 2016 is related to the Congolese government's decision to launch tenders for the selection of the developer before the bank-funded social, technical financial and environmental studies were finalised. Another reason for the World Bank's withdrawal is that the authority which is supposed to manage the entire project, the *Agence pour la promotion et le développement d'Inga* (ADPI-RDC), is not under government's supervision but depends directly upon the president office.

In such context, the announcement in July 2017 by the director-general of the Congolese Agency for the Development of Inga (ADPI), Bruno Kapandji, that Inga 3, which he described as the first phase of Grand Inga, was not expected to start producing electricity before 2024 or 2025, and not 2020 or 2021, did not come as a surprise.

However, the consortia which had been invited by Kapandji to merge their offers and submit a single one in September 2017, failed to do so. One of the reasons is that they were deprived from an important element to design the project, which were the studies on the development of Grand Inga, co-financed by the World Bank and the African Development Bank (AfDB).

This factor combined with other obstacles is also making fund-raising more and more difficult. The leader of the ProInga consortium, the Spanish firm ACS, has been confronted since November 2017 with a hostile campaign which makes fund-raising even more difficult from international financial institutions such as the European Investment Bank (EIB). In the same month, the European Commission, whose opinion matters at the EIB, was informed about reports from Greenpeace Spain and the Guatemalan NGO *Alianza por la Solidaridad* that one of the ACS subsidiaries was responsible for huge environmental damage as part of the construction of a dam on the Río Cahabón at the expense of 29,000 Maya indians.

Moreover, the EIB and other development financial institutions cannot ignore that the context is not appropriate to sign important deals with the government of the DRC, which may increase sizeably the country's foreign debt (Jones 2017). Some of the country's ministers are under EU and US sanctions because of their alleged responsibility in the delays of the transition which should have led to presidential and parliament elections at the end of 2017. A prominent Congolese opposition leader has also warned that contracts awarded by the Congolese government, given that the mandates of the president or of the parliament have expired since 19 December 2016, would be considered null and void.

Regardless of the DRC's internal political squabbles, the financing of large dams is facing strong opposition in both the European Union and United States. In 2011, under the pressure of environmentalist lobbies, the European Parliament passed a resolution, urging the World Bank "to refrain from investing in large hydroelectric projects, whose negative social and environmental impacts resulting, inter alia, from greenhouse gas emissions from reservoirs must be properly assessed prior to their financing". In 2014, the US Congress urged the Obama administration not to finance anymore large dams either through the US-AID or via multilateral institutions.

A waning enthusiasm was also observed at the time of writing this paper in South Africa, which, according to the Grand Inga Treaty, should be the main recipient of the electricity produced at Inga. The political future of President Jacob Zuma, the main supporter of the project, became uncertain, to say the least. The crisis at ESKOM triggered by bad governance problems also contributed to the weakened interest in Inga with the questions of nuclear energy and supply from independent power producers being among the few energy-related issues enjoying more attention.

Even China, considered as the alternative to the international financial institutions as a source of public funding, owing to its capacity to mobilize resources, has not renewed promises made in 2015 to President Joseph Kabila during his visit to China by the Three Gorges Corporation to build the dam and get it financed by the Exim Bank of China. According to sources among the donors' community in Kinshasa, the lack of maturity of the project could explain the Chinese wait-and-see attitude.

Geological Problems

Besides governance issues, at the beginning of 2018, a number of technical problems concerning the construction of the dam still needed to be solved.

The need for more technical and financial studies prior to the construction of Inga 3 and the other phases of Grand Inga seems to be wall justified. Five years before Congo's independence, Pascal Geulette, member of Belgium's Royal Academy of Colonial Sciences, already raised the problem of the stability of the rocks of the Bundi Valley where the Inga 3 and the Grand Inga dams were to be built (Geulette 1955). Other testimonies including those of hydrology engineers interviewed by the author of this paper have confirmed the nature of geological problems such as rock porosity, which has already been noticed at the existing Inga 1 and Inga 2 dams.

An additional problem, according to hydrology engineers, is that during the construction works of the intake canal that will divert the main flow of the Congo river into the Bundi valley, the existing Inga 1 and Inga 2 hydropower stations will probably stop operating at least a few days or a few weeks.

Who is Going to Pay and How?

The huge cost of the Grand Inga project is a serious issue. Especially if one considers that the figure of U.S. $ 14 billion for Inga 3 Basse Chute (Lower Fall) is conservative, owing to the fact that the final cost of most hydropower projects can be much higher in the end than foressen (Lunde 2014). A number of factors should be taken into account including a 10 % power loss for the transmission lines and the need to apply a 0.855 factor to calculate the available potential of the hydropower plant (Rubbers 2014). However, in the case of Inga, this potential only corresponds to the 40 GW maximum during four months per year between October and January. And the return on investment has to be calculated by taking this factor into account. In his assessment made on behalf of the American advocacy NGO, International Rivers, Jones also stressed that there are risks on the sustainability of the debt incurred by the Congolese authorities, which want to develop the construction of Grand Inga as a public-private partnership (PPP). Accordingly, 70 to 80 % of the financing would be from debt and the rest from private equity.

The ADPI's decision to more than double the capacity of Inga 3 has hiked considerably the financing challenge. The decision to increase the capacity of Inga 3 has also raised doubts among engineers and economists about the viability of the project. Nigeria has expressed several times an interest to acquire a 3,000 MW capacity from Inga, according to a source from the Congolese national company, *Société nationale d'Électricité* (SNEL). However, even if this option was confirmed, the gap between demand and capacity would still range around 3,000 MW in the event of a 12,000 MW expanded scenario. The trouble is that no power purchase agreement (PPA) has been signed so far neither with the Power Holding Company of Nigeria nor with the South Africa's company ESKOM. And the trouble also is that an agreement on tariffs and PPAs is absolutely essential to secure financing for the project.

Underestimated Costs

Another problem that has not been considered by the World Bank, the AfDB and the Congolese authorities is the cost of ancillary infrastructures. In fact, according to engineers, the size of the turbines and the need to transport building equipment to the Inga site require the construction of a deep-sea harbour on the Atlantic at the mouth of the Congo river and the improvement of the access road to the Inga site. Such infrastructures are also needed for the industries which would be located near the Inga site, in order to evacuate their products towards the harbour. The most conservative estimate made by a South-Korean consultancy is that the harbour alone would cost at least U.S. $ 400 to 500 million. Other estimates made by the *Organisation pour l'équipement de Banana-Kinshasa* (OEBK) consider that the construction of a railway between the harbour and Matadi would represent an investment of circa U.S. $ 500 million. At the end of the day, the total cost of the dam, of the transmission lines and of the ancillary infrastructures would rather account for U.S. $ 15 billion, including financial costs, in the perspective of the initial 4,800 MW scenario for Inga 3 Lower Fall and probably much more if eventually the scenario of a larger capacity power station retained by the government materializes.

For the time being, it is unclear who will finance the construction of the dam. The only indications provided by the World Bank in 2014 were that the Development Bank of Southern Africa, was considering to finance the transmission lines to Southern Africa, which represent roughly 20 % of the initial total cost of Inga 3 Lower Fall (4,800 MW) and even less according to the new scenario of a 10,000 MW to 12,000 MW generation capacity. The financial gap can thereby be estimated at a minimum of U.S. $ 12 billion.

The Inga Paradox

In summary, the DRC is provided with Africa's most important hydropower potential but it does not have the financial means to tap this resource alone. Moreover, Africa's largest potential is located in one of the most fragile states.

Therefore, Inga finds itself in a totally different situation from the other main projects under construction in Africa. The 6,000 MW Grand Ethiopia Renaissance Dam (GERD) on the Blue Nile, whose total cost is estimated at U.S. $ 4.4 billion, is entirely financed by Ethiopia, mainly by the government and partly by the sale of bonds by the government to the public. The trouble in Ethiopia is rather of geopolitical nature. Ethiopia has to reassure Egypt that filling the dam reservoir will not have damaging consequences for water supply in the downstream countries.

Another country which is developing considerable hydropower capacity is Angola. Like Ethiopia, the state totally finances the large dams on the Kwanza river: Lauca (2,070 MW) of which two turbines started operating in July 2017 and Caculo Cabaça (2,171 MW). Lauca has been funded by Brazil's *Banco Nacional de Desenvolvimento Económico* (BNDES) until the suspension of its loans in May 2016, since Brazilian companies involved in the construction of the dam were caught in Brazil's corruption probe into the state oil giant Petrobras. This forced Angola to look for alternative funding which was obtained partly from the Gemcorp British Investment Fund and from the Standard Chartered Bank. Caculo Cabaça dam, however, is financed by China's Exim Bank. Both of them involve a cost ranging between $ 4 and $ 5 billion, which represents the equivalent of three quarters of the Inga 3 Lower Fall cost. In Angola's case, the problem is that the projects were launched before the oil price crunch and it is therefore more difficult for the state to finance these investments. Anyway, the development is going ahead, owing to a strong political will of the Angolan authorities.

The Controversy on the Use of Inga's Energy

Beyond the cost and the technical issues, the economic development model of the Inga project is far from reaching a national consensus in the DRC. In fact, the Inga 3 and Grand Inga projects are primarily designed as energy-export schemes. The anchor client of Inga 3 is South Africa, which is seen as providing the financial backbone and sustainability of the project. In the future, however, the operators and managers of Inga will be confronted with the competing demand of the continent's first economy, Nigeria. For the last five years, Nigeria has already expressed its interest in purchasing up to 3,000 MW from Inga.

Inga's development model has been criticized. The Civil Society Organizations Coalition for the Monitoring of Reforms and Public Action (CORAP), which includes one hundred and three NGOs, considers that the 1,000 MW left to SNEL to supply the domestic market in the Inga 3 Lower Fall scenario are insufficient to meet local needs.

In August 2017, CORAP also regretted the "absence of transparency" in the development of the project and urged President Kabila to publish all data about it, including the text of the Grand Inga International Treaty with South Africa, which has not been disclosed so far. The NGOs also regretted the absence of a resettlement plan for the inhabitants of five villages who will have to move out of the site area. CORAP called for the involvement of the civil society and local communities in all the phases of the project development. CORAP also remembers that hundreds of people are still asking for compensations as a result of the existing Inga 1 and Inga 2 dams. Since their recommendations were not met, in a communiqué released on 30 January 2018, CORAP declared that it was no longer supporting the Inga 3 project in the present conditions. Accordingly, its concerns, which include the citizens' access to information about the project, the quota of energy supply to the DRC and its population and the completion of social and environmental studies, were not met.

The former Belgian Cooperation Agency AGCD director-general, Paul Frix, considers that under its present form, the project is not in Congo's interest. He rather advocates for a project that would be more geared towards the development of an industrial zone around Inga to transform the DRC's natural resources locally, which could serve as a pole of regional integration for Central Africa (Frix 2007). His vision is shared by the Congolese economist Venant Kinzonsi who has listed a number of domestic industries which could be developed around Inga as a result of the combination of the abundance of electricity and of local resources (bauxite, phosphates and ferlilizers, agricultural products, fisheries, etc,…).

The Social and Environmental Debate

There have also been a lot of speculations about the potential negative impact of the construction of the Inga 3 dam and of the implementation of the next phases of the Grand Inga project. The surface of the reservoir is fairly small, around 400 km², which is much less than the Aswan dam reservoir (6,500 km²). Besides, evaporation levels are much inferior in this part of Africa.

The number of people who should be displaced or affected is not so important for such a king-size project. A reinstallation plan of 8,000 people has been considered by the World Bank. The AECOM-EDF study has estimated that the affected area will be the smallest of all other large hydropower projects, considering the number of displaced persons per megawatt (Rousselin 2014).

However, Grand Inga's financial and technical parameters may be affected by environmental factors such as climate change, as we suggested above. Congolese hydrologists expect Congo river flows to fall by 5 % between now and 2030 and even more afterwards. The authors of a recent study of the United Nations University (Swanson & Sakhrani 2016) have warned that in order to attract investment, "planners need to ensure that investors are protected from unnecessary risks, including those from climate change and cost overruns".

Conclusion

Inga site is the largest single hydropower site in the world with an estimated capacity of 40 to 44 GW. It has the potential to provide the cheapest clean energy to the DRC and to other regions of Africa, and thereby to provide them with a powerful competitive advantage. But the paradox is that Inga is located in one of the continent's most fragile states riddled with corruption and bad governance. Such challenges but also technical and political ones, including the need to address the domestic demand of the DRC and meet the expectations of the impacted population, should be tackled in order to reach the maximum consensus before embarking on a project of such magnitude.

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The Development of Small Modular Reactors for Emerging Nuclear Countries in Africa

by

Peter Baeten[*], Hamid Aït Abderrahim[**] & Ramón G. Rubio[***]

Keywords. — Africa; SMR; Nuclear Energy; MYRRHA.

Summary. — The electricity deficit is one of the most serious threats to the development, stability, economic and social well-being of many parts of Africa. Electricity shortages are a constraint on the sustainable development of the continent. The resolution of this problem should include internationally coordinated efforts to improve the governance of the existing utilities in the regions concerned, a better utilization of natural resources in the continent and, ultimately, the construction of facilities for the increase of the generation capacity. In this context, there is a renewed interest in nuclear power in Africa driven by predictions of a rapidly growing energy demand, persistent concerns about climate change and dependence on overseas supplies of fossil fuels. This paper deals with the role that small modular reactors (SMR) can play in ensuring access to affordable energy for the sustainable development of the African continent.

Introduction – Status of the African Power Sector

While most of the rest of the world is experiencing the digital revolution, large parts of the African continent are still unplugged in what refers to the access to reliable generation of electricity. It affects every aspect of life, with children being unable to read or do their school tasks after dusk, hospitals not being able to conserve medicines in the right conditions to avoid their degradation, and businesses operating under the constant threat of interruptions, or having to opt for expensive backup generating solutions.

According to Kessides (2014), there has been no significant capital investment from either the private or public sector into Africa's power sector for the last twenty years. External finance during the same period has averaged to only around $ 600 million per year of official development assistance plus a similar volume of private finance. The consequences of this were predictable and are starting to materialize. In the period from 2012 till 2014, worldwide access to

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[*] Technical manager MYRRHA Project, Belgian Nuclear Research Centre, Boeretang 200, B-2400 Mol (Belgium).

[**] Deputy director Belgian Nuclear Research Centre, Boeretang 200, B-2400 Mol (Belgium).

[***] Department of Physical Chemistry, Universidad Complutense de Madrid, avda de Séneca 2, Ciudad Universitaria, 28040 Madrid (Spain).

electricity increased only slightly faster than the total population in absolute terms. The number of people without access to electricity reduced marginally from 1.063 billion in 2012 to 1.061 billion in 2014 (SE4ALL 2017). During the same period, access to electricity in Africa increased by nineteen million a year but the population grew by twenty-five million a year.

In urban areas, the electricity access rate increased from 70.4 % of people in 1991 to 76.0 % in 2014. But about 110.6 million people still lacked electricity in 2014, as urban population growth had offset access gains.

In rural areas, 21.7 % of people had access to electricity in 1990, a rate that went up merely to 27.3 % by 2014 because the total population had grown much faster than the population with access. About five hundred four million people in rural areas did still not have access to electricity in 2014.

Electrification programmes have largely aimed at extending the distribution grid to new consumers. However, this strategy is slow due to a lack of resources and the high connection fees that consumers are expected to pay. In the end the situation is such that rural consumer's low demand doesn't justify the cost of grid extension. This fact maintains hundreds of millions of people living in rural areas with no access to electricity.

The Global Energy Framework Report of the Sustainable Energy for All initiative (2017) also reports that, from all the regions in the world in 2014, Africa and the Asia-Pacific region presented the highest energy intensity, defined in megajoules per 2011 purchasing power parity dollar. Energy intensity is a measure of the energy efficiency of a nation's economy, as it measures the cost of converting energy into Gross Domestic Product (GDP).

In summary, the challenges faced by the African continent in terms of energy production and consumption, which have a direct impact on the economic development of a region, can be identified as:

- Accessibility: the prices of electricity in Africa are high for a relatively low-quality service in terms of reliability. Power outages on average amount to more than fifty days per year with some areas experiencing daily power interruptions.
- Energy security: baseload reliable capacity promoting investment and economic development is scarce.
- Economic competitiveness: there is a need to make electricity affordable and accessible through economic competitiveness, so that investment can be attracted to build grids in areas that, at the moment, remain largely unelectrified.
- Climate change: fossil-fuel CO_2 emissions in Africa are low in absolute and per-capita terms, although per-capita emissions have risen sharply in recent years (but still only about 6 % of the comparable value for North America).

The Relation between Demographics and Economic Development.

Demographics is a fundamental driver of energy demand and plays a fundamental role in decisions made by local and national governments related to the right energy mix. Based on United Nations projections (Birol 2013), the world population is set to rise to 8.7 billion in 2035 (compared with seven billion in 2011), mainly led by Africa and India. In an ideal scenario, the relation between population and energy demand would be linear. In reality, this relation is not always linear, as it depends on many other factors, mainly of economic nature. Although this relation is starting to decouple to a certain extent in advanced countries with more efficient energy-use practices, fundamentally, the growth in energy demand is closely correlated with growth in per capita income. Nonetheless, and especially in economies that are emerging today, rising incomes will continue to lead to increased demand for goods that require energy to produce and to use, such as cars, refrigerators and air conditioners.

Figures 1 and 2 show respectively the increase in population and in GDP per capita for the period between 2011 and 2035 for different regions of the world. From these graphs it is clear that demographics and economic growth are decoupled and that the areas that are expected to have the biggest increase in population in the next twenty years are not the areas where the economy is predicted to grow in equal terms.

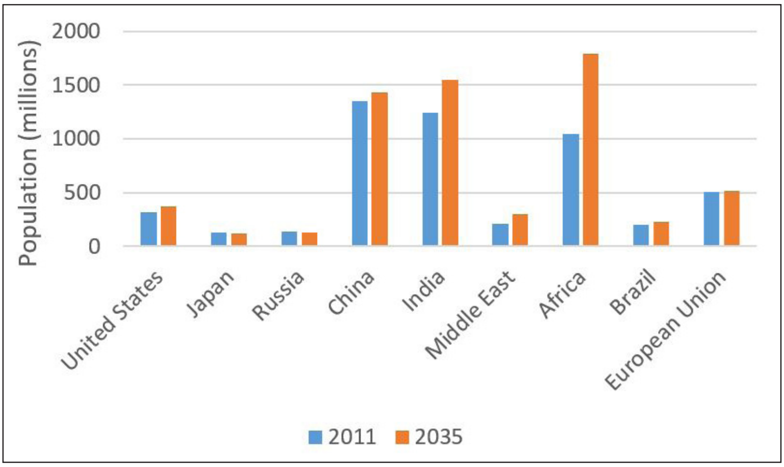

Fig. 1. — Population growth forecast for the period 2011-2035 (Birol 2013).

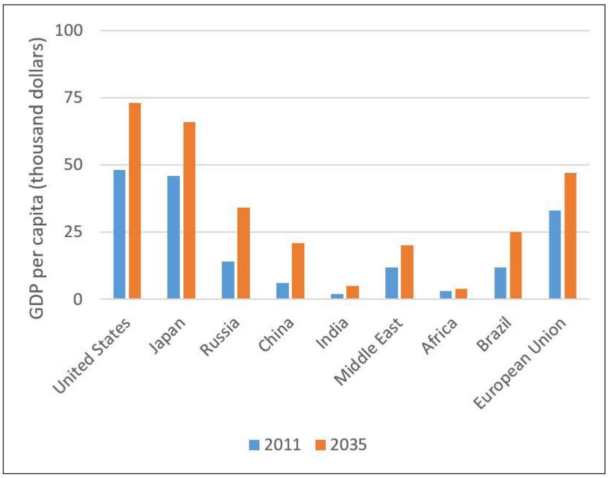

Fig. 2. — GDP per capita growth forecast for the period 2011-2035 (Birol 2013).

This is better seen in figure 3 where the graph shows in the horizontal axis the compounded average annual growth rate expected in population, and in the vertical axis the compounded annual growth rate expected in GDP per capita for the same period 2011-2035. Whereas Africa is expected to experience the largest increase in population by far (2.3 % per year, followed by the Middle East at a considerable distance with an expected growth in population of 1.5 % per year), in terms of GDP per capita growth, the African continent is at the lower end of the scale with an expected annual growth of 1.7 %. It is interesting to note that this growth rate is similar to that expected in developed regions of the world, including the United States, Japan and the European Union. These are, however, developed economies, with electrification rates close to 100 % and where the expected growth in population is much lower.

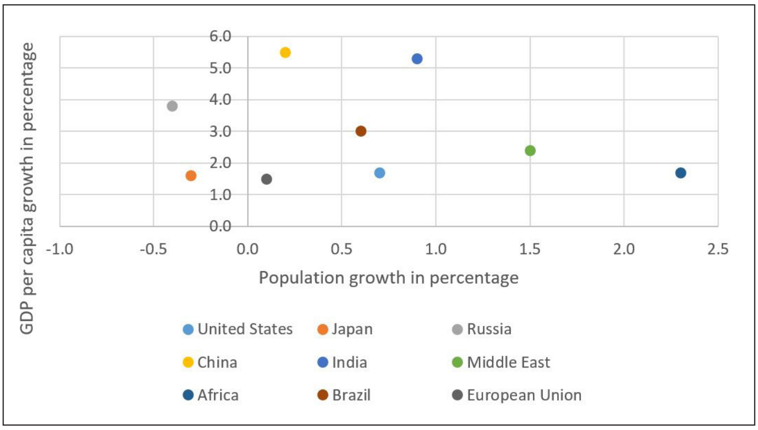

Fig. 3. — Annual population growth rate vs annual GDP per capita growth rate for the period 2011-2035 (Birol 2013).

From the previous analysis we can conclude that the needs for generating capacity for the African continent for the period up to 2035 are going to be significant. In fact, these were quantified by the International Energy Agency (Birol 2013). Depending on the scenario under consideration, the electricity demand on the African continent is planned to increase from 692 in 2011 to between 1,272 and 1,539 TWh (terawatt-hours) per year in 2035. To meet these needs, the continent's electricity generating capacity will have to increase from 155 in 2011 to between 386 and 409 GW in 2035, requiring about 250 GW (depending on the scenario) of capacity additions.

The Nuclear Option for Africa

Having established that Africa will require 250 GW of additional capacity in the next twenty years, the next objective is to find out what is the right energy mix that would sustain economic development while maximizing the use of local resources and without increasing the burden in environment.

The recent situation (Kessides 2014) is that coil and gas account for more than 80 % of the continent's total power generation, hydropower for 16 % and other renewables for 1 %. The relative importance of these numbers is shown in figure 4.

Figure 4 also shows that nuclear accounts for only 2 % of electricity generation in Africa, with all the African nuclear power stations concentrated in one country. Globally, nuclear energy accounts for 12 % of the total electricity generation in the world, and this in spite of Africa's significant mineral deposits including uranium. According to figures from the World Nuclear Association (WNA 2017), five African countries are among the top fifteen countries with most recoverable reserves of uranium in the world. Together, South Africa, Niger, Namibia, Botswana and Tanzania account for 18 % of the world total reserves.

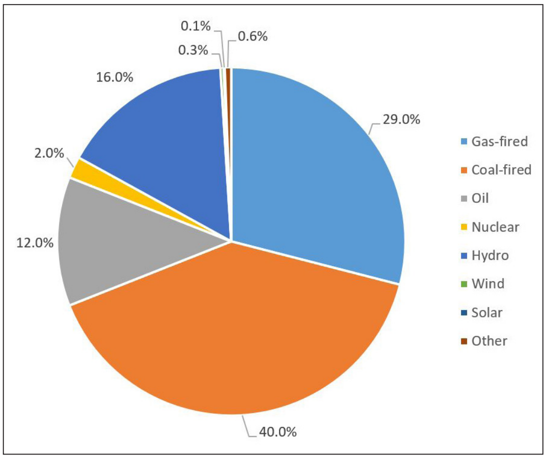

Fig. 4. — African power generation by fuel (Kessides 2014).

So, what are the options for Africa? At the moment hydropower represents about 93 % of the continent's total installed renewable energy capacity. Africa has substantial remaining hydropower potential with about 140 GW economically exploitable under current conditions (IRENA 2012). Hydropower is a cheap and clean form of generation but has the disadvantage that the location of hydro resources tends to be poorly matching with the demand. It can be also very disruptive for the environment as large areas will be flooded and the course of rivers disrupted, which has a strong impact on the aquatic ecosystem.

Although 14 % of the total world population live in Africa, only one out of five hundred wind turbines have been installed in this continent so far (WWEA 2013). Recent studies suggest that the potential for wind energy in the country is significant, around 100 GW (IRENA 2012). These wind resources are, however, distributed rather unevenly from the geographical point of view, with the bulk of high-quality resources in coastal regions. Solar energy plays a very minor role in Africa, even if the annual mean irradiance for most of the regions is in many cases double than that for Europe. However, renewables pose their own set of problems which might make them not the most suitable alternative to contribute to the development of largely unelectrified areas. Renewable energy does not provide baseload capacity. It is non-dispatchable by system operators and needs a reserve of dispatchable energy so that operators can maintain network grid reliability. Moreover, the potential sites are far from load centres and, in many cases, biased towards specific areas.

Grid and off-grid electricity solutions based on modern forms of renewable energy have been tried across the continent to increase electricity access, secure reliable power supply, and ensure energy sustainability. However, due to the fluctuations in the production of energy from renewable sources, it is often the situation that an increase in generation based on fossil fuels is needed to cope with an increasing demand. Even hydropower is often affected by drought and can cause significant fluctuations from one season to the next.

Based on the discussion above it seems obvious that nuclear energy could offer a solution for the development of the African continent. The reasons for this are multiple and include:

- Reduced reliance on fossil fuels: in 2013, Africa accounted for 6.3 % of global total final energy consumption and emitted 3.4 % of global carbon emissions (SE4ALL 2017). A capacity increase based on nuclear would help maintain the African continent as a low producer of carbon emissions.
- Efficiency and sustainability: nuclear power plants produce a high amount of energy per unit of fuel. New nuclear reactors aim at working on a closed fuel cycle and being more efficient with the consequent reduction in the amount of waste.
- Reliability: nuclear energy produces reliable baseload capacity to support the development of businesses and critical sectors such as education and health.

- Market stability and competitive prices: taking Belgium as an example, the OECD/NEA report on the “projected costs of generating electricity” (2015), the Levelized Cost Of Electricity (LCOE) generated with nuclear power plants is lower than that produced with any other generation means.
- Proven technology: Gen III+ reactors are based on fifteen thousand reactor-years of accumulated operational experience.

The Challenge of Adopting Nuclear Power in Africa

Adopting nuclear power is not an obvious decision. Before embarking in a nuclear programme, a country needs to check its readiness in terms of energy demand, finance and economics and also physical and legal infrastructure. It also needs to understand how nuclear fits in the energy mix and the contribution that it makes to a sustainable economic development.

Furthermore, it is important to think what type of nuclear generation capacity is better suited to the needs of the region. Historically, the only option in the market has been large nuclear reactors with GW capacities. However, these might not be well suited for the African continent for a number of reasons:

- They require an important upfront investment of the order of several billion US$.
- Large construction periods imply that the financial risk is high.
- There is a need for legal policies and regulatory frameworks.
- They pose challenges on electricity networks.
- They require a number of active safety systems. Operating large nuclear reactors implies large technical capability and a significant amount of trained personnel.

These problems have led to increased uncertainty around large nuclear reactors in USA and Europe, given their poor track record on several key performance indicators (affordability + predictability). The same problems are likely to happen in Africa if such nuclear reactors are adopted.

However, small modular reactors (SMRs) might offer an attractive alternative which would be better suited for Africa.

SMRs are defined as reactors that provide a maximum output of 300 MW electrical power with a significant number of components manufactured and integrated in factories which can be assembled on site taking advantage of modular construction techniques. SMRs offer a number of advantages at different levels:

- Economics:
  - CAPEX: SMRs require an initial reduced capital investment which limits risks and, in turn, the cost of financing construction;

  - Factory production: parts of the plant that require high levels of quality assurance can be manufactured in a controlled environment taking advantage of accelerated learning;
  - Modularity: the addition of modules of up to 300 MW improves the economy and allows matching expenditure and return periods.

- Safety:
  - Passive safety features: smaller size means smaller source terms and smaller decay heat loads. These can be handled taking advantage of inherent and passive safety features.
  - Proliferation-resistant: depending on the design, SMRs can operate with very long fuel cycles.
  - Modularity: standardization and economies of volume have a positive impact on safety through better return of experience.

- Integration:
  - Grid: they have a smaller impact on the grid, which allows for an easier integration in countries with a less developed infrastructure;
  - Baseload: they provide a stable and predictable baseload;
  - Accessibility: SMRs can make electricity accessible in remote regions.

A recent study performed for the International Atomic Energy Agency by the Center for Advanced Energy Studies' Energy Policy Institute (EPI) at Boise State University (SOLAN 2015) in the United States, identified twenty-two indicators that can be used by a country to understand its level of readiness to adopt nuclear. From those, seven indicators are focused on meeting growing energy demands that could be accommodated by selecting and deploying SMR technology.

The assessment that needs to be made against each of these indicators is likely to be different whether the country is trying to assess its readiness level for adopting SMRs or large nuclear technology. But in essence, the questions need to be focused on where the country is today and what it is trying to achieve by adopting nuclear. Is the country trying to cope with an increasing demand or trying to develop remote areas? What are the characteristics of the grid? What are the physical (geography, climate, geology,…) characteristics of the country? Depending on answers to these questions an assessment of deployment indicators might conclude that a country is not ready, or well-suited for large nuclear. However, it might still be for the deployment of SMRs.

The indicators selected in the study are shown in table 1 with the indicators that are particularly important to SMR technology highlighted in red. Indicator data for the assessment can be harvested from local governments or from institutions such as the World Bank, the Organization for Economic Cooperation and Development, the World Economic Forum or the International Energy Agency.

SMRs can achieve cost reductions in a number of different ways. In the long term, and although the initial specific cost (per MW) of SMRs relative to large nuclear is likely to be larger due to the development costs, SMRs have the potential to see technology costs reduce at a faster rate than large nuclear costs due to a higher pace and volume of reactor production, but also because of the stronger learning that could be achieved with a greater proportion of factory-built components.

Table 1

Nuclear deployment categories and indicators*

Demand and energy	**Financial and economic**	**Physical and legal infrastructure**	**Carbon reduction incentives**
Gross Domestic Product growth rate	Gross Domestic Product (PPP)	Total installed electric capacity	Carbon dioxide emissions per capita
Growth rate primary energy consumption	Per capita GDP (PPP)	Infrastructure index	Fossil fuel energy consumption (% of total)
Per capita energy consumption	International trade (% of GDP)	Ease of doing business index	Oil, gas, coal (% of electric capacity)
Percent rural population	Foreign direct investment, net inflow (% of GDP)	Rule of law index	Energy imports (% total energy use)
Desalination capacity	Credit rating / External debt stock	Political stability and absence of violence index	Uranium resources
District heating demand			
Energy intensive industries			

* Indicators particularly important to SMR technology are highlighted in red (Solan 2015).

A cost reduction due to a higher pace and volume of production can only be justified if there is a market to sustain those. A study from the UK National Nuclear Laboratory (NNL 2014) concluded that there is a very significant market for SMRs when they fulfil a need that cannot, in all circumstances, be met by large nuclear plants. The size of this potential market is calculated to be approximately 65-85 GW by 2035 and it is valued at $330-$530 billion, if the economy is competitive The same study shows that SMRs can also fulfil a market niche for alternative applications to traditional grid connection electricity production, such as desalination, production of district heating or using SMRs off-grid in remote areas. The African continent could also take advantage of these features of SMR electricity production to attend some of its specific needs.

Licensing Aspects

An important aspect of nuclear power is that it requires the existence of a safety authority that has competence and capabilities in the areas of nuclear engineering and radiation protection. This requires the availability of large numbers of suitably qualified and experienced personnel which is not always easy to find in newcomer countries.

The Forum of Nuclear Regulatory Bodies in Africa (FNRBA) provides an efficient and effective regional network advancing excellence in regulatory systems for radiation protection, nuclear safety and security in Africa (Bester 2016). It does so by:

- Creating awareness amongst policy makers;
- Ensuring understanding, development, promotion and implementation of high standards of radiation protection, nuclear safety and security;
- Implementing capacity-building activities at regional and national level;
- Promoting the harmonization of regulatory frameworks across different countries.

The FNRBA is organized in different thematic working groups covering legislation and regulation, radiation safety, regulatory frameworks, education and training, waste management, transport safety and emergency planning and response. It offers an excellent platform for the development and harmonization of regulatory requirements, but also for the training and development of nuclear professionals who would be needed to establish utilities in Africa as operators of nuclear power plants.

In fact, the commercial success of SMRs is highly linked to the development of a harmonized regulatory framework that can be internationally accepted. This is necessary because the current business case in SMRs is based on the production in factories placed in one country that exports SMRs globally. Current regulatory frameworks are very rigid, and it often happens that designs having been approved by a regulator in one country need to be substantially changed before being approved by a different regulator in a different country. This is a costly and time-consuming process which would make impossible to achieve some of the potential benefits of SMRs.

At present, there are a number of working groups in the area of international regulatory harmonization of SMRs. These could be joined by African regulators in order to make sure that the needs and the specific characteristics of the African continent are taken into account when elaborating these harmonized regulatory frameworks.

The IAEA Regulators Forum (IAEA 2017) aims at identifying, understanding and addressing key regulatory challenges that may emerge in future SMR regulatory discussions. The forum produces position statements on regulatory issues, suggests revisions to IAEA documents to adapt them to the reality of SMRs, and makes proposals for enhanced regulatory frameworks.

The SMR task force of the World Nuclear Association within the Cooperation in Reactor Design Evaluation and Licensing group (CORDEL), has a mission to promote the standardization of SMR designs. The task force claims that harmonization of licensing for SMRs will attract investment as it will increase the predictability of regulatory activities. Apart from the benefits of this for exporting or importing the technology, the reduction of licensing risks will directly translate into a reduction of cost for potential investors, developers and operators. The group ultimately aims to justify a new approach to licensing, given the design characteristics of a SMR (WNA 2015). This approach is based on the issuing of an international design certification that will be accepted by several countries.

The MYRRHA Project
(Multipurpose hYbrid Research Reactor for High-tech Applications)

MYRRHA is a flexible fast spectrum irradiation facility, operating as a subcritical (accelerator-driven) or critical system for material and fuel developments for GEN IV and fusion reactors and also for radioisotope production. Operating as an accelerator-driven system the aim of MYRRHA is to demonstrate the ADS concept and the efficient transmutation of high-level nuclear waste (minor actinides). A schematic representation of MYRRHA is shown in figure 5.

MYRRHA has been conceived as a multipurpose flexible irradiation facility that can replace the research reactor BR2 currently in operation at SCK•CEN in Mol. MYRRHA will support the next generation of research projects needed to sustain the research centre’s future.

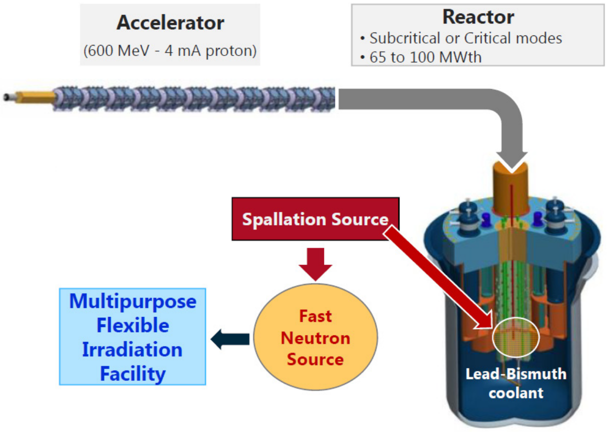

Fig. 5. — The MYRRHA reactor.

One of the main scientific interests of MYRRHA arises from the clear need to obtain a sustainable solution for the high-level long-lived radioactive waste (HLLW) consisting of minor actinides (MAs), namely Neptunium, Americium, Curium and long-lived fission products (LLFPs). These MA and LLFP stocks need to be managed in an appropriate way. Reprocessing and geological disposal are today the proposed solutions. However, the timescales required for geological disposal exceed the time span of several generations and this creates problems of public acceptance for this unwanted legacy. The partitioning and transmutation concept has been pointed out in numerous studies (OECD/NEA 2002) as the strategy that can relax the constraints on the geological disposal of waste, and that can reduce the monitoring period to a technologically-manageable timescale. These are the concepts whose feasibility MYRRHA aims at demonstrating.

An SMR for Africa Based on MYRRHA Technology

Among the many applications of MYRRHA is the development of technology for fast metal cooled reactors that could be easily transferable to the design of an SMR. On top of the advantages already discussed of SMRs over large nuclear plants, a Lead Small Modular Fast Reactor (LSMFR) presents further advantages over those offered by SMRs based on a different technology and, in particular, light water. These advantages can be summarized in four main areas:

- Safety: the LSMFR is a small reactor that, due to the lower levels of energy and residual heat produced by the core, can be cooled by passive means using natural circulation and, therefore, without any pumps or other active components. Lead also has inherent safety benefits for the prevention and mitigation of accidents when compared to water, in terms of specific heat and thermal conductivity. Finally, lead shows good retention properties for a number of radiotoxic isotopes.
- Sustainability: the technology for LSMFRs is developed in the MYRRHA project, which makes a closed fuel cycle possible with full recycling of the nuclear fuel in a manageable timescale. On top of that, the LSMFR is a reactor that operates with enhanced efficiency generating less waste than those based on a different technology.
- Affordability: the highest efficiency achieved in the use of the fuel and the longer fuel cycle result in higher operational efficiencies and, in turn, lower operational costs. The inherent safety features of the reactor and the passive safety systems translate into a design with less nuclear grade systems and lower costs for construction and maintenance.
- Operation: a LSMFR can be used to develop remote areas where there is momentarily no access to the grid. When connected to the grid, the LSMFR

offers reliable baseload capacity with the ability to load follow, providing price stability by matching the demand for electricity with the offer.

Transferring the technology developed by MYRRHA into a LSMFR is straightforward. MYRRHA is a research reactor planned to be built on the site of SCK•CEN in Mol toward 2030. MYRRHA will be the first prototype in the world with an accelerator-driven system. Given the impact that research done through MYRRHA is likely to have in the well-being of the society, it is expected that MYRRHA will be financed to a large extent with the support of the Belgian government and other supranational institutions such as the European Investment Bank.

MYRRHA is based on a technology using Lead-Bismuth Eutectic (LBE) as a coolant, instead of lead. For the development of a power reactor, lead has a number of advantages over LBE, but both coolant media are sufficiently similar to allow for a straightforward transfer of technology. This is schematically shown in figure 6.

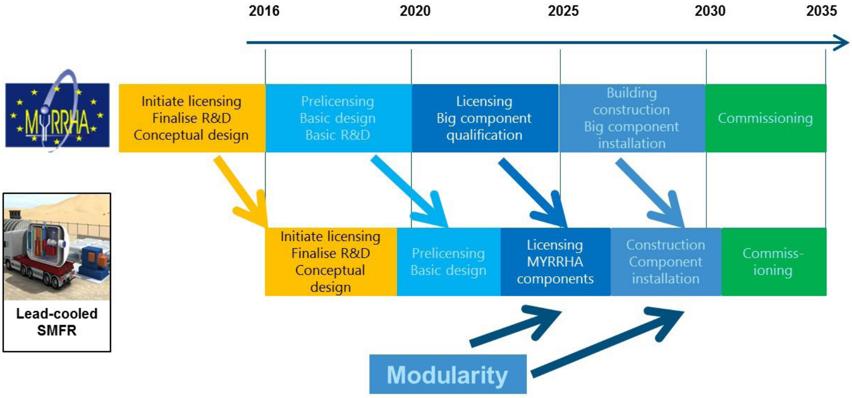

Fig. 6. — Technology transfer from MYRRHA to a lead cooled small modular fast reactor.

Based on the current development programme for MYRRHA, the technology is already at a point where a transfer can start by introducing the concept of modularity for the development of a power reactor. The first units of a LSMFR can be commissioned toward 2035. As the first units go into operation, research done with MYRRHA will allow for the development of materials able to stand ultrahigh temperature conditions. This will allow for a second generation of LSMFRs that can take advantage of the operational experience of the first generation, and operate with higher efficiency due to the use of more advanced materials. This second generation of LSMFRs could be ready for the market toward the half of the century.

Conclusion

This paper provides an analysis of the current situation in the African energy market and presents the small modular reactor nuclear technology as an option for the economic development of the continent. The most sustainable option for this economic development is likely to be based on an energy mix where renewables will offer carbon-free electricity by taking advantage of the vast natural resources of the continent. The inherent lack of reliability of renewable sources can be compensated by the stable, carbon-free, non-intermittent baseload provided by nuclear power plants. Large nuclear power plants have been challenged in Europe and USA by budget delays and cost overruns that have put in doubt the viability of developing such a large GW plant. Small modular reactor technology is an affordable nuclear option and offers a number of advantages in terms of safety and sustainability. Furthermore, their ability to be used in areas with underdeveloped grids or no grid at all, and the possibility of using the technology for desalination and other off-grid applications, place SMR technology in an outstanding position to help the African continent in solving the challenges of today and developing its full potential.

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Wood: An Ever Present Domestic Energy Priority for People in Emerging Africa

by

Jean-Noël Marien[*], Régis Peltier[**], Émilien Dubiez[**] &
Théodore Trefon[***]

Keywords. — Africa; Domestic Energy; Charcoal; Natural Resource Sustainable Management; Agroforestry.

Summary. — In most African countries, the use of wood for domestic energy involves numerous, interacting issues. Wood mainly comes from degraded natural forests and is generally produced within traditional agricultural systems (*e.g.*, shifting cultivation). Sustainable management of wood-energy resources is possible and is one of the keys for the future. This was demonstrated by the Makala project in DR Congo, which developed on a large scale various operational tools for sustainable wood resource management. Given that urban population growth will in many cases lead to increased household energy requirements that will surpass what tree formations can provide, planners should consider the development of energy mixes that combine the sustainable production of wood energy with a partial transition to other energy sources (fossil, hydro-electricity, solar or biomass). The importance of carbon economy must be understood by examining some international processes such as the REDD initiative ("Reducing Emissions from Deforestation and Forest Degradation") and the Green Fund for the Climate (UN).

1. Wood Energy for People in Africa: Main Drivers and Issues

1.1. Main Drivers

1.1.1. Wood Resource

Of all the wood removed from forests and woody ecosystems in Africa, 80 to 90 % are intended for wood energy. However, wood-energy consumption varies according to sub-regions (from 0.25 in dry areas to 1 m^3/inhabitant/year in Central Africa). The wood productivity of tropical forest ecosystems varies from 0.5 to 10 m^3/ha/year for natural forests and 5 to 25 m^3/ha/year for plantations, depending on how well they are managed (Marien 2010).

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[*] Retired CIRAD UR Forêts et Sociétés, Montpellier (France).
[**] CIRAD UR Forêts et Sociétés, av. Agropolis, F-34398 Montpellier Cedex 5 (France).
[***] Royal Museum for Central Africa, Leuvensesteenweg 13, B-3080 Tervuren (Belgium).

While most resources come from unmanaged, multi-use forests, urban and suburban forests provide a major (and increasing) part of wood-energy supply for urban areas (Marien 2008). At present, the wood-energy supply comes from all raw sources (forests, agroforests, trees outside forests, agriculture residues, wood industry by-products,…). Wood resources supplied to big cities can originate from distant locations as transportation represents a small part of the total cost. This means that wood still arrives in towns and that the predicted "fuelwood crisis" has not (yet!) occurred.

1.1.2. Social Drivers

Population growth in Africa, which is on average 3 to 5 % per year, is the major driver of domestic energy consumption (Marien 2009). Urbanization is another factor. In 1970, only eighteen cities had a population of over one million; in 2020, over seventy cities are expected to do so.

Wood energy for domestic use reveals two sides of a dilemma. On the one hand, it is a major health and gender issue in cities; on the other, it provides a lot of jobs and income for the poorest population (the use of wood and charcoal generates twenty times more jobs than fossil fuels). Another important related issue is the perception of wood resources as a shared heritage, which tends to be weak when populations are trapped in poverty.

A global trend is a shift from fuelwood to charcoal in cities, which is determined by the availability and cost of fuelwood and charcoal and household incomes.

1.1.3. Economic Drivers

Compared to other forest products (industrial wood, bushmeat, NWFP/Non-Wood Forest Products,...), wood energy (in a broad sense) is one of the most important. It is part of a mainly informal economy and fragmented supply chain, but one that can be very organized depending on local supply and market conditions.

In many countries, the relation between supply and demand becomes unbalanced, with few effects on prices but a lot of negative impacts on forest and the degradation of ecosystems. The shift from wood energy towards other energies depends mainly on subsidies from governments.

1.1.4. Institutional Drivers

Institutional drivers are commonly noted as potentially major tools to orientate policies. This has been demonstrated in numerous African countries (Trefon 2016). For example, there is often a dichotomy and confrontation between government authority, based on laws, and traditional authority, based on local power.

Secure land rights and tenure are essential for a long-term management perspective and investment. In many countries, however, there is a lack of clear governance and effective application of laws.

The development of alternative energies (fossil or renewable) also relies on strong national policies and incentives, but LCA (Life Cycle Analysis) has yet to be done.

1.1.5. Environmental Drivers

The environmental impacts of wood energy must be assessed on two scales:

- A spatial scale, as impacts and consequences on environmental issues vary as one moves from a compartment or forest area to a landscape and large supply area;
- A time scale, as short-term (*e.g.*, supply distances) impacts are not the same as long-term events (*e.g.*, climate change).

1.2. Domestic Energy Needs in Cities: From Key Factors to Topology Analysis

More than 50 % of the population in Africa are now living in urban areas, and this figure will continue to increase in the future. As a lot of these new urban residents come from rural areas, a rural approach to domestic energy supply often persists. This can change after one or two generations as ties to nature and rural ways of life are gradually disappearing.

Urban domestic energy needs continue to increase and have huge impacts on forest degradation and deforestation on an ever larger scale. Although road networks remain poor, this does not impede trucks from carrying charcoal or wood from remote areas to towns.

However, wood energy in suburban areas is an issue which is affecting to varying degrees almost the entire African continent. With the exception of a few countries, the situation is getting worse. It may soon become totally out of control and lead to incalculable consequences on the environment and the development of African societies. This is particularly true in megacities, whose rapid increase in size and number is not matched with updated management. So far, solutions have only been defined and applied at local level. There are no simple solutions to the questions raised by the recent awareness of this problem. If global strategies are not defined and implemented regarding, for example, the sustainable management of Central African forests, there is a high risk of major disaster.

Initially, it is important to clearly identify and prioritize the main criteria and indicators determining the interactions between cities and suburban forests with regard to wood energy (Marien 2010). We should therefore quickly come to a comprehensive typology of local situations. This typology and the segmentation that could be achieved is likely to guide the definition of priority intervention strategies.

A typology of energy supply can vary according to the various factors considered. To explore this variation, a typology study, which considered a large range of characteristics related to domestic energy, was carried out on fourteen African towns. Eight criteria were analysed, each of them associated with one or more indicators as described in table 1 below.

Table 1

Criteria and indicators related to domestic energy.

	Criteria	Indicators
1	City size and consumption	Number of inhabitants Consumption of wood, charcoal and other woodfuel Share of wood in the energy balance of the city
2	Use and consumption distribution	Consumption by type of use (heating, electricity, cooking, crafts, industry,...)
3	Current trends	Evolution of consumption Evolution of types of energy
4	Resource types	Resource types Dedicated use or not (plantations/natural forest) Average productivity Access rules, rules of use
5	Spatial distribution of the resource	Distribution (homogeneity, fragmentation) Accessibility (distance, cost)
6	Production organization	Actors of the cut (farmers, professionals) Level of professionalization Level of organization (cooperatives) Technical mastery (chainsaws, carbonization techniques,...)
7	Collection, transport and distribution organization	Level of concentration Rules of access to the profession
8	Exploitation and marketing control	Organization Number of controls, fines

One result of our analysis is linked to the situation of forest ecosystems in relation to urban pressure on wood products. Four cases can be distinguished (fig. 1):

— No significant pressure (*e.g.*, Rabat, Cape Town): this includes towns which have developed a strong and vigorous policy of alternative domestic energy sources.

— Low pressure (*e.g.*, Pokola, Mahajanga, Ifrane, Pointe-Noire, Antananarivo): wood resources are managed (it can be in different ways). While not perfect, forest management provides towns a fair supply with relatively low impacts, except if natural conditions are difficult, as in the Sahel (*e.g.*, Bamako, Ouagadougou, Abéché).

— Strong pressure on wood resource in dry areas (*e.g.*, Conakry, Bangui): if natural resources are not managed, the situation is more critical and pressure on natural resources is directly related to the city size. The situation becomes complex and very difficult to manage if these cities grow rapidly, even in relatively favourable areas.

- Megacities mean mega problems (*e.g.*, Abuja, Kinshasa): the situation is out of control and natural resource degradation is a major problem on a large scale, which can cover several hundreds of kilometres around such cities.

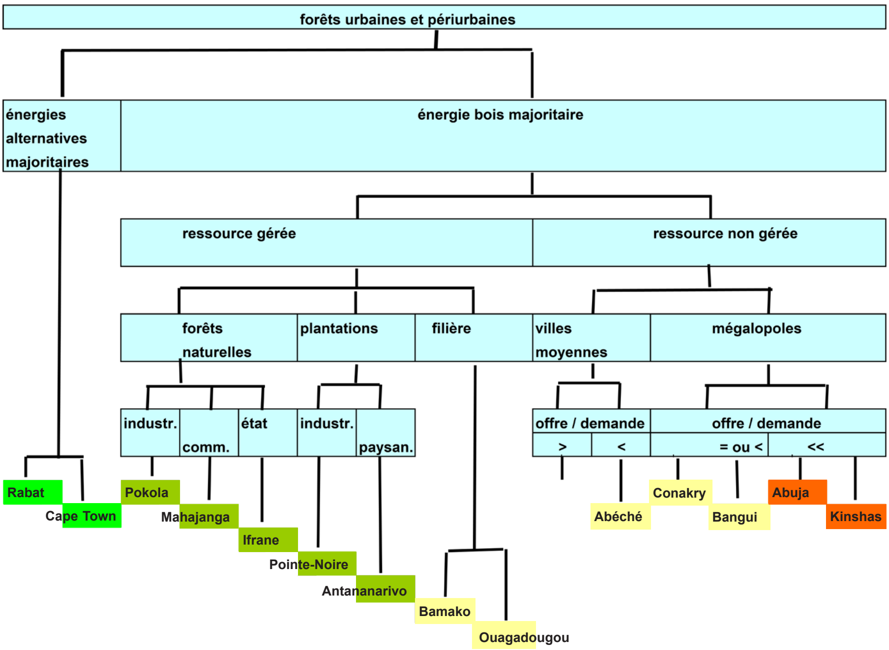

Fig. 1. — Typology example of suburban forests in Africa.

The search for solutions must be adapted to each individual case. Inspiration can be drawn from measures that have already been successful in other African cities. This typology example shows that it is possible to maintain, or even create, urban and suburban forestry provided that certain basic rules are followed.

2. A Case Study: The Republic of Guinea (Conakry)

The case of the Republic of Guinea (fig. 2) may be used as an illustration. The country is very diverse, ranging from semi-arid areas to humid forests and from rural areas to the heavily populated capital (Marien 2017).

Fig. 2. — Map of the Republic of Guinea.

2.1. An Institutional and Fiscal Framework for Wood Energy Exists… but is not often Applied

Legal texts on wood energy do exist, showing the importance of this resource for the country:

- The “Forest Code” is still in draft form but is quite complete and deals with all kinds of forestry. Wood energy is therefore considered as the wood with a diameter greater than or equal to ten centimetres, intended for firewood or charcoal. Authorization can be required or not, according to the forestry regime. Collection of taxes and royalties is clearly mentioned. Operation and movement of wood energy is allowed only with authorization.
- Decree 5019 (September 2016) states that charcoal is considered as a non-wood forest product and that a professional licence is required.
- Decree 6009 (September 2016) lays out the level of taxes and royalties as follows: cutting royalties: firewood = 5,000 FG/stere and charcoal = 1,000 FG/kg; allocation of revenue: development fund = 50 %; functioning local structure = 50 %.

These contributions are determined at national level and focus on mitigation measures (technologies, practices and sustainable forest management).

However, as in many other countries, these regulations are applied irregularly and much progress remains to be made at various levels.

2.2. An Important and Ever Increasing National Consumption

National annual consumption of wood energy is about 1 m^3 equivalent of wood/inhabitant/year, which is the average for many tropical African countries. The type of wood energy varies, with charcoal accounting for 80 % of wood energy consumption in urban areas, while fuelwood represents 90 % of consumption in rural areas.

It has also been found that:

- Individual consumption is 0.5 kg charcoal/person/day, amounting to ten to twelve million cubic metres equivalent of wood/year (9.6 million tons equivalent of wood/year).
- This important quantity of wood means that nearly five million tons of carbon (or twelve million tons CO_2) are burnt each year. This means that wood energy also can become a major tool in the perspective of a future national REDD strategy.
- Low productivity is a significant issue for charcoal production as the average charcoal productivity is 15 % (but can increase to 20 to 25 % with improved production processes).

2.3. An Important Economic Contribution at All Levels of the Supply Chain

Another point to note is the short supply chain, with generally two to four steps from the forest to the final consumer. Wood energy represents an income opportunity at all levels, including in rural areas. In figure 3, we show two supply chain cases:

- In the first case, a very short supply chain (two levels) shows that the major part of income is located at the production level, with a small part at the transport level. Most of the benefit stays in the rural area.
- In the second case, the supply chain is professional and more complex. We clearly see that most of the benefit is transferred from the rural production level to the urban retailer level.

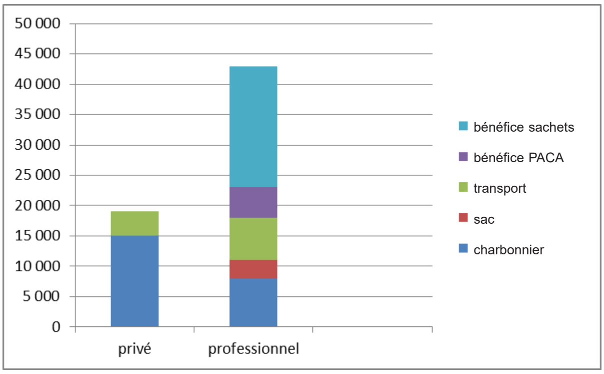

Fig. 3. — Conakry wood-energy supply chain (private producers/professionals).

2.4. A Major Contribution to Natural Resource Degradation

A transect was undertaken from the capital city Conakry to Dabola, 350 km east, along the main road. On a 5 km scale, we counted the number of charcoal bags along the road (in blue in figure 4). At the same time, we noted the wood resource going from 0 (no vegetation) to 3 (good availability of wood — natural, planted or agroforestry — in red dotted).

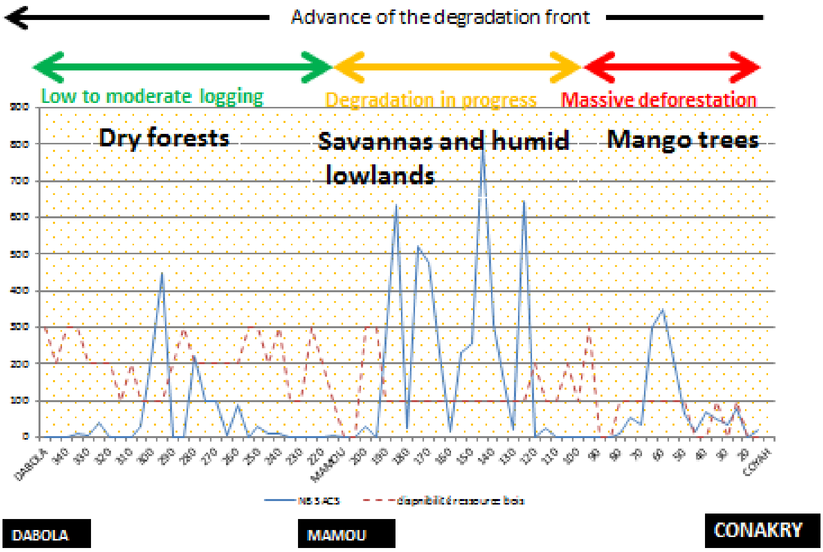

Fig. 4. — Number of charcoal bags and wood resource types, along the road from Conakry to Dabola (350 km).

Three steps of degradation are clearly seen:

- From Conakry to 100 km east, there is massive deforestation with no more forests, not even degraded ones. The only wood resource comes from fruit trees (mangoes,…).
- From 100 km to Mamou (200 km), degradation is in progress. The main wood-energy supply of Conakry comes from this area, as indicated by the high number of charcoal bags on sale.
- After 200 km, the situation is getting better and natural vegetation is observed, even if composed of dry forests, which remain present and in relatively good condition.

If no action is taken, the situation is likely to deteriorate and the degradation zone will rapidly spread eastwards.

3. Actions to Find Solutions:
The Makala (= Charcoal in Lingala) Project

3.1. Sustainable Management of Wood-Energy Resource in Central Africa

The following data are widely shared on wood energy in Central Africa:

- It represents 90 % of the wood exported out of forests (Marien 2013);
- It is the first factor, together with shifting cultivation, behind forest ecosystem degradation and deforestation (Molinario *et al.* 2015);
- An ever-increasing imbalance between supply and demand is expected in the future;
- Supply areas are constantly widening;
- Supply chains are 100 % informal, but very well organized;
- The share of profits is particularly unequal;
- Laws and regulations are weak and/or not applied;
- Land tenure securitization is a global problem with no short-term solution.

But also:

- Efficient technical solutions do exist (Megevand *et al.* 2013);
- Wood energy creates jobs and income-generating opportunities in remote and poor rural areas;
- It represents major economic and social opportunities in most countries in the region;
- In the majority of cases, the natural regeneration and growth dynamics of forest ecosystems remain important.

3.2. Makala Project: Actions Focused on Wood Resource

From 2009 to 2014, the Makala project, funded by the European Union (EU EuropeAid DCI-ENV/2008/151-384), undertook research and development activities in DR Congo and PR Congo. The project addressed the following points in particular:

- Knowledge of supply chain;
- Degraded forest rehabilitation and restoration;
- Dedicated wood resource creation;
- Community landscape organization and management;
- Training;
- Prospective studies on the future of the wood-energy sector and the evolution of ecosystems.

Among the many results obtained by the project, most of which can be found on CIRAD's website (http://makala.cirad.fr/), we can briefly mention the following:

- The wood-energy supply chains of Kinshasa and Kisangani were described and quantified. The population of Kinshasa is estimated at ten million inhabitants, 90 % of whom rely largely on charcoal for cooking. This value chain supports more than three hundred thousand producers, transporters and traders. The city's annual needs were assessed at 4.8 million cubic metres of wood equivalent, in the form of firewood or charcoal, with a value of one hundred forty-three million US$ (SCHURE 2014). Shifting agriculture practised most often in forest covers most of the demand for food (cassava and maize) and charcoal.
- Institutional and socioeconomic environment, including land tenure, were analysed (VERMEULEN *et al.* 2011).
- An analysis of land-cover change allows one to understand and document the spatial organization and mechanisms of forest degradation and forest stand restoration. Between 2000 and 2012, the average volume of woodfuel in Kinshasa's woodfuel supply basin fell by more than 50 % (GOND *et al.* 2016).
- Large areas of agroforestry plantations were made by and for farmers (BISIAUX *et al.* 2013).
- Degraded forest regeneration techniques were tested and made available. The objective was to adapt and test Assisted Natural Regeneration (ANR) and to improve slash-and-burn crop systems. The sprouts and root suckers of natural forest species protected by ANR during agricultural weeding grow rapidly inside the plots, allowing the quick installation of woody fallow without costly inputs or heavy labour. In 2014, three and a half years after slashing and burning, these fallows had greater biodiversity and biomass than non-ANR fallows. Charcoal and crop productivity were improved (PELTIER *et al.* 2014a).
- Community landscapes were organized with participative management plans (PELTIER *et al.* 2015).
- Charcoal production techniques were improved (PINTA *et al.* 2014).
- Technical and university level training courses were targeted.
- Prospective analysis has shown that only a conscious woodfuel resource policy and sustainable community land management, combined with a very high dynamic of tree reintroduction on agricultural land, can reverse the degradation curve.

3.3. NEW PERSPECTIVES

The final report of the prospective analysis on forest ecosystems of Central Africa, produced for Comifac in July 2013, gave the following recommendations (MARIEN & BASSALER 2013):

- Anticipate future changes, identify priority areas, using the map of forest socio-ecosystems of Central Africa (fig. 5) and plan specific activities;
- Adapt solutions to the local environment;
- Include various land uses in community landscape planning;
- Enhance the development of an economically-viable resource;
- Develop more sustainable family agriculture;
- Quantify the non-monetary values of a sustainable wood-energy resource.

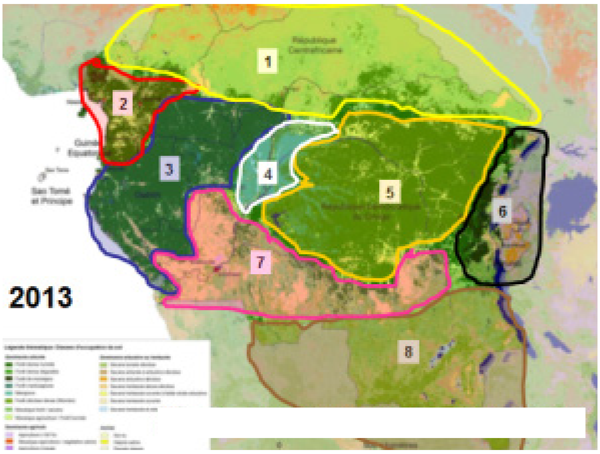

Fig. 5. — Map of forest socio-ecosystems of Central Africa.

4. Main Conclusions

- Wood is the most important domestic energy source in most African countries, and in both urban and rural areas;
- This is a long-term trend, with an important informal economy component;
- Negative impacts on natural ecosystems are very important, with extensive deforestation and forest degradation;
- Even when available, there are few examples of large-scale energy source substitution for domestic uses;
- National policies and regulations are often unable to address the problem effectively.

Our vision is the following:

Given that urban population growth will in many cases lead to an increase in household energy requirements which will surpass what can be provided by tree formations, we argue that planners should consider the development of energy mixes that combine the sustainable production of wood energy with a partial transition to other energy sources (fossil, hydro-electricity, solar or biomass).

The importance of carbon economy has to be examined through some international processes such as the REDD initiative and the Green Climate Fund (UN).

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Sharing Knowledge Online and Improving Education by Using MOOCs

by

Sandra SOARES-FRAZÃO[*] & Yves ZECH[*]

KEYWORDS. — Online Course; MOOC; Fluvial Hydraulics; Sediment Transport; RESCIF; North-South Exchanges.

SUMMARY. — In the frame of the RESCIF (*Réseau d'Excellence des Sciences de l'Ingénieur de la Francophonie*) network and the MOOCs for Africa's initiative, a MOOC (Massive Open Online Course) in fluvial hydraulics was developed by the *Université d'État d'Haïti* (UEH), the *Université catholique de Louvain* (UCL, Belgium) and the *École polytechnique fédérale de Lausanne* (EPFL). The first edition (2016) was organized in eight weeks with quizzes, intermediate and final exams. This paper deals with the challenges and the advantages of such a collaborative approach for a hard-science topic with heterogeneous and distant audience. Some statistics of participation are presented and discussed, leading to modifications of the course for the second edition. For this second edition (2017-2018), special attention will be paid for assessing the efficiency of such a MOOC in terms of North-South exchanges.

Context of the MOOC Project

The RESCIF network (*Réseau d'Excellence des Sciences de l'Ingénieur de la Francophonie*) was launched in 2010 by the *École polytechnique fédérale de Lausanne* (EPFL) around three priorities: water, energy and food security. The network includes fourteen faculties of engineering from eleven countries in Africa, America, Asia, Europe and the Middle East. One of its main objectives is the training of young researchers in developing countries, among others by the conception of MOOCs.

A complementary initiative of EPFL was the launching of MOOCs for Africa in 2013. In line with the RESCIF network, the programme focused on higher education by developing and co-developing MOOCs for the undergraduate, graduate and continuing education. Inside and with the support of this initiative, three members of the RESCIF network — the *Université d'État d'Haïti* (UEH), the *Université catholique de Louvain* (UCL, Belgium) and the *École polytech-*

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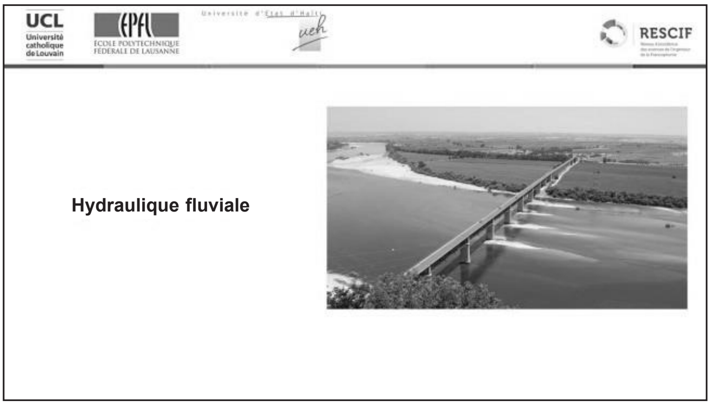
[*] Institute of Mechanics, Materials and Civil Engineering (IMMC), Université catholique de Louvain, Place du Levant 1, B-1348 Louvain-la-Neuve (Belgium).

nique fédérale de Lausanne (EPFL) — joined their efforts to build a MOOC in French on fluvial hydraulics (fig. 1).



Hydraulique fluviale

Fig. 1. — A collaborative MOOC on fluvial hydraulics.

River management, and specifically flood management, is crucial for the Haitian territory where a large part of the population is dependent on agriculture and is thus very sensitive to the river flow, especially during cyclonic events. In this context, improving local river knowledge is a clear priority for the country. Therefore, the topic of fluvial hydraulics, as a mix of universal physically-based theories and local observations and experience, offers a perfect opportunity of win-win collaboration where local expertise complements and enriches universal knowledge. Moreover, another cooperation programme, funded by the Belgian *Académie de Recherche et d'Enseignement supérieur – Commission de la Coopération au Développement* (ARES-CCD) for the period 2014-2019, aims precisely at improving the ability of Haitian institutions to better understand and manage their rivers and prevent potential flood damage. In this context, a collaborative MOOC with the *Université d'État d'Haïti* appeared as something evident.

This paper presents the content and the organization of the MOOC and some experience from the first-year run.

Building a Collaborative MOOC

A North-South collaborative MOOC project is something amazing but not simple to operate. The challenge was to combine the theoretical expertise of some of the participants to the field experience of other contributors. Initially, it was expected that most of the work could be carried out on a remote mode, but it was rapidly noted that face-to-face meetings are crucial for the smooth running of the project and for the coherence of the final product.

Thanks to a double financial support from UCLouvainX fund for technical development and from EPFL MOOCs for Africa fund for mobility, it was possible to have some movie records in Haiti, which allowed very rich *in situ* illustrations for the course.

Objectives and Content of the Course

The course basically aims at better understanding the river behaviour in order to better manage it. This means better understanding of the river flow mechanisms, of the sediment transport mechanisms and of the morphological evolutions of the river (fig. 2).

Plan du cours

UCL
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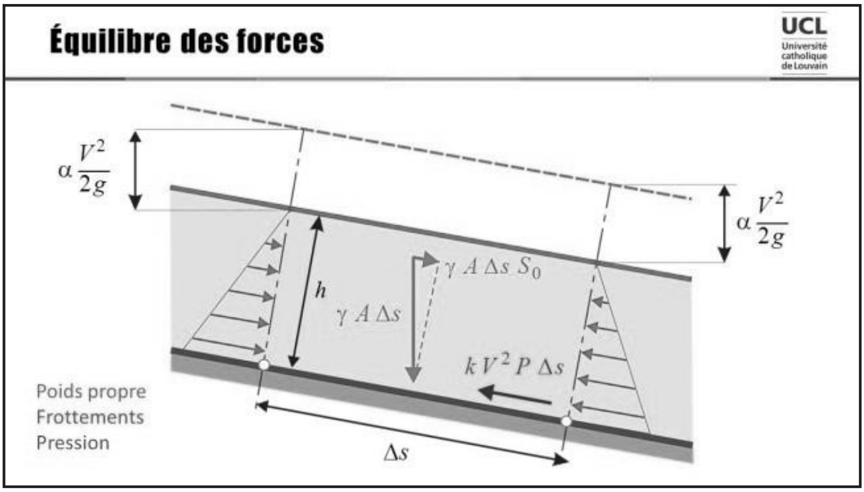
catholique
de Louvain

- L'écoulement en rivière: les lignes d'eau
  - Un modèle de référence simple: l'écoulement uniforme
  - Un modèle plus réaliste: l'écoulement non uniforme ou graduellement varié
  - Le lien entre les lignes d'eau: les ressauts
  - L'écoulement en géométrie complexe: singularités et obstacles
- Sédiments et transport solide
- Morphologie fluviale

Fig. 2. — Course outline (in French).

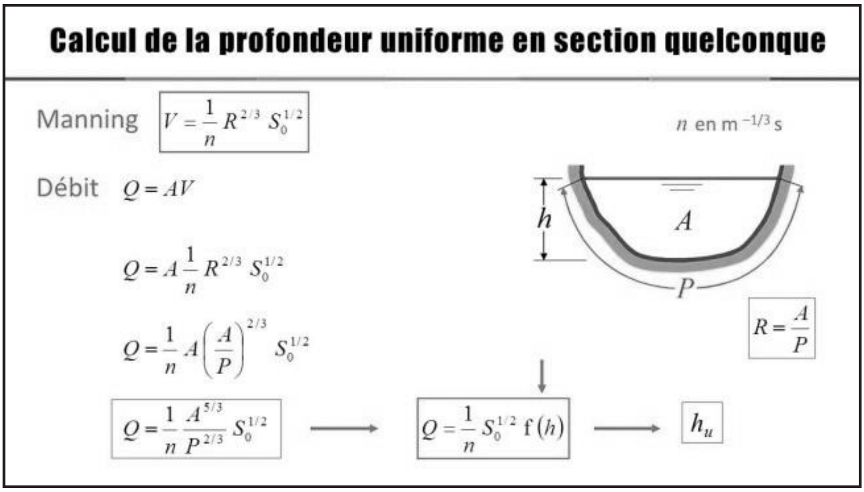
The course runs over eight weeks, each week including five lessons. Typically, a lesson consists of one or two videos presenting the theory and the computational aspects, followed by some quizzes that are automatically noted by the system. Two exams are provided, one at mid-term and the other one at the end of the course with a weight of half the total note. This schedule appeared too heavy for the majority of learners and from the second edition 2017-2018 it was decided to divide the courses into two parts of four weeks each. Two types of quizzes are proposed: multiple choice or numerical results. Besides, a forum was open for questions and discussions and revealed to be fruitful as well for learners as for teachers.

The first part about river flow mechanisms introduces some essential concepts of open-channel hydraulics: uniform flow, non-uniform or gradually-varied flow, hydraulic jumps. As an example, figure 3 shows the physical background of the uniform flow model (the equilibrium of forces acting on a given control volume of fluid) and the translation of this concept into equations.



Équilibre des forces

Poids propre
Frottements
Pression



Calcul de la profondeur uniforme en section quelconque

Manning $\boxed{V = \frac{1}{n} R^{2/3} S_0^{1/2}}$

n en m$^{-1/3}$ s

Débit $Q = AV$

$$Q = A \frac{1}{n} R^{2/3} S_0^{1/2}$$

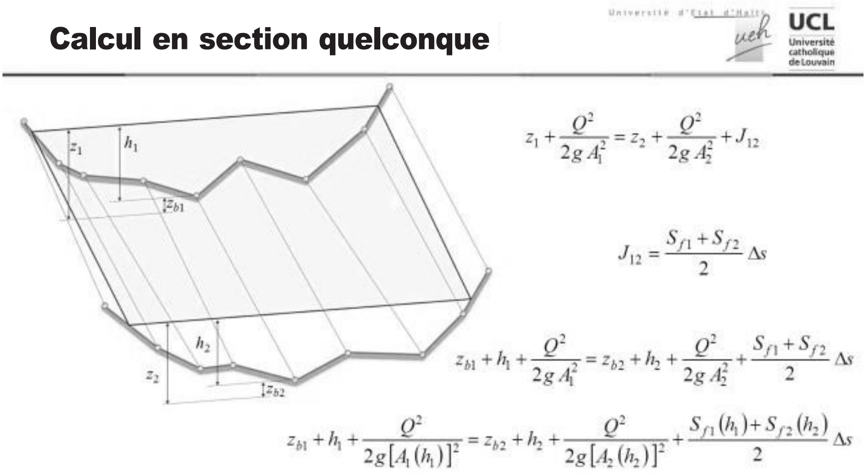
$$Q = \frac{1}{n} A \left(\frac{A}{P}\right)^{2/3} S_0^{1/2}$$

$$\boxed{R = \frac{A}{P}}$$

$$\boxed{Q = \frac{1}{n} \frac{A^{5/3}}{P^{2/3}} S_0^{1/2}} \longrightarrow \boxed{Q = \frac{1}{n} S_0^{1/2} \mathrm{f}(h)} \longrightarrow \boxed{h_u}$$

Fig. 3 — Uniform flow model: physical assumption (equilibrium of forces) and translation into equations.

The course also explains how to compute the relevant parameters in practice as well in prismatic canals (as irrigation canals) as in complex geometries generally featured by natural rivers (fig. 4).



Calcul en section quelconque

$$z_1 + \frac{Q^2}{2g A_1^2} = z_2 + \frac{Q^2}{2g A_2^2} + J_{12}$$

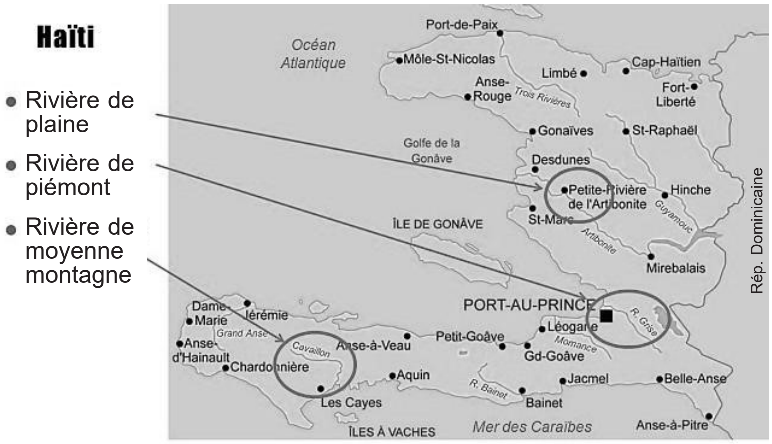
$$J_{12} = \frac{S_{f1} + S_{f2}}{2} \Delta s$$

$$z_{b1} + h_1 + \frac{Q^2}{2g A_1^2} = z_{b2} + h_2 + \frac{Q^2}{2g A_2^2} + \frac{S_{f1} + S_{f2}}{2} \Delta s$$

$$z_{b1} + h_1 + \frac{Q^2}{2g[A_1(h_1)]^2} = z_{b2} + h_2 + \frac{Q^2}{2g[A_2(h_2)]^2} + \frac{S_{f1}(h_1) + S_{f2}(h_2)}{2} \Delta s$$

Fig. 4. — Water profile computation.

Finally, this first part of the course presents how to characterize a river and how to measure the relevant parameters. Three typical sites in Haiti were selected for representing various types of river and watersheds (fig. 5).

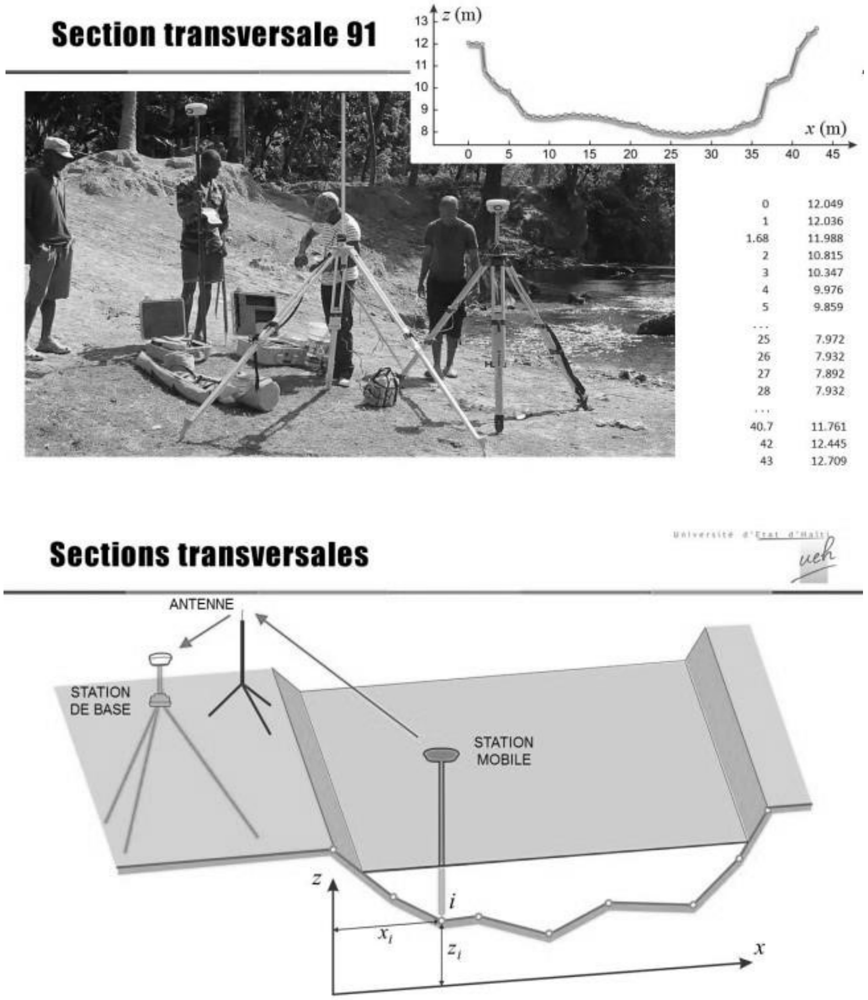


Haïti

- Rivière de plaine
- Rivière de piémont
- Rivière de moyenne montagne

Fig. 5. — Haitian sites used as typical examples: plain watershed, piedmont watershed, mountain watershed.

As an example, figure 6 shows the lesson that explains how to measure and characterize a cross-section in the river, using a mobile GPS device linked to a fixed one through a wireless system. In the MOOC a movie illustrates the whole process.



Section transversale 91

0	12.049
1	12.036
1.68	11.988
2	10.815
3	10.347
4	9.976
5	9.859
...	
25	7.972
26	7.932
27	7.892
28	7.932
...	
40.7	11.761
42	12.445
43	12.709

Sections transversales

Fig. 6. — Measurement of a cross-section: *in situ* example and theoretical interpretation.

The second part of the course introduces sediments and morphological aspects, with special attention to the response of a natural river to any artificial modification of its plan view, its length, its local slope or its local width. An example is given in figure 7 that explains in which conditions a sediment grain is entrained or not by the river flow.

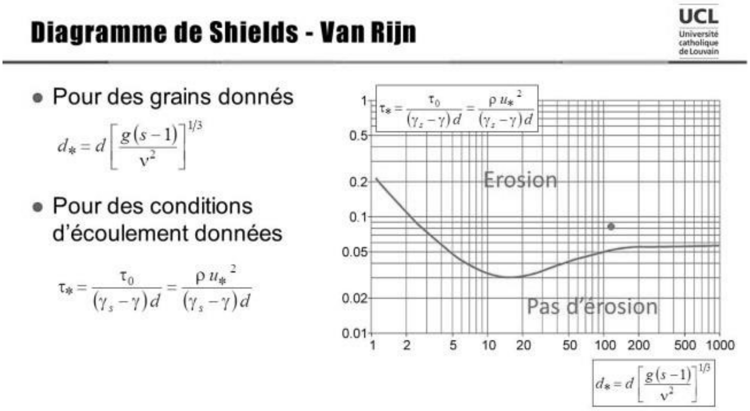


Diagramme de Shields - Van Rijn

UCL
Université catholique de Louvain

- Pour des grains donnés

$$d_* = d\left[\frac{g(s-1)}{\nu^2}\right]^{1/3}$$

- Pour des conditions d'écoulement données

$$\tau_* = \frac{\tau_0}{(\gamma_s-\gamma)d} = \frac{\rho u_*^2}{(\gamma_s-\gamma)d}$$

Fig. 7. — Threshold of grain entrainment according to sediment and flow characteristics.

Lessons learned from the First Edition (Autumn 2016)

The first (good) surprise was the success in terms of inscriptions. More than one thousand five hundred people registered, which was considered an important number for such a course with rather hard science and designed for students at Master level. Another surprise was the geographical distribution of learners for a MOOC taught in French (fig. 8): Haitian representation was of course boosted by the participation of local teachers, but it was less expected to count so many students from Spanish-speaking countries (seventy-two from Columbia, sixty-three from Peru) and also a lot from English-speaking countries (thirty-five from USA, nineteen from India, seventeen from UK).

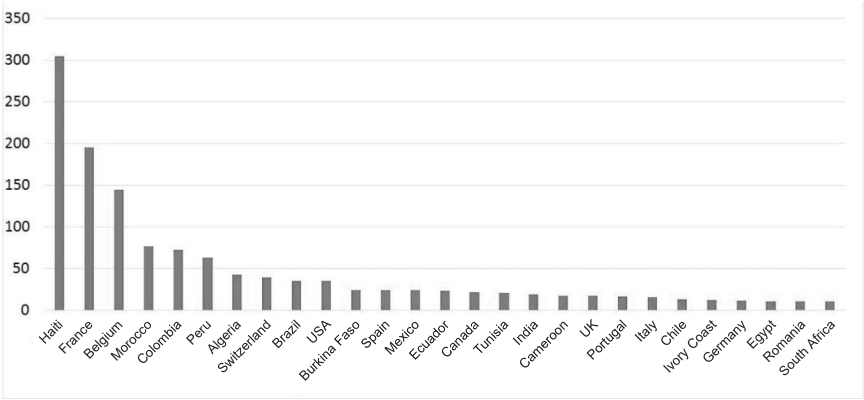


Fig. 8. — Origin of the registered learners (countries with ten learners or more).

The median age of the participants was 27.5 years, which means that most learners had probably already finished at least a first cycle of high education studies rather than still being student. Their level of education was more widely distributed than expected: 45 % had got a Master or a PhD degree, 35 % a Bachelor degree but 20 % registered with a lower level of education.

Looking a little further, there is a significant difference between registration statistics and real participation. The edX platform provides different tools for analysing the learner's participation, such as statistics about video views and answers in the quizzes. However, it is practically impossible to extract information from the number of video views, because, among other reasons, students are allowed to download the videos, so escaping to online viewing statistics. Statistics related to the participation in the quizzes provide rather reliable information on the learners' engagement. Figure 9 represents the number of participants in the series of quizzes and in the intermediate (after four weeks) and final (after eight weeks) exams. Only 21 % of the registered students completed the quizzes of the first lesson, 60 % of them completed the first week, and respectively 28 and 14 % the two exams.

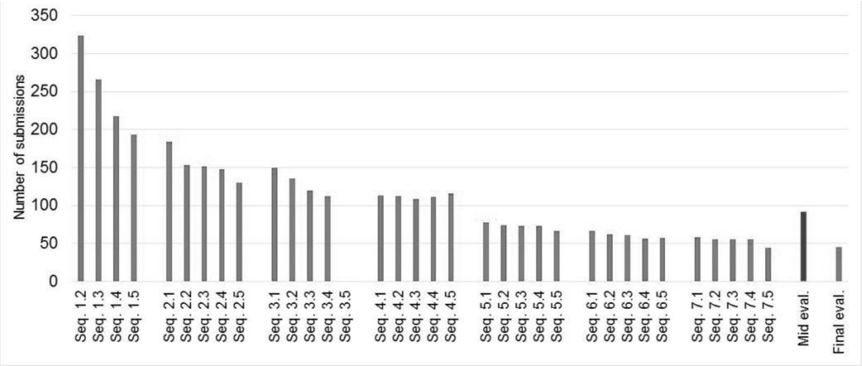


Fig. 9. — Participation in the quizzes, in the intermediate exam and in the final evaluation.

On the other hand, participants who persevered in their efforts got a rather high success rate as shown in figure 10. This indicates that the level of difficulty of the proposed evaluation was apparently appropriate, at least for the learners who could follow the course until the end.

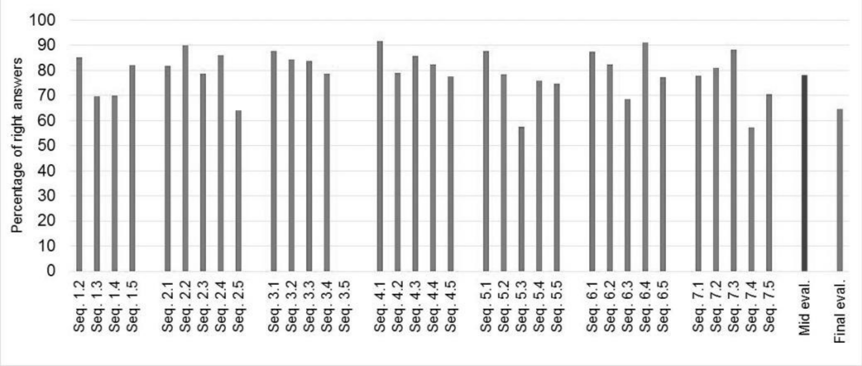


Fig. 10. — Success rate to the quizzes, to the intermediate exam and to the final evaluation.

At the end of the course the learners were asked to respond to a satisfaction survey. The students having completed the course declared a high level of satisfaction but with some reservations regarding the time required for completing the quizzes and exams, which was often much longer in the reality than the time announced in the course description. They also underlined the limitations of the quiz system with multiple choice or numerical results without the possibility of qualifying the answers. They also requested additional documentation beyond the course.

Conclusion and Perspectives

First of all, it must be said that building a MOOC is an amazing experience for teachers. It requires a huge preparation time but it is a rare opportunity to improve significantly the available teaching material that will then be usable also for regular face-to-face lectures. A lot of new illustrations, in the form of graphs, photographs and videos, were produced as part of the present MOOC. However, the time spent for building such a course is generally much longer than expected, at least if the MOOC is not only a video capture of a usual lecture. The quality is directly proportional to the time spent.

The erosion rate between registered and active students and along the learning process is of course an issue of this kind of learning tool. It seems very difficult to have the courage to continue the activity day after day. Since a setback prevents them from continuing, it is difficult to re-enter the learning process, especially if the delays accumulate. For reducing this risk of dropping out, it was decided to divide the eight-week course into two four-week modules.

Finally, from our experience, it seems difficult with a MOOC to go beyond a given level of difficulty in the course content. Some in-depth approaches are practically impossible to explain without the interaction of a face-to-face lecture. In this sense, a MOOC could be the source of an illusion or frustration for the learner, mainly if this person is isolated without the possibility of referents. This point is of course crucial in a context of North-South knowledge dissemination. It seems that local relays could be a part of the solution, for example by using the MOOC material as an additional material to a face-to-face lecture and allowing more refined and certified evaluation than the automated quizzes and exams.

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Measuring Sustainable Energy Projects to Orient Strategies for Meeting People Needs, and a New Role of Science

by

Emanuela Colombo[*] & Lorenzo Mattarolo[**]

Keywords. — Sustainable Development; Access to Energy; Impact; Developing Countries.

Summary. — Over the last few decades, the international community has shown increasing interest in sustainable development and in the multiple interconnections existing among energy, environment and society. Despite the relevance of energy in the development framework, 1.1 billion people today still do not have access to electricity, 2.8 billion depend on traditional biomass for their domestic use and around another billion lack access to a reliable electricity grid. These numbers are not likely to change significantly in the near future. Why? Reasons are different and worth a deep analysis, which may also vary from country to country, but the literature agrees that we need to learn how to measure the impact of energy strategy to better distil the best practices and drivers of future success. Within this approach, we have to revise the role of people and capacity building in the sector and be brave enough to go beyond science as usual.

Introduction

The centrality of energy in the new paradigm of sustainable development is well consolidated within the 2030 Agenda where, among the seventeen Sustainable Development Goals, Goal 7 is fully dedicated to energy with its three main targets: ensure universal access to modern energy services, double the rate of improvements in energy efficiency, double the share of renewable energy in the global mix (UNIDO 2010).

In fact, energy and development are closely related. Energy plays a fundamental role in shaping the human condition and is the key to socio-economic progress, especially for developing countries. The necessity to enhance the access to modern energy services for finding sustainable solutions is globally recognized: affordable energy services are key elements of economic development and eradication of extreme poverty, through the support to local enterprises and the creation of new jobs, the improvement in health and education, the provision of basic needs, such as food and

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[*] Member of the Academy; Department of Energy, Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milan (Italy).

[**] Department of Energy, Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milan (Italy).

water, matching with local resources and local capacity. For this reason, the Sustainable Energy for All initiative together with the World Bank and the International Energy Agency (IEA) are also redesigning the framework of access to energy for better highlighting the link between energy, services and local development (International Bank for Reconstruction and Development / The World Bank Group 2017, Bhatia & Angelou 2015). Moreover, the recent conclusions of COP21, COP22 and COP23 have confirmed energy to be at the heart of discussions for any mitigation actions aiming at reducing the overall emission of greenhouse gases.

Within the energy dimension, human production activities rely on natural resources. Nowadays, the majority of the resources used by human activities are non-renewable. They are limited, their misuse may affect the environment and their non-equitable management may affect social inclusion. This means that there are implications in our rate of using them. In fact, over the last decades, the concern about overexploitation of natural resources from the environment and the consequent injection of waste due to human activity has come to be a global issue. We know we are now at a turning point with two counteracting elements:

— On one side, if we could not learn how to decrease and properly manage the consumption of natural resources, reduce waste and pollution, proceed toward a more equitable distribution of them, no sustainable development might ever come;
— On the other, if we reduce dramatically our resource use and we run into a shortage of resources, we could put under severe threat our life and society.

What the history of mankind proves is that human and economic activity went along the discovery of new sources of energy. To be more precise they went along the "development of the right capacity of using new sources of energy". Looking at some quantitative data (Klugman *et al.* 2011, IEA 2012), the link between energy and development includes the economic dimension, but goes beyond and embrace the multidimensional concept of human development (fig. 1), connecting the Human Development Index (HDI) and the Energy Development Index (EDI).

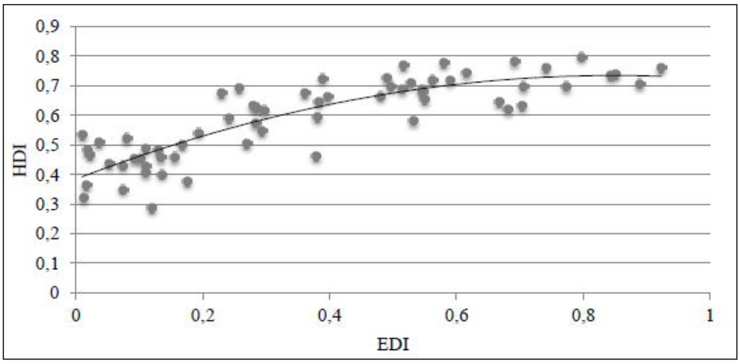

Fig. 1. — HDI-EDI for medium and low HDI countries
(authors' elaboration based on UNDP and IEA data).

Energy as an Instrumental Right to Resources and Services

Despite an increasing worldwide interest in the energy challenge and the link with sustainability, almost 1.1 billion people today are living without access to electricity, 95 % of whom are located in sub-Saharan Africa and developing Asia, and one billion people do not have access to a reliable electricity grid, affected by outages which can occur up to thirty to fifty days per year. More than 2.8 billion people rely on traditional solid biomass for cooking and lighting. These people mainly live in rural areas of developing countries or in peri-urban areas of emerging countries. Although the lack of access to energy mostly affects developing countries, new evidence of energy poverty is also emerging in Europe and in other industrialized countries, confirming the global character of the energy challenge.

The availability of reliable and affordable renewable energy allows developing a series of public services that may improve considerably the livelihood of the communities involved. Access to modern forms of energy is essential for the provision of healthcare, sanitation and all the related services, and outcomes are consistently the strongest among vulnerable groups, including children and the elderly. Across the globe, more than a quarter of healthcare facilities lack proper access to electricity. Consistent electricity is pivotal to enable basic lighting, mobile phone charging for communications, access to clean water via water pumps and is needed to power medical diagnostic equipment as well as appliances required for maternal and child healthcare. In addition, electricity enables refrigeration for vaccines, blood and medicine and allows basic procedures to be carried out during the day and, in particular, after sunset. Daily power shortages at health clinics are a counteracting force towards maternal and child health.

Proper energy systems may offer an effective way forward in avoiding sudden power outages and the high cost of traditional energy, and may lead to a considerable reduction in the number of illnesses and deaths in notoriously underserved rural areas. Such systems, including lights, mobile phone chargers, water pumps, refrigerators, fans, radios, TVs and solar PV panels with batteries allow healthcare workers to perform critical work in a reliable and conducive environment. At the same time, reliable and constant energy access in rural areas can help attract and retain medical personnel. A further health impact of access to modern energy is related to the reduction of respiratory disease symptoms and may have positive outcome in reducing mental health impact including anxiety, stress, depression. Finally, improvement of individual health also has direct social impact and relieves pressure on public budgets for health.

Access to reliable and affordable energy is also crucial for improving the access to other social services, such as education centres, public institutions and other infrastructure services. Energy may also represent a remarkable stimulus to the economy of a rural community. In fact, increased access to energy can create new earning opportunities. First, it can encourage new business options for micro, small or medium enterprises in the manufacturing, agriculture and service sectors. It can enhance existing earning activities by increasing productivity, lowering costs and improving the quality of goods and services. Secondly, it can generate additional employment opportunities in the energy supply chain or in other sectors. Moreover, new energy availability can reduce opportunity costs, by reducing drudgery and releasing time to allow new income-generating activities.

For the above-mentioned reasons, energy should be treated as an instrumental right: energy by itself does not affect human dignity, but it is today recognized that without energy, or with poor access to energy, the fundamental rights might not be guaranteed.

A Focus on Africa

Despite a number of positive signs, the energy paradox in Africa is still evident (Mandelli *et al*. 2014). Energy demand over the last decade has grown by more than 30 %. But even if home for the 16 % of the global population, the continent accounts for only 6 % of the total primary energy supply at global level and the 3 % of the total electricity demand being responsible for the 5 % of the CO_2 emission burden. Africa still lags behind other regions: per capita availability of energy is very low, not sufficient to meet the daily basic need at household level and to provide neither community services nor productive uses of energy in the industrial or agricultural sector. Energy and CO_2 intensity are higher than in other regions and are the evidence of underinvestment in Africa in terms of power generation. Reliability is low and frequent power shortages are threatening the regional socio-economic prosperity.

Africa is untapping its domestic renewable resources and the generation mix, except for the Maghreb region and South Africa, does not mirror the local natural endowment. In one of the most probable outlook scenario to 2040 in the sub-Saharan Africa power system (excluding the North-African region) the power sector would at least expand its capacity to more than four times and diversify its mix: coal (South Africa) and hydropower (all regions) will be supplemented by natural gas and by an increased share of renewables (including solar, wind, geothermal and biomass). Assuring the proper infrastructure and regulatory framework are in place, RES (Renewable Energy Systems) penetration could represent 20-30 % of the total power generated. In the same period, for sub-Saharan Africa, the share of installed fossil fuel capacity will decrease by supporting the path toward a more decarbonized system as CO_2 emissions from the power sector will decrease to 2 to 3 % of the global share while electricity production will increase more than 3.5 times. Electricity is not the only concern affecting local development. Bioenergy in Africa, mainly firewood and charcoal, is still the dominant source of energy. In sub-Saharan Africa, a bit less than 80 %

of the population rely on the traditional use of solid biomass affecting the health of hundreds of thousands of people and the expected 1.1 % annual rise in demand until 2030 will exacerbate stress on environment (such as forestry stocks) and health (induced by indoor pollution). In the areas where progress will occur, LPG is the most common solution to clean cooking access, with over half of those gaining access by 2030 relying on it followed by improved cook stoves (IEA 2017).

Many governments in the sub-Saharan region and the different power pools are getting more aware of the described scenario, promoting reform programmes to improve efficiency and working for removing regulatory and political barriers that prevent investment in domestic energy supply, thus preparing the enabling policies for a major and regulated penetration of renewable energies into their national grids and for off-grid solutions. So, the progress reached over the last decade will continue further as stated by the different scenario outlooks, but to scale up the process and provide universal energy access, by decreasing the current number of more than 0.5 billion people affected by energy access in 2040, a paradigm shift is required.

There are many different elements which are requested for this paradigm shift. Here we would like to focus on three of them: the relevance of measuring impact, the consequent new role for people and capacity building and the need to go beyond "science as usual".

The Relevance of Measuring Long-term Impact

Given the above-mentioned scenario for Africa, the adoption of an evaluation metric able to address the complexity and interconnections of current challenges has become necessary. In fact, proper communication and reporting of undertaken programmes represent useful instruments for the stakeholders involved, in terms of accountability, for setting priorities, and guiding and better addressing future interventions, which can act as support for a paradigm shift in strategies and policies.

Given this framework, a proper evaluation metric able to assess the effects of energy projects on the changes of community livelihood and the positive effects on social, economic and environmental levels is strongly needed.

Starting from this perspective, in the field of energy it is therefore important to measure impact on a twofold perspective (fig. 2):

- In terms of accountability, assessing project performance, with the aim of identifying relations between costs and effects or needs;
- In terms of strategic planning, in order to assess the changes induced in the communities, for setting priorities and guiding and better addressing future interventions.

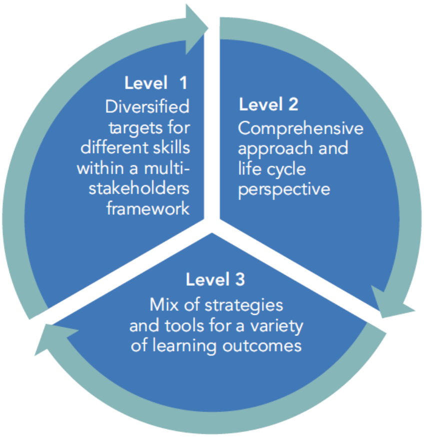

Fig. 2. — Twofold approach of impact.

Relying on some recognized evaluation frameworks, as the five DAC (Development Assistance Committee)-OECD criteria (relevance, efficiency, effectiveness, sustainability and impact), and the process perspective of the Results Chain (input, activities, output, outcome, impact), our research proposes a framework for performance and impact assessment of energy projects. This approach may provide a model-based set of information for comparative analyses among projects and feedback for decision making, in order to orient policies.

An Integrated Framework for Evaluation

When dealing with evaluation of energy projects and impact assessment, a wide range of frameworks may be found in scientific and grey literature related to the sector of energy and development, which tackle a broad range of complementary aspects. However, it is difficult to identify a standardized and shared approach: most evaluation metrics today are qualitative, poorly structured and do not enable a comparison of different actions. Some frameworks are at the level of the global development agenda, promoted by international institutions and agencies; others constitute instruments of the project cycle management; criteria and logical outlines are also defined to structure or give an accountable measure of a project (McDonald 1999).

In an attempt of harmonization, the DAC of the OECD has proposed some evaluation criteria (DAC 2018), which are globally recognized and utilized, and which can be assessed along the Results Chain of a project (input, activities, output, outcome, impact) (DAC 1991).

These principles have been prepared mainly for use by donors and agencies for evaluating funded activities, but they are also useful for country authorities in leading their own evaluations of activities, public programmes and projects. Upon these principles, the five DAC criteria (relevance, efficiency, effectiveness, sustainability, impact) for evaluating development assistance have been designed, so that they represent a general guide applicable for assessing development projects. These five criteria, used by the most important international players, are recognized as consolidated and shared framework for project evaluation.

Such criteria constitute the starting point of the new Performance and Impact Evaluation Framework (Colombo *et al.* 2018). The framework developed by the

UNESCO Chair in Energy for Sustainable Development at Politecnico di Milano, in collaboration with Enel Foundation, aims at providing an integrated framework, in order to understand the performance and impact of energy development projects.

It is structured into two phases: an internal one, project-based, which assesses projects in terms of performance, and an external one, people-based, which assesses the project impact on the beneficiary communities in terms of livelihood changes, shifting the attention from the project itself to the context concerned. The objectives and timeframes of the two analyses are different and require different approaches and tools in order to perform an integrated assessment of the cooperation projects in the energy area.

The first phase is a project-based step, which assesses projects in terms of process performance (fig. 3). Starting from the flows of inputs utilized by the project, in terms of materials, energy, goods and services, or other externalities, by means of quantitative models from Energy System Analysis (*e.g.*, exergy-based accounting methods, life-cycle approach, macroeconomic input/output), it is possible to calculate an overall estimation of resource consumption, and thus calculate multidimensional reference metrics. Such metrics can be expressed in terms of:

— Effects (like energy produced, income or value added, employment creation);

— Societal costs (like monetary input, embodied energy, virtual water, carbon footprints).

Through the combination of these metrics, intensive measures of DAC-OECD criteria can be calculated.

In this way, a 'proxy' of the total resources undertaken during the project can be captured. Different projects can so be compared in terms of efficiency, effectiveness, relevance and sustainability. This step gives a measure of the performance of the project in terms of resources consumed to obtain a given set of results, creating a database of benchmarks and standards.

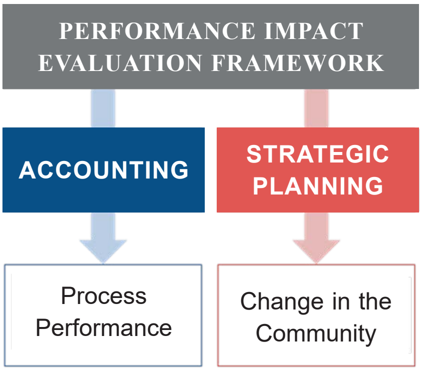

Fig. 3. — Model-based approach.

The second phase is a people-based step, which assesses the project impact on the beneficiaries (fig. 4). This phase aims at measuring the effects of the project on local livelihoods, assessing in terms of target community's capitals. The model takes its rationale from the "Sustainable Livelihoods Framework", adopted by the Department for International Development and investigated by the Imperial College (Scoones 1998, DfID 1999, Cherni *et al.* 2005).

Fig. 4. — People-based phase, procedure to follow.

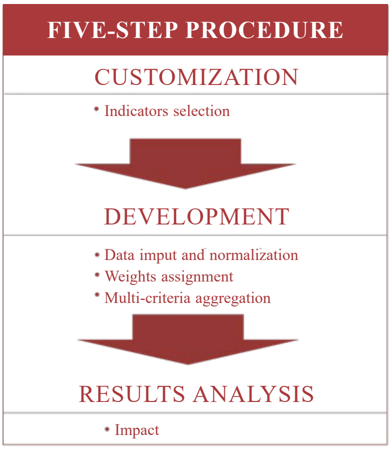

Fig. 5. — The evaluation hierarchy.

This phase has been defined starting from two necessities: on the one hand to enable the model customization and applicability to different scales and contexts, allowing to design a proper indicators' set, on the other to provide a common structured metrics, which can be utilized for different projects and for their comparisons.

A schematization of the proposed methodology for the impact assessment is based on: (*i*) an application procedure structured into three steps, customization, development and result analysis; (*ii*) an evaluation hierarchy (fig. 5), made of five capitals, representing community livelihoods and dimensions, *i.e.* those topics and themes relevant for a complete impact evaluation, covering both tangible and intangible aspects of a community and necessary to get a comprehensive overview of changes. First, most relevant dimensions for each capital are identified. Then, individual indicators are defined and selected within each dimension, being specific and adaptable to each project.

A defined procedure then follows, to normalize and weigh such indicators. The impact evaluation methodology, by measuring the indicators' status before and after the project, allows the identification of those dimensions over which the intervention has had an improvement or worsening. The aggregation procedure of indicators then quantifies the contribution of each dimension to each capital (fig. 6).

The methodology can have different utilizations. It can represent an ex-post analysis, assessing already completed projects by comparing the measure of capitals in the baseline situation with the changes brought by the project and assessed at its end. It can also be used for ex-ante analysis, at an appraisal phase, during the selection process among possible project alternatives; in this case the result gives an expected impact of the intervention.

The framework can give useful information to a wide range of stakeholders: (*i*) for policy makers at local, national or regional level, it can provide feedbacks for development strategies; (*ii*) investors from the public or private sector may receive feedback on investments in addition to bankability indexes; (*iii*) science community as research centres or academia may have further information on effectiveness of strategies and research directions.

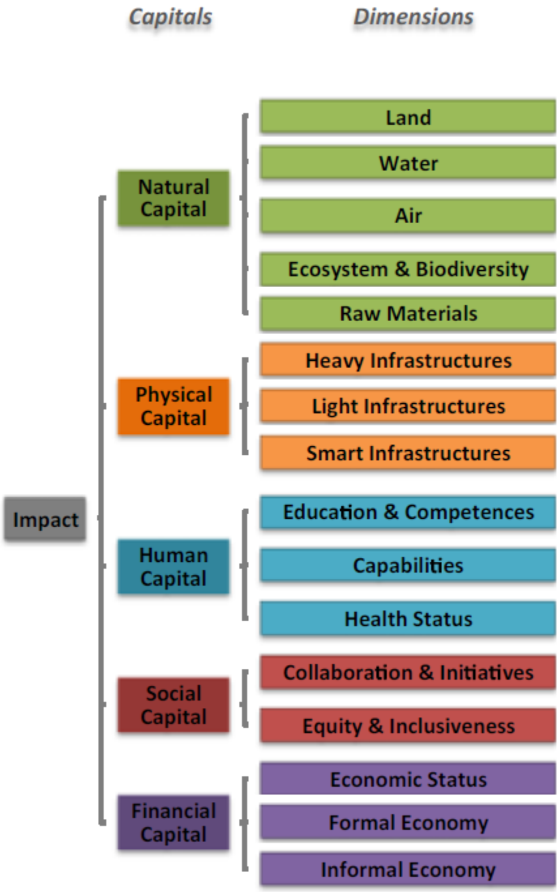

Fig. 6. — Example of impact assessment.

THE ROLE OF PEOPLE

As already mentioned, energy access is a prerequisite for improving the quality of life and enabling socio-economic development. Moreover, appropriate energy solutions and technology choices must respond to the needs, capacities and aspirations of people, and be absorbed within the local culture, or adapted and later improved by the local population.

For these reasons, people should be at the heart of any strategy to promote energy access and capacity building and are considered a key asset for achieving the goal in a sustainable way (International Bank for Reconstruction and Development / The World Bank Group 2017). Capacity building needs to go beyond the delivery of training hours and needs to be designed to fully deploy the power of human capital as one of the crucial assets of any community (fig. 7).

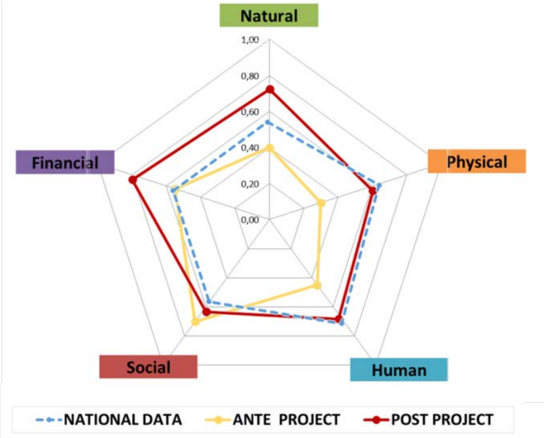

Fig. 7. — Multi-level breakdown for capacity building.

In strengthening the role of people throughout the energy supply chain — from production to users — capacity building and training activities become essential components of any successful project aimed at enhancing energy access. If properly designed, they develop the local expertise needed to replicate and scale up successful initiatives, support ownership of stakeholders, and foster sustainability beyond the withdrawal of external partners. The development of a skilled local workforce is also an opportunity for private investors to reduce risk and facilitate long-term sustainability, and therefore it represents a win-win option.

Beyond Science as Usual

In the global challenge of development as well as in the specific energy challenge, universities are increasingly recognized to be key players, since innovation and knowledge, capabilities and skills are needed today (Colombo & Mattarolo 2017). Recently at international level several initiatives have been promoted to activate the scientific community, contributing to define the role of academia. Several declarations and charters have been built in education and higher education, representing the university intents to support the enhancement of the effectiveness of the 'Education for Sustainable Development' discipline.

'Education for Sustainable Development' means that key sustainable development issues are embedded into teaching and learning. This allows students to acquire the knowledge, skills, attitudes and values needed to contribute to a sustainable future. New teaching and learning methods are needed to motivate students and contribute to create competencies like critical thinking, collaborative approaches.

Starting from the Earth Summit in Rio de Janeiro in 1992 with the Agenda 21, the role of science and academia was clearly addressed (Zilahy & Huisingh 2009). Later on, the declaration of the 'Decade 2005-2014 for Education for Sustainable Development (DESD)' emphasized the role of education as a necessary prerequisite for the achievement of sustainable development, as also recently pointed out by the launch of the United Nations Sustainable Development Solutions Network (SDSN) in 2012.

All these initiatives have confirmed that academia are today playing a fundamental role in the development challenge and in the transition towards a new path.

At the university level, one of the most relevant components of this transition is the introduction of a multi- and trans-disciplinary approach, not common yet within the academic institutions. It also shows the importance of a systemic approach crossing all the missions of academia (fig. 8), through the upgrading of curricula and the shift towards a scientific research which allows creative innovation that is needed and contribute to society with science diplomacy and outreach programme.

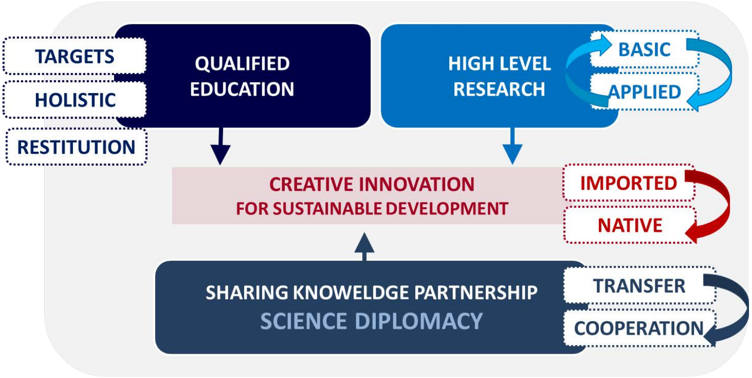

Fig. 8. — Academic mission, enriching the traditional approach.

In fact, on the one hand sustainable development should be integrated in curricula, upgrading models, methodologies, tools, and related practical skills. This would make students able to work and play an active role in society at global level, in developed and developing countries.

On the other hand, the main objective of scientific research is to realize the needed innovation to meet emerging and current societal needs. Research results are expected to enable the transition towards sustainability in the sectors of society (resource management, wealth distribution, job creation, environmental preservation), which are different but related with each other, crossing the boundaries among traditional disciplines.

Finally, the so-called third mission of universities turns out to have a new role in the current challenges: academia can prove the effectiveness of their educational and research programmes by proposing outreach action capable of bringing innovation and produce a high-level and long-lasting impact.

Conclusion

Over the next decades, Africa is expected to become more and more energy-demanding due to its growing population and growing economy, both claiming access to reliable and affordable energy services. At the same time, Africa would like to confirm the continent commitment to maintain its low contribution to global carbon emissions. For this reason, Africa cannot lose momentum to investigate energy alternatives for supporting the transformative path toward a more sustainable, affordable and clean energy system able to unleash local development. The needed paradigm shift has to lead to more sustainable choices that will be designed FOR the people, BY the people and WITH the people.

New planning methodologies are necessary to be able to understand local needs, transform them into loads and finally drive the energy planning. At the same time, we need to measure how far energy can support the process of local development and the promotion of an equitable and environmentally-friendly energy economy.

Energy solutions have to contribute to local empowerment. This means that creative and native innovation is mostly needed instead of traditional imported innovation. An education based on holistic approach, different targets, strategies and learning outcomes is mandatory. The same is true for scientific research, which needs to be less speculative and more oriented to overcome local barriers. This is one of the crucial roles of academia and in this way, technology transfer can become a true and effective mutual learning among African and European scientists, researchers and students. Transversal partnerships are requested since the complexity of the energy sector in Africa is obvious. The role of governmental institutions, private sectors, academia, civil society will be crucial for any effective scale-up. In the same way, the need for joint projects among engineering, economy, social sciences and other disciplines can no longer be neglected. In this sector, partnerships North-South and South-South are a key to success.

Beyond the many discussions on the most appropriate technologies, the needed business models and the enabling policies, the approach proposed here confirms the relevance of a modified paradigm based on measuring impact, attributing a new role to the people and with the urgency to go beyond science as usual.

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Posters

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Royal Academy for Overseas Sciences
Brussels, 23-25 October 2017
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Development of Advanced Energy Technologies in Africa: Success Stories obtained and Challenges left from both Technological and Managerial Points of View

by

Peter KONINCKX[*]

Siemens' power generation, transmission and distribution portfolio covers the whole value chain of electricity and important evolutions have taken place all over the continent in recent years, especially in the thermal sector. Without neglecting the enormous potential that PV (photovoltaic) and hydro technologies offer, small and large thermal power generation projects have contributed to the building of the backbone on which growing countries like Ivory Coast are developing their energy mix.

Over the last few years we have seen on a regular basis projects for small heat recuperation or cogeneration being carried out. Typically based on a 1-2 MW steam turbine technology and all located within the palm oil and cacao industry, these power generation units are often dedicated to supporting the local industrial electricity consumption and not the electrification of the society. Also, though biomass for power generation is abundantly available in the equatorial region of Africa and politics have now included it in their energy plans as part of the future energy mix, no project has come to closure. Among others because suitable feed-in regulatory framework is missing.

As the large-scale power generation installed under impulse of the energy ministries, the power plants being constructed are too often based on reciprocating engines running on heavy fuel or on gas turbines in open cycle. Both alternatives are decided upon because there is an urgent need for power capacity, a lack of long-term planning and in the case of reciprocate engines, also a lack of gas availability in the country. In any case, both solutions result in a high cost per MWh for the society and a high amount of emissions.

At Siemens we believe that, complementary to the strong increase in PV and Hydro, small to medium-scale biomass and medium to large-scale gas-fired combined cycles are the best fit to lead West and Central Africa to a more sustainable and stronger energy system, which is necessary for the development of the industry and social welfare.

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[*] Director Power Generation for Belux, North Africa and West and Central Africa, Siemens n.v./s.a., Guido Gezellestraat 125, B-1654 Beersel (Belgium).

Different technological and geopolitical evolutions support that scenario:

- Small to medium-scale biomass: the technical evolutions in boilers, exhaust gas treatment and turbines make it possible to deliver more efficient and sustainable biomass solutions for small and medium-scale applications. Provided that one masters the local supply chain for biomass, these projects have a strong contribution to local economy and they can be used in off-grid solutions complementary to PV and Hydro instead of diesel engines.
- The increased attention from international financing institutions will automatically help to shift from 'short-term' engine solutions to combined-cycle applications because of their lower CO_2, NOx and SOx emissions and more competitive electricity for the local industry and population. Also, the numerous LNG regasification stations being developed in the region show a good trend. The reduction in cost of these regasification units and the homogenization of gas prices worldwide support this evolution. Once the gas available locally, it will enable power generation applications, but also allow the development of other local industrial activities today limited by a lack of this primary energy source.
- For utility scale power generation the F-Class combined cycles like the Siemens SCC-4000F achieving ~60 % efficiency @ ISO conditions are of course state of the art. Their application in Africa, however, requires transnational cooperation because the smallest building block would be 400 MW, which is too much for most of the local national requirements. However, thanks to the WAPP (West African Power Pool) initiative, this becomes a real scenario, giving access to the lowest cost of electricity for several West and Central African countries.

A new evolution is also the medium-scale combined cycle SCC-800, which generates approximately 75 MW in 1x1 or 150 MW in 2x1 (2 GTs on 1 ST) configuration while achieving an efficiency of >56 % @ ISO conditions. This power range enables an easier integration in the power grid in case of weaker grid conditions and the 2x1 configuration ensures an even more flexible and available solution, fitting to the local grid requirements.

Because of its low cost of electricity and high sustainability, it clearly beats out the 'short-term' engine solutions, which are still too often being installed and might become the solution of choice for many African countries.

With these evolutions, biomass and combined-cycle power plants are on a good way to become the preferred thermal power generation solutions contributing to the energy transition in Africa, paving the way for large renewable installations of PV and hydro power, as has been the case in many developed countries.

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Role of Renewable Energy in the Fight against Global Warming: The Context of Africa

by

Yezouma Coulibaly[*]

Keywords. — Renewable Energy; Global Warming; Africa; Access to Energy; Energy Transition.

Summary. — Africa is the most vulnerable continent to the effects of climate change. To combat these effects, the governments of the countries concerned multiply the calls for aid while striving to reduce greenhouse gas emissions as their own contribution to the fight against global warming. One of the most effective ways of this initiative is the energy transition, which replaces stock energy by renewable energy. The objective of this presentation is to discuss the role of mature renewable energy technologies in solving energy problems especially in Africa. This is therefore an overview of energy problems in Africa. It deals with energy as a whole but also with renewable energy sources and how these can help solve African energy problems and combat global warming.

ACRONYMS USED

2iE	International Institute for Water and Environmental Engineering
AES	Access to energy services
CEDEAO	Communauté économique des États de l'Afrique de l'Ouest
CNESOLER	Centre national d'Énergie solaire (Mali)
ENSUT	École nationale supérieure de Technologie (Sénégal)
GHG	Greenhouse gas
kWp	Kilowatt peak
LESEE	Laboratoire d'Énergie solaire et d'Économie d'Énergie
NGO	Non-Governmental Organization
PV	Photovoltaics
RE	Renewable energy
TOE	Tonne of oil equivalent

1. Introduction

The driving role of energy in the development of nations is no longer disputed. Energy is the capacity to make, move, or change things. Without energy nothing

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[*] International Institute for Water and Environmental Engineering (2iE), Ouagadougou (Burkina Faso).

can be done. However, levels of consumption vary greatly from one nation to the other.

Generally speaking, the least developed nations are also those which consume the least energy. Africa has a per capita energy consumption of less than 0.2 TOE/cap/year (fig. 1). As a result, the development of the continent involves necessarily meeting its energy demand by providing adequate access to energy to its population. The effort to be made is considerable in view of the delay and the difficulties of energy supply to the continent.

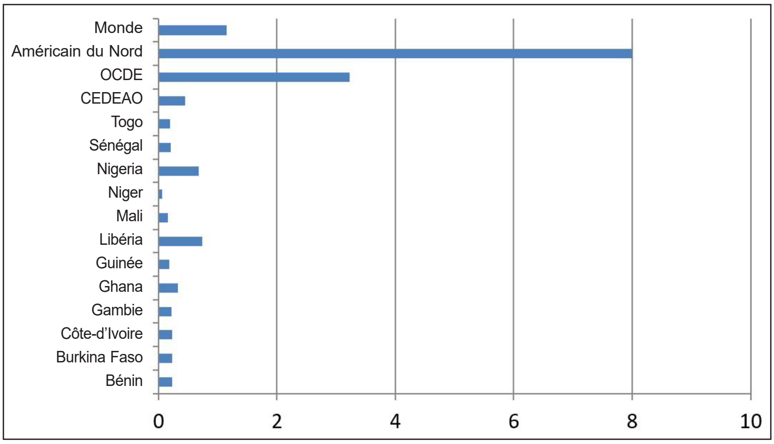


Fig. 1. — Final energy consumption in TOE/cap/year (*source*: ECOWAS & UEMOA 2006).

At the same time, environmental problems and the depletion of fossil fuel reserves mean that the global trend is towards reducing energy consumption. The environmental problems at stake are essentially greenhouse gas emissions, air pollution and, for Africa, desertification and deforestation mainly due to the excessive use of fuel wood as a source of energy.

If people in the whole world lived the same way as Americans do, with the same rate of energy consumption (*i.e.* 8 TOE/cap/year), we would be close to 50 GTOE/year of energy consumption in the world. The figure is 12 GTOE/year currently. The fossil fuel reserves would be exhausted in less than thirty years. A solution to this huge consumption dilemma for an environment-friendly and reserve-based development is a large-scale choice and use of RE. There are five of them that can be used today for that: biomass energy, hydropower, solar energy, wind energy and geothermal energy. They can roughly be defined as the flux of energy that derives from the exploitation of non-stored natural resources, provided that their consumption is less than the incident flux. This underexploited potential around the world is not only huge in Africa as compared to the needs. It is also and especially adapted to the weak decentralized demands of the continent. The objective of this paper is the analysis of the problems and the search for solutions to the obstacles encountered in sub-Saharan Africa, for a more intensive use of RE resources.

2. Overview of REs in Sub-Saharan Africa

Few African countries have reliable and consistent energy accounting for the assessment of their REs in national energy balances. Apart from South Africa and Maghreb countries some countries have only occasional (not updated) records that are often incomplete. In this context, it is difficult to assess the share of renewable primary energy in the energy supply of the countries concerned. Moreover, the high proportion of traditional energy makes energy balances unreliable. We give below a global vision of the continent's potentialities and resources of RE starting from some global estimated studies.

2.1. Biomass

Biomass is the most widely used energy source in Africa. The average proportion of primary energy consumption is estimated at 70 to 80 % (ECOWAS & UEMOA 2006) for the whole continent. Furthermore, biomass is very little used as a modern energy, *i.e.* as fuel in engines or fuel in boilers and furnaces, which would have significantly increased its contribution to energy supply and access to energy services. It is used mainly as home energy (fig. 2).

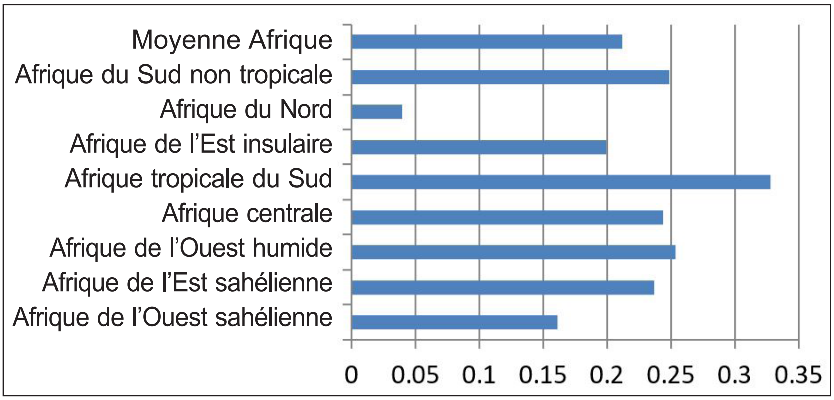
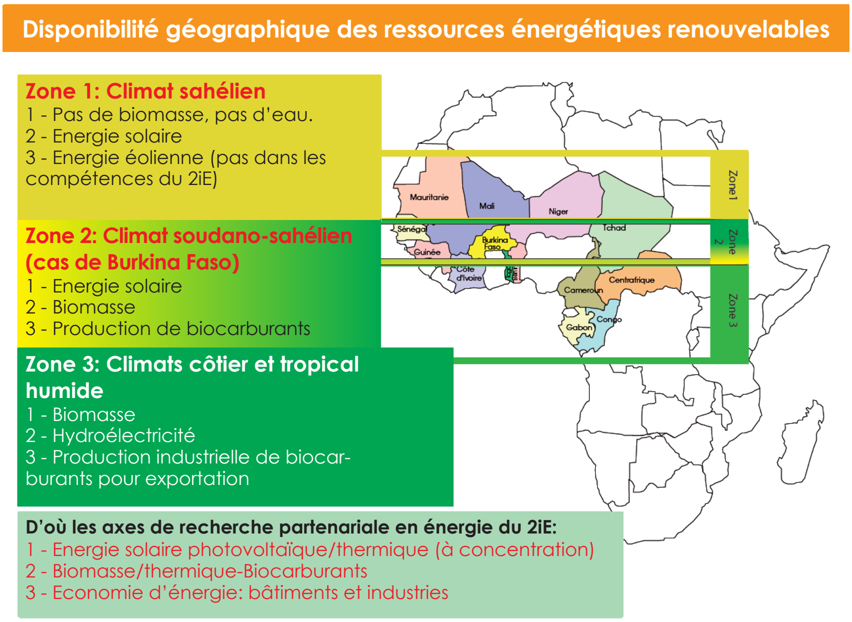


Fig. 2. — Average consumption of fuelwood and wood resources by region of Africa in TOE/cap/year (*source*: ECOWAS & UEMOA 2006).

This is the reason why the most widespread research in the energy field ever made in Africa concerns improved stoves to bring their combustion efficiency from 10 or 15 % to 30 or 40 %. Their promotion potential is however promising. The most promising promotions known to date are:

- The use of biomass (vegetable waste, waste of food industry and wood industry) for combustion in furnaces and boilers;
- The cultivation of sugar plants for the production of alcohol for energy purpose;
- Biogas production from waste-fed digesters (straws, animal excrement, septic tanks and other wastes);
- The production of biodiesel or other engine biofuels such as alcohol from cultivated plants.

Biomass resources are large, especially in equatorial and tropical Africa. Figure 3 shows the areas of potential exploitation of biomass as a modern energy source in Africa (zones 2 and 3).



Disponibilité géographique des ressources énergétiques renouvelables

Zone 1: Climat sahélien
1 - Pas de biomasse, pas d'eau.
2 - Energie solaire
3 - Energie éolienne (pas dans les compétences du 2iE)

Zone 2: Climat soudano-sahélien (cas de Burkina Faso)
1 - Energie solaire
2 - Biomasse
3 - Production de biocarburants

Zone 3: Climats côtier et tropical humide
1 - Biomasse
2 - Hydroélectricité
3 - Production industrielle de biocarburants pour exportation

D'où les axes de recherche partenariale en énergie du 2iE:
1 - Energie solaire photovoltaïque/thermique (à concentration)
2 - Biomasse/thermique-Biocarburants
3 - Economie d'énergie: bâtiments et industries

Fig. 3. — Potential of RE on the African continent (*source*: FAO 2011).

It can be seen that a considerable effort must be made to move from this traditional use of biomass (fig. 4) to modern large-scale use. A lot of promising research is done in the field but is still at the laboratory stage.

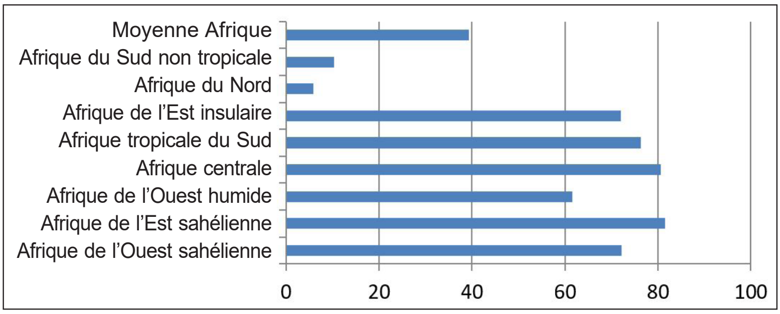


Fig. 4. — Share of wood resource consumption by region of Africa as a percentage of total final energy consumption (*source*: FOLEY *et al*. 2002).

2.2. HYDROPOWER

If in many industrialized countries the hydro potential can be considered as well exploited it is not the case for Africa. Africa has considerable resources in this area which are little or not exploited at all. The Democratic Republic of Congo is the most striking example with an estimated potential of more than 100 GW of hydropower (fig. 5).

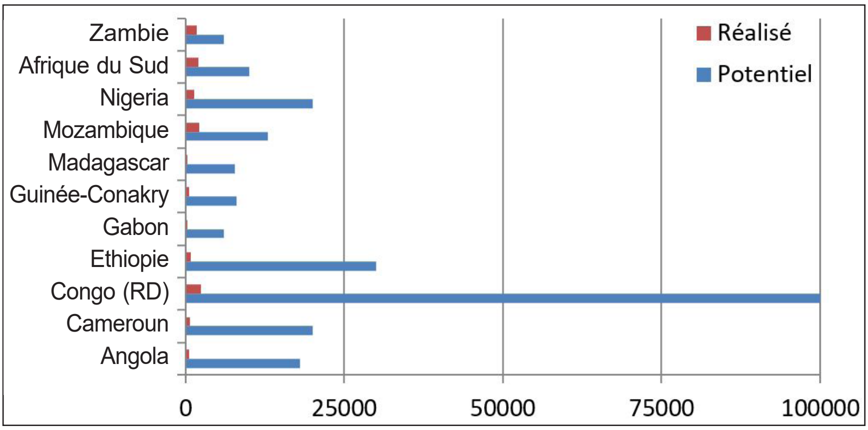


Fig. 5. — Hydropower in Africa (MW) (*source*: AMOUS 1999).

The difficulties of exploiting hydropower in Africa are at the same time technical, financial and political. As a result, the resource is largely underused. Large dams are expected to be built in the medium term. It is striking to see how African rulers and scientists look to nuclear power as "the ultimate solution" to all Africa's energy problems instead of hydropower. And yet the cost of hydropower kWh strongly competes with that of nuclear power, let alone all the nuisances and string of disadvantages of nuclear energy.

The development of African micro-hydropower in particular is an asset and an alternative to meeting rural energy needs as opposed to the trend observed in developed countries. In western countries, it is often considered unprofitable or uncompetitive as compared to conventional energies. For Africa, whose energy needs are scattered and weak (not centralized), the construction of small hydro plants instead of power lines or diesel units is sometimes an attractive solution even when the operating efficiencies of these plants are weak. Rural electrification, which poses tremendous financial problems to African states, would therefore get solutions to reduce its costs. The target powers ranges from 50 or 100 kW to 1 MW. The sites are innumerable especially in equatorial Africa where small rivers and potential sites are numerous and varied.

2.3. Solar Energy

It is the source of renewable energy that has been the focus of attention since the 1970s. Policy makers and consumers see solar energy as one of the most credible short- and medium-term energy solutions for Africa, especially rural Africa, but also as an alternative to the fossil fuels used in the diesel generators of power plants.

The proven reliable solar technologies are mainly photovoltaic electricity, production of hot water or hot air by flat panels for domestic use, as well as passive air conditioning and ventilation for homes. In the 1970s all observers agreed that in the 1980s, Africa would be covered with solar collectors to provide energy to rural areas and poor people. The overall recorded results are disappointing. The main reasons for this failure are:

- The haste that led to bringing to the field technologies that are little (or not) mature and reliable;
- The cost of the equipment, often too high;
- The lack of maintenance and management of the systems installed, which is important when dealing with rural areas in Africa;
- The non-adaptation of the needs to the supply of equipment.

Today, the most widely used solar technology in Africa is by far the production of electricity from photovoltaic panels. Applications that have been most successful are solar water pumping systems for isolated sites, lighting in rural areas, refrigeration for drug preservation, power supply for radio-relay remote pylons, and more generally electrical equipment for remote sites. For all these applications the main restraint to large-scale diffusion is the cost of the systems. A study carried out at 2iE in Ouagadougou on various types of buildings to be equipped with PV solar power in Burkina Faso gave the following results, which concern two types of buildings whose characteristics are indicated:

- B1: university residence of seventy-three single rooms and one hundred and sixty-one double rooms each equipped with two lamps, one fan, one to two computers, one to two mobile phones and one radio. Consumption assessment: 4,430 kWh/month, *i.e.* 769 €/month of electric bill. PV installation required: 48.5 kWp; storage: 26,600 Ah; cost of installation: 251,700 € excluding VAT!

- B3: a villa of F3 type (three rooms) in a rural environment equipped with one fridge, one TV, one HiFi, three fans, fourteen lamps, twelve plugs. Consumption: 256 kWh/month. Power bill of 42 €/month; PV installation required: 2.4 kWp; storage: 1,460 Ah; cost of the operation: 33,485 €!

The study focused on the realization of typical solar-powered villas for civil servants with average monthly income ranging from 230 € to 450 € and solar energy equipment for student residences. For a level of comfort lower than the one obtained from the national electricity grid, the cost of energy is significantly higher and not affordable for the target group.

2.4. Wind Energy

Sub-Saharan Africa (especially Western and Central Africa) has low potential. Only a few countries stand out, like Mauritania whose potential is high. Senegal, South Africa and the Indian Ocean islands are also favoured (fig. 6).

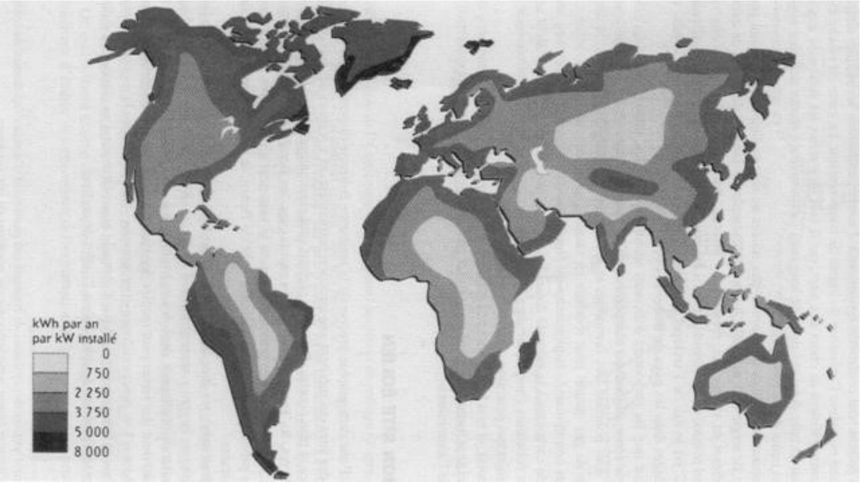


Fig. 6. — World wind potential. Increasing potential from light to dark areas (Foley *et al.* 2002).

While in western countries wind power is the one that has experienced the most important evolution, in Africa wind energy remains marginal both by the achievements and by the available resources and projects. In the 1980s the most tested application was water pumping by horizontal multi-blade wind turbines. In all countries of the Sahel region for instance, artisans have largely participated in the promotion of this technology.

It was recognized that wind power would be a reliable energy source for water supply in western African villages. Major research centres have also tested other technologies such as Savonius and Darrieus vertical axis wind turbines. African research centres such as Senegal ENSUT and Malian CNESOLER actively participated in this experimentation. However, the results have been disappointing in this area. Today wind applications focus on electricity generation following the success of wind energy in Europe and United States. Africa is lagging behind in that other area too. The most advanced countries in terms of installed facilities are those of the Maghreb and South Africa.

2.5. Geothermal Energy

Its potential is low and limited to a few sites or countries of the East African coast. Kenya is a pioneer in this field with one of the oldest 45 MW geothermal power plants. Countries with high potential in Africa are given in figure 7 below.

Date de création: avril 2011
Auteur: LESEE, 2iE, Ouagadougou (Burkina Faso)

Fig. 7. — Geothermal potential in Africa (Azoumah *et al.* 2011).

3. Prospects for RE Development in Africa

The development of RE is too often perceived as an official affair with a policy tending to force consumer choice. It seems that the major asset of REs is their decentralization with a large range of power levels available from a few watts to the GW per plant. The majority of the African population, who live in rural and peri-urban areas, and who are also the poorest and on whom depends the future development of countries, live without electricity. The energy demand of these populations is low and decentralized. Without being against centralization, it must be emphasized that decentralization must be complementary to centralization. It must reflect the differences in population densities that exist between cities and the countryside. An effort must be made to tilt the balance towards decentralization when dealing with rural Africa where the needs are:

- Lighting;
- Cooking;
- Ventilation;
- Refrigeration for medicine preservation;
- Water pumping;
- Electricity for various small applications;
- Driving force for transport and irrigation;
- Socio-economic activities (mechanics, carpentry, shop keeping, battery charging, catering, hotel business, refreshment,...).

The ultimate goal of energy consumption in Africa is to be at the root of the continent development.

It is difficult to model human behaviour in order to influence it, and probably even more difficult to modify the behaviour of societies because of the weight of habits. The best results ever obtained for Africa, especially in this area of RE, have been through a succession of tests and failures. Everything we have been able to do so far is a short-term forecast that is more like an explanation of the present than an objective prospective. That is to say, we tend to follow what has been tested and accepted by society, which always puts us behind evolution.

To be effective it seems that RE actors have to be less ambitious than they were in the past in their search for viable projects. They must have the role of trainers, explanation, information and awareness providers, with the support of the necessary demonstrations to convince. In this field, decentralized REs have an asset that must be learned and used, and this is their low overall cost and their easy implementation. It is not possible to proceed with a succession of tests and failures when dealing with large power plants of several MW. For the poor countries of Africa, it is a luxury they cannot afford.

This is the biggest advantage in the field of small power installations, for which each user can do his own experimentation. The current success of PV, although mixed, has gone through this process. This is also the case for mobile phones for which no one would have bet and argued that they would be introduced to the most remote villages in Africa. When we analyse this success, we find out that it was neither imposed nor proposed to the villagers.

The same phenomenon has been observed for the adoption of solar panels. The observable panel theft, all over Africa today, is a consequence of their success. Today, only the high cost of panels inhibits the development of solar PV.

Some rules can be selected from this analysis for the success of RE projects. They may be expressed as follows:

- Projects must correspond to the need of beneficiaries;
- Projects should be a source of income for beneficiaries;
- Reliability and efficiency of installations are essential;
- Costs should be comparable to conventional solution costs;
- Acceptability by beneficiaries must be taken into account;
- And, of course, projects must tend to replace fossil fuel projects for sustainability issues.

In any case, one must think about raising awareness of potential users, and inform and train them if necessary (demos, drivers, tests,...).

4. Conclusion

Energy demand and the related services, aiming at ensuring economic and social development and also improving welfare and health, are on the rise. GHG emissions from the provision of energy services have increased significantly in the atmosphere. Recent data confirm that burning of fossil fuel accounts for the majority of global GHG emissions of human origin. The role of REs has been clearly established for the reduction of GHG emissions due to the energy sector.

This is why policies are essential to stimulate the investment needed for the development of REs, particularly in African countries. Significant advances in RE technologies and corresponding decline in prices over a long term have taken place over the past few decades. Further price declines are expected to improve the opportunities for the development of these technologies and will therefore contribute to the mitigation of the effects of climate change.

Various renewable energy resources have already been successfully integrated into old energy supply systems and end-use sectors. Today REs can be integrated into all types of power grids, from large interconnected continental networks to small self-contained networks and individual buildings.

The cost associated with the integration of these RE sources, whether for electricity generation, heating, cooling, or for the production of gaseous or liquid fuels, depends on the context and site considered but is still high. In recent years, there has been substantial development of RE technologies through the development of R&D and the implementation of various energy policies around the world. These policies have been adopted in a growing number of countries at the municipal, provincial, state, regional and international levels.

RE technologies are mature today with mitigated results however when it comes to their contribution in fighting global warming. This is because the word "environment" is not inciting enough to make people move, at least in Africa. People, wherever they live, are mainly moved by (economic) needs but also and mostly by (political) constraint. We are at the stage where the development of REs is irreversible for obvious economic reasons. However, strong political decisions are still needed to speed it up and make the right choices. This is what Africa lacks today for a significant contribution to the fight against climate change.

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Industrial Waste Heat Recovery: Innovative Solutions for Steel Industry

by

Thomas Steinparzer[*], Alexander Fleischanderl[*],
Manfred Haselgrübler[*] & Paul Trunner[*]

Keywords. — Industrial Waste Heat Recovery; Steelmaking; Integrated Steelmaking; Electric Steelmaking.

Summary. — Over the last few years, waste heat recovery in steel industry has received more and more attention. Additionally, the demand for increasing energy efficiency is one of the global megatrends of our time. The combination of steel production and waste heat recovery systems leads to a win-win situation for economic growth and decentralized power generation. Besides economic and social aspects, natural resources are saved and an economic value is created (*e.g.* by carbon emission trading). The presented waste heat recovery systems are based on simple and proven technologies (*e.g.,* hot water production, steam generation, ORC (Organic Rankine Cycle) units, etc.). This fact makes an application also from a social point of view reasonable. Waste heat recovery potential for mini mills (electric steelmaking) will be presented. Moreover, typical waste heat recovery solutions and possibilities for waste heat utilization will be briefly discussed. The objective of this paper is to demonstrate possibilities for energy recovery and utilization for the electric steelmaking route under consideration of economic feasibility.

Introduction

Africa's population is growing rapidly. Therefore, it is crucial to provide dedicated infrastructure and energy grids, especially electric energy, to a broad part of the population. A high diversity in energy production leads to a robust and stable energy network which is key to industrial and GDP growth. Power generation by industrial waste heat recovery can be a cornerstone for an efficient and socially acceptable energy system.

The demand for increasing energy efficiency and CO_2 reduction is one of the global megatrends of our time. Although the steel industry suffers from a volatile economic environment, the steel plants are interested in finding opportunities for sustainable cost reduction and putting efforts into healthy solutions for the environment. Steel plants are trying to cut down electrical power and energy costs as these are among the biggest cost factors that can be influenced.

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[*] Primetals Technologies, Turmstraße 44, 4031 Linz (Austria).

Considering waste heat recovery solutions, the key question for economic energy recovery is how to use waste heat. Electric power generation is a particularly attractive option for steel plant operators since it can easily be connected to the public power grid and therefore provide energy for people. This option is always possible, but economic feasibility is at present typically low due to the relatively low market price of electricity. Owing to developments in the energy market, the price of electricity has fallen in many countries but on the other hand the price of natural gas and steam or heat in general is comparably high. This leads to the fact that waste heat recovery systems focusing on heat production are getting more economically feasible. But this leads to the following question: what is the price of heat or energy in general?

The price of energy with respect to heat depends on many factors or questions which have to be answered by each steel plant individually:

- What is the price of electricity?
- Can natural gas be substituted by using waste heat?
- Can heat be delivered locally to other industries or local communities?
- Can chilled water be used for cooling purpose?
- Can carbon dioxide emissions be reduced by using waste heat?
- Can further advantages be created by a waste heat recovery system?

Typically, smaller natural gas-fired boilers in facilities not directly related to the steel plant itself, like pickling lines, can be substituted by waste heat. This question should be analysed in detail since these opportunities are the most feasible for waste heat recovery. Besides pickling lines, steam production for processing (*e.g.* vacuum degassing) or annealing lines can be very attractive.

Heat supply for other industries like chemical plants, glass industry or even sea water desalination can be very reasonable and is often done by steel plant operators. Also hot water supply for heating purposes in local communities like district heating applications helps generate profit out of waste heat and closely connects the steel plant to local communities. Heat supply can also have a very quick static payback since power plant operators are at the moment often not interested in operating their power plants due to the low price of electricity. Nevertheless, heat has often to be supplied to local communities. This leads to an often unreasonable price of heat compared to electricity (up to 25$ per MWh can be reached), at least from an energetic point of view.

Depending on regional conditions cooling can be preferred to heating. Waste heat can be also used for operation of heat pumps based on mechanical or absorption systems to produce chilled water, which can be applied for cooling purposes (*e.g.* for office applications or IT systems).

Besides static payback, reduction of carbon dioxide emissions and therefore greenhouse gas emissions helps strengthen the green reputation of a company. Furthermore, carbon dioxide reductions often allow to obtain public subsidies.

Above all economic benefits resulting directly from the waste heat recovery system, the use of waste heat can lead to further advantages for the existing process and plant beyond the sole waste heat recovery. By installing a waste heat recovery system operational safety due to increased standards and redundancy can be created. Also, other effects like relief of the existing recooling system or reduced corrosion due to increased cooling media temperature can have a positive influence on the overall feasibility.

Therefore, depending on the application, the prices of heat or steam can be above 30$ per ton of steam or even zero. Hence, circumstance and boundary conditions for the steel plant have to be analysed individually but can lead to relatively short payback time according to the situation.

Waste Heat Recovery Solutions for Mini Mills

In times of increasing awareness of energy consumption and tightening emission control, energy efficiency measures become more and more important for steel plant operators. For integrated iron and steel plants as well as for mini mills energy is one of the most important cost factors. Especially the vast amount of electric energy forces operators to improve the overall energy situation, in order to reduce the specific costs per steel ton and also to comply with legal requirements in terms of energy efficiency.

There are numerous opportunities along the iron- and steelmaking process for implementing energy efficiency technologies. Small improvements can be easily implemented without big actions. Such measures can be for instance a modified plant operation, simple plant upgrades, or smaller automation packages. For a more decisive impact on the energy balance of a steel plant, bigger actions are required. With the installation of a waste heat recovery system a large amount of off-gas energy can be used in form of steam and electricity, and hence reduce the specific energy cost of the plant.

Figure 1 shows a typical 3D model of an electric arc furnace gas-cleaning system comprising waste heat recovery. The orange-marked part is the waste heat recovery system. The picture shows also the two possibilities for using waste heat. The first one is steam or heat production for internal usage. This possibility leads to savings in fossil resources like natural gas respectively to liquid or coal. The second one is electric power generation. This can be done either by steam turbines or by ORC modules. The electric energy can be used in the steel plant directly or sold to the public grid.

In the following chapter these two options (heat or electricity production) will be explained in more detail.

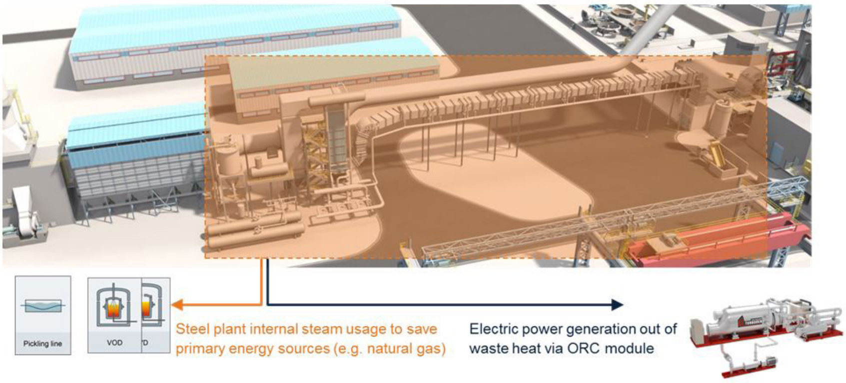

Fig. 1. — 3D model of a waste heat recovery system for mini mills with typical heat usage possibilities.

Internal Heat Usage

Primetals Technologies has developed a novel solution for internal waste heat utilization within a mini mill based on an innovative waste heat recovery system. This new solution is installed at an Italian steel plant, whereas the heat is used for on-site steam production. With the newly-installed system, almost the entire steam demand of the plant can be covered.

For the steel plant described above the recovered energy is used for steam generation. Therefore, the hot water is fed to two different pickling lines at a distance of 1.5 and 0.5 km. The large distance between heat recovery system and consumer is covered by long piping throughout the entire steel plant. This specific solution demonstrates that even long distances throughout the steel plant can be handled.

Steam generators are installed, which are heated by hot water from the waste heat recovery system. Feed water is thus fed to the steam generator and is evaporated. In parallel, hot water is cooled down by transferring heat to the water/steam side. The cooled water is fed back to the heat recovery system. The steam produced is enough to substitute the existing gas-fired boilers.

Electric Power Generation

Besides internal or external heat utilization electric power generation can be an attractive option depending on the price of electricity. Especially considering various heat sources within the steel plant (*e.g.* electric arc furnace, reheating furnace, etc.) these sources can be bundled for one combined power generation unit and therefore increase economic feasibility.

A schematic drawing of an electric arc furnace waste heat recovery system with ORC unit for power generation is shown in figure 2 (for technical details regarding electric arc furnace waste heat recovery systems, please refer to Trunner *et al.* 2017).

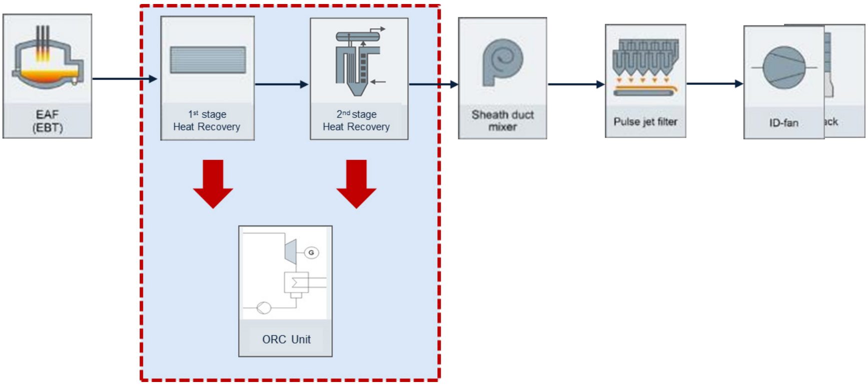

Fig. 2. — Schematic drawing of a waste heat recovery system with electric power generation.

A simple and reliable solution for a power generation unit is an Organic Rankine Cycle (ORC) unit instead of a steam turbine power block. ORC is a proven technology and ORC units have been widely used in renewables and distributed power since the 1970s. Typical ORC size ranges between a few hundred kW electric up to 15 MW and above. Most common applications are in geothermal and biomass fields where several hundred ORC power plants are in operation. In the ORC process, designed as a closed loop, the organic working medium is preheated in a regenerator and in a preheater, then vaporized through heat exchange with the hot source (heat carrier or exhaust gas). The organic vapour is expanded in a turbine that drives an electric generator converting mechanical into electric power. Leaving the turbine, the organic working medium (still in the vapour phase) passes through the regenerator which is used to preheat the organic liquid before vaporizing, therefore increasing the electric efficiency through internal heat recovery. The organic vapour then condenses and delivers heat to the cooling water circuit or directly to ambient air through air-condenser. After the condensation, the working medium is brought back to the pressure level required (for turbine operation) by the working fluid pump and then preheated by internal heat exchange in the regenerator.

The main following advantages can be recognized for ORC-based heat recovery systems:

— Totally automatic system, no need of supervision personnel: ORC needs supervision personnel neither in normal operating conditions nor in shut-down procedure. No additional personnel is needed.

- Flexible operation in a wide range of thermal power loads: ORC module has a high level of automation and is designed to automatically adjust itself to the actual operating conditions: variations on exhaust gas temperatures and flows will not affect the functionality of the system, but only the power output.
- High efficiency even at partial load.
- Long life with no major overhaul.
- Minimum maintenance requirements: ORC units are remotely monitored and require minimal yearly maintenance activities.
- Possible configuration with no water consumption.

For more information regarding ORC technology, please refer to Steinparzer *et al.* 2017.

Conclusion

The above-described solutions demonstrate economic feasible opportunities for waste heat utilization. Primetals Technologies can provide strong support during project development and has also numerous references in waste heat recovery systems for steel industry.

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Variable-Speed Pumped Storage Bringing Flexibility to the South African Power System

by

Thomas MERCIER[1,2], Mathieu OLIVIER[2] & Emmanuel DE JAEGER[1]

KEYWORDS. — Pumped Hydro Energy Storage; Variable-speed Drive; Hydraulic Machine; Operation Ranges.

SUMMARY. — Recent developments in power electronics have brought the possibility to operate 'pumped hydro energy storage' (PHES) units at variable speed. This feature enables to operate hydraulic machines over wider head ranges. For a given head, the variable speed allows power variation in pumping, but leaves the power range unchanged in turbine mode. Variable-speed PHES is thus able to provide primary frequency control both in pump and turbine modes. Operation ranges are limited to prevent undesired flow phenomena. Given a head, the studied pump-turbine's allowed power range spreads 24 and 53 % of and from the maximum allowed power at the given head. South Africa has already several PHES plants, such as *Ingula* 1332 MW, *Palmiet* 400 MW, and *Drakensberg* 1000 MW, all with reversible fixed-speed Francis pump-turbines. In the future, these plants could be upgraded with the variable-speed feature, thereby extending the flexibility provided to the grid.

Introduction

South Africa has a relatively infant but growing renewable energy industry. According to its department of energy, renewable energy will contribute to a total of 18.2 GW by 2030 (about 42 % of the new build). Regarding nuclear energy, 9.6 GW will be added by 2030. To ensure the reliable operation of the power grid, while integrating significant amounts of renewable intermittent generation on the one hand, and of non-flexible nuclear generation on the other hand, flexibility will be needed. 'Pumped hydro energy storage' (PHES) is a good candidate to provide this flexibility, and this is not a coincidence if South Africa has already several PHES plants, such as *Ingula* 1332 MW, *Palmiet* 400 MW, and *Drakensberg* 1000 MW, all with reversible fixed-speed Francis pump-turbines.

PHES is the most established technology for large-scale energy storage. Up to now, PHES has mainly consisted in large fixed-speed reversible pump-turbines driving or being driven by a grid-connected synchronous machine. The power in

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[1] Mechatronic, Electrical Energy and Dynamic Systems, UCLouvain, Place du Levant 2/L5.04.01, B-1348 Louvain-la-Neuve (Belgium).

[2] Laboratoire de Mécanique des Fluides numérique, Université Laval, Québec (Canada).

turbine mode is varied at the expense of efficiency by controlling the flow in the machine while the power is fixed in pump mode. The best efficiency point (BEP) corresponds to different speeds in pump and turbine modes, resulting in a loss in efficiency as the machine is mainly operated at one single constant speed, the synchronous speed.

In the last decades, developments in power electronics have enabled the supply of electrical machines with variable-frequency voltages, resulting in the possibility to vary the speed of PHES plants. Large machines, of more than 50 MW, use a 'doubly-fed induction machine' (DFIM) with a power converter rated to only a few percent of the nominal power while smaller machines use a synchronous machine with a full-size power converter (Ardizzon *et al*. 2014, Beevers *et al.* 2015, Ciocan *et al*. 2012, Krenn *et al*. 2013). Some examples of variable-speed PHES plants are given in table 1.

Table 1
Features of some of the largest variable-speed PHES plants

Power plant	**Number of units**	**Unit output (MW)**	**Speed range**
Nant de Drance (CH)	6	157	± 7 %
Linthal (CH)	4	250	± 6 %
Tehri (Inde)	4	255	± 6 %

This variable speed possibility can be used to always operate the hydraulic machine at its BEPs, as these are related to different speeds in pump and turbine modes, thereby increasing the revenues from price arbitrage on the energy markets. Sometimes the variable speed becomes a necessity in order for the pump mode to support high head variations and be able to operate between its stability and cavitation limits (Ardizzon *et al.* 2014). Besides, the increased head range can lead to a better use of the basins' capacity. Another option is to make use of the variable speed to provide 'transmission system operators' (TSOs) with ancillary services, in particular primary and secondary frequency control, both in pump and turbine modes. The basic idea behind those services is to adjust power injections/offtakes in real-time, so as to keep the balance between electricity generation and consumption. The provision of primary and secondary frequency control imposes high technical requirements on power plants, as these must have a range of power within which injections/offtakes can continuously and rapidly be varied.

Several authors have emphasized that a significant share of PHES revenues could be achieved through the provision of ancillary services (Pérez-Díaz *et al*. 2015, Pinto *et al*. 2011, Deb 2000). While these studies aim to give an overview of PHES, they fail to provide important technical details regarding the variable-speed operation of PHES to provide ancillary services. Economic calculus is often based on rather vague assumptions regarding the operation range of PHES, *e.g*. from

20 to 100 % of the nominal power in turbine mode, and from 60 to 100 % in pump mode if variable-speed operation is considered in both cases (Beevers *et al.* 2015).

In this paper, we shed light on the operation ranges of variable-speed pump-turbines, thereby characterizing the flexibility they provide to power systems.

Operation Ranges of Fixed- and Variable-Speed PHES

The detailed characteristics of a Francis pump-turbine are given in Pannatier (2010). These characteristics are obtained from laboratory measurements on the scale model of a real machine by varying the head H [m] across the machine, for different guide vane positions y ∈ [0;1], while the rotational speed N [RPM] is kept constant. Both discharge Q [m^3/s] and torque T [Nm] are measured, which gives a vector (y, N, H, Q, T) for each measurement. The measurements are then provided as charts giving the relations between the unit numbers [1]*, namely unit speed N_{11}, unit flow Q_{11} and unit torque T_{11}, with D_{ref} [m] the pump-turbine's reference diameter (Jaumotte *et al.* 1991):

$$N_{11} = \frac{ND_{ref}}{\sqrt{H}}, \qquad Q_{11} = \frac{Q}{\sqrt{H}D_{ref}^2}, \qquad T_{11} = \frac{T}{HD_{ref}^3}.$$

The mechanical power can be derived from the unit numbers according to the following relation:

$$\mathrm{P_m} = \frac{2\pi \mathrm{NT}}{60} = \frac{\pi}{30}\mathrm{H}^{1.5}\mathrm{D}_{\mathrm{ref}}^2\mathrm{N}_{11}\mathrm{T}_{11}. \qquad \text{Eq. 1}$$

The operation range of the studied turbomachinery is provided by the same reference (Pannatier 2010) and indicated on the T_{11}-N_{11} charts, as shown in figure 1.

In turbine mode, the limitation of the operation range is mainly due to several flow phenomena taking place in the hydraulic machine (Avellan 2004). The A-B and C-D limits are defined by the manufacturer to avoid discharge ring swirl cavitation. In fact, at high and low discharge, a swirling flow appears at the runner outlet (fig. 2), with eventually cavitation at its centre, in which case the phenomenon is referred to as vortex rope. The whirl dynamics compromises the machine's operation stability, since it is the main source of pressure fluctuations in the hydraulic installation. The B-C and D-E limits are set to respectively avoid leading edge pressure- and suction-side cavitation (fig. 3) as it can lead to a severe erosion of the blades. Finally, the A-E limit is set by the rating of the electrical generator. In pump mode, the operation range is limited by lower and upper N_{11} bounds, *i.e.* higher and lower head values, to respectively prevent suction- and pressure-side cavitation on the runner blade (Avellan 2004, Krenn *et al.* 2013). In addition, the operation range is limited by another upper N_{11} bound, corresponding to the pump stability limit (Krenn *et al.* 2013).

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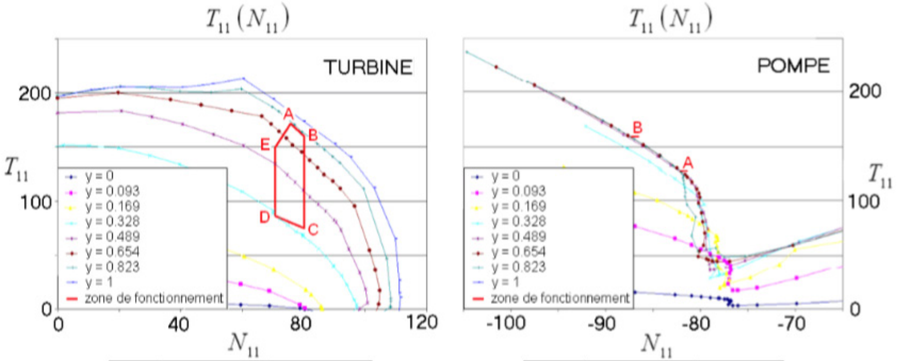
* Number in brackets [ ] refers to the note, p. 183.



Point	N_{11}	T_{11}
A	75.6481569	171.685041
B	80.1760764	159.858624
C	80.1760764	74.7710555
D	70.6751414	86.1941526
E	70.6751414	149.854271

Point	N_{11}	T_{11}
A	-81.7429833	127.80629
B	-86.8688621	158.9985

Fig. 1. — Characteristics and operation ranges of the studied pump-turbine, as found in Pannatier (2010).

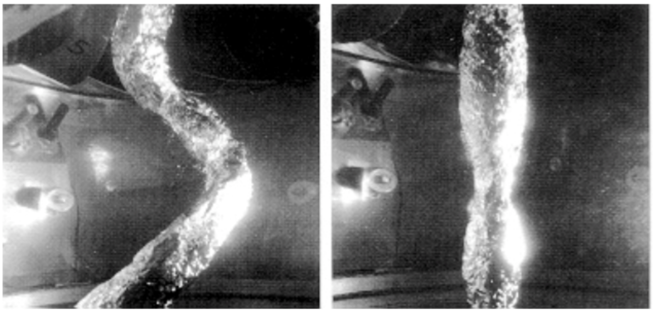


Fig. 2. — Cavitation at Francis runner outlet.

Fig. 3. — Leading edge cavitation in Francis machine.

The operation ranges associated with the studied Francis pump-turbine can be derived, for both fixed- and variable-speed cases, from the machine characteristics. These ranges are given in figure 4. The grey area corresponds to the case where the rotational speed can be varied from 0 to 100 % of its nominal value, while the segments in red indicate the range if the speed is kept at the nominal value.

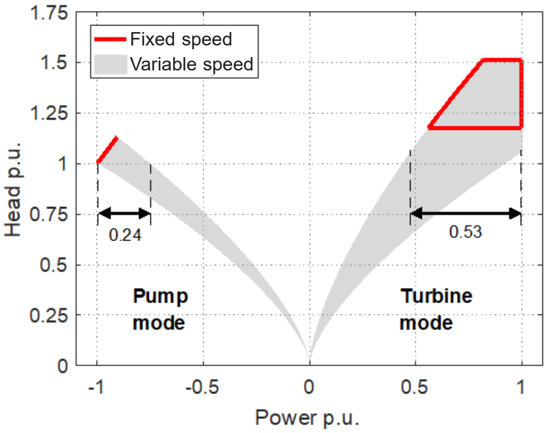


Fig. 4. — Operation ranges of the studied Francis pump-turbine.

We see from figure 4 that at a given head, the variable-speed feature provides the pump mode with a non-zero power range, while the turbine mode does not see its power range affected. The variable speed enables both pump and turbine modes to operate at lower heads. Besides, the extent of the power range varies with head, both in pump and turbine modes, and can precisely be quantified using equation 1 and the ranges of figure 1, *i.e.* substituting in equation 1 the extreme values that can be taken by N_{11} and T_{11}.

Following the methodology mentioned for the pump mode, the allowed power range can be derived as a ratio:

$$\frac{P_{m,A}}{P_{m,B}} = \frac{N_{11A}T_{11A}}{N_{11B}T_{11B}} = 0.76$$

This relation shows that given a head, the allowed power range is 24 % of the maximum allowed power at that head. It is important to emphasize that the maximum allowed power depends on the available head. The lower the available head, the lower the maximum allowed power. The same computation can be carried out for the turbine mode, which gives the following power range:

$$\frac{P_{m,C}}{P_{m,B}} = \frac{N_{11C}T_{11C}}{N_{11B}T_{11B}} = 0.47$$

Here again, the minimum allowed power at a given head is a fixed percentage of the maximum allowed power at that head.

To sum up, given a head, the range of allowed power of the studied pump-turbine is respectively 24 and 53 % of the maximum allowed power at the considered head. These ranges are limited to prevent undesired flow phenomena. The fact that the power range varies with head is crucial for the provision of primary frequency control. In fact, as the level of water varies with time, so does the available power range and the amount of primary frequency control that can be provided. Whether in pump or turbine mode, the amount of primary frequency control that can be provided by a pump-turbine should be computed based on the minimum operation head. Another important consideration is that variable-speed PHES must be operating rather far from the zero output to be able to provide primary frequency control, which implies frequent switches from pump to turbine, and vice versa, in order to continuously provide this ancillary service. The energy market implications of this last point should be taken into account when assessing the revenues of variable-speed PHES for the provision of primary frequency control.

Conclusion

Recent developments in power electronics have brought the possibility to operate PHES units at variable speed. This feature enables to operate hydraulic machines over wider head ranges. At fixed speed, the power setpoint is fixed in pump mode, but can be varied in turbine mode, from typically 47 to 100 % of the rated power. For a given head, the variable speed allows power variation in pumping, but leaves the power range unchanged in turbine mode. Variable-speed PHES is thus able to provide primary frequency control both in pump and turbine modes. Operation ranges are limited to prevent undesired flow phenomena. Given a head, the studied pump-turbine’s allowed power range spreads 24 and 53 % of and from the maximum allowed power at the given head. Whether it is in one or the other mode, the allowed power range varies with head, which impacts the amount of primary frequency control that can be provided. Besides, the continuous provision of primary frequency control requires PHES units to constantly be operating rather far from the zero output, which implies frequent switches from pump to turbine mode and vice versa.

South Africa already has several PHES, such as *Ingula* 1332 MW, *Palmiet* 400 MW, and *Drakensberg* 1000 MW, all with reversible fixed-speed Francis pump-turbines. In the future, these plants could be upgraded with the variable-speed feature. New electrical machines would be required, namely DFIM, instead of the synchronous machines currently in operation. The result would be an extended operation range in pump mode, and thus an increased flexibility for the grid.

ACKNOWLEDGEMENTS

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NOTE

[1] The advantage of providing the characteristics of the studied turbomachinery using unit numbers is the following. If one can make the similitude hypothesis, *i.e.* if one can neglect the effects of both the Reynolds number and roughness, the provided characteristics can easily be extended to (*i*) the same machine operated in other working conditions, and (*ii*) to machines having the same geometry as the scale model but a different size.

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Small Hydropower Development in Burundi

by

Jean Bosco NIYONZIMA* & Patrick HENDRICK*

KEYWORDS. — Energy Resources; Small Hydropower; Sankey Energy Flow Diagram; Banki-Michell Turbine.

SUMMARY. — According to HARVEY *et al.* (1993), hydropower schemes are classified into three levels of size and power: (*i*) full-scale hydro schemes that produce enough electricity for large cities and extensive grid supplies and produce more than 10 MW of power; (*ii*) small hydropower schemes that make a smaller contribution to national grid supplies and produce power in the range from 300 kW to 10 MW; (*iii*) micro hydropower schemes that are used in remote areas where the grid does not extend and that produce power lower than 300 kW. Therefore, the definition of small hydropower schemes made by HARVEY *et al.* (1993) matches well with the context of Burundi in which small hydropower is defined such as hydropower schemes in power of size minor than 10 MW.

In Burundi, all existing hydropower plants are classified within the small hydropower units, except for the ones of Rwegura with a capacity of 18 MW. The first hydropower plant was implemented in 1980 and the last one in 1986. The total national installed capacity was around 54 MW in 2016 (including both hydro and diesel production) compared to an electricity demand of 250 MW by 2020, not including the required electricity for mine extraction.

Several conflicts took place in the country after independence (1962), which slowed strongly down its socio-economic development and resulted in the limitation of studies and tools that could be used to inform about the energy situation of the country. We have analysed the energy production in 2011 through sources, we have realized that the energy produced from biomass represents the major part of the total energy produced (94.5 %) because it is the major primary energy source used by the majority of the population. Biomass is used for cooking in the households in both urban and rural areas. There is no use of biomass in electricity production. The electricity production represents 0.8 % of the total energy production and includes the domestic hydro production, diesel generation and the electricity imported. This paper aims to collect the useful data on the present energy sources, analysing the Burundi energy production by the use of a Sankey energy tool and showing the interest of the Banki-Michell turbine in small hydropower.

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* Aero-Thermo-Mechanics (ATM), Université libre de Bruxelles, avenue F. D. Roosevelt 50, CP 165/41, B-1050 Brussels (Belgium).

1. Introduction

Burundi is a landlocked country and is surrounded by the Democratic Republic of Congo (west), Republic of Rwanda (north) and Republic of Tanzania (east) (fig. 1). The land area of the country is about 27,834 km^2. Burundi has both the favourable climate and topography for the development of renewable energy. The average annual rainfall is about 1,500 mm with two dry seasons (June to August and December to January) and two wet seasons (February to May and September to November). The topography is hilly and mountainous with a mean altitude of 1,700 m. Burundi has several types of vegetation. The country has two main types of energy resources, biomass and hydropower, biomass still being the main energy resource used by the population in households, essentially for cooking purposes. On the other side, hydropower is the main energy resource used for electricity purposes.

Fig. 1. — Map showing the provinces of Burundi (African Development Bank 2009).

Concerning electricity purposes, several studies have been made to identify the global hydropower potential of the country, such as the studies carried out by Lahmeyer (1983), the *Direction générale de l'Hydraulique et de l'Énergie rurale* (DGHER) in 2010 and 2011, Nzeyimana (2010), and recently in 2013 by SHER *Ingénieurs Conseils* (MEM 2012, 2013; SHER Engineering s.a. 2013). These studies show that Burundi has a significant hydropower potential but not exploited so far. According to Lahmeyer (1983), Burundi has a global potential hydropower of 1,371 MW, in which a capacity of 294 MW is economically feasible. Lately, SHER Engineering s.a. (2013) showed that Burundi has a feasible hydropower capacity of 414 MW in which 125 MW can be exploitable in priority. Since April 2015, the government has reviewed the electricity law that allows the restructuration of the electricity domain. This law seems to give legal framework to private investors in the energy sector, removing the monopoly made by REGIDESO (*Régie de distribution d'eau*) on power generation (République du Burundi 2015a,b) and stimulating new private investors in the field.

In Burundi, the production, transport and distribution of electricity is fully managed by the government via two main public companies which are directly under the authority of the Ministry of Energy and Mining:

- REGIDESO is a public institution, which manages the production, transport and distribution of water and electricity. It is responsible for commercialization of water and electricity within urban areas. The capacity of hydropower under the control of REGIDESO is about 32.85 MW.
- ABER is a public institution, which is responsible for rural areas. It has established twelve small hydropower plants with a total capacity of 1.35 MW. According to REGIDESO's annual report (2016), some of them are for now out of operation.
- Other private producers have in total 0.63 MW. These production stations are under the authority of some public companies (*Office du Thé du Burundi,* for instance) and under the authority of catholic communities.

The department in charge of energy named *Direction générale de l'Énergie* (DGE) is a public administration which plays the role of defining the energy policy of the country such as planning, coordination and implementation of programmes in the field of energy (MEM 2012, SHER Engineering s.a. 2013).

The lack of private investors is due to the absence of an effective legal framework for electricity business. The updated law is available since April 2015 and is coming to officially remove the title of monopoly from the REGIDESO and to allow the participation of private investors in the energy business. According to REGIDESO's reports (2016), the electricity prices per kWh for households remain lower in the range of 68 to 260 FBU (0.034 to 0.13 euros) up to August 2017, which is not interesting for private investors in the energy field. In addition, the Agency of Control and Regulation (ACR) of electricity was established in 2007 to reinforce the liberalization of electricity business. The ACR is aimed at making control and regulation on the production, transportation and distribution of electricity (République du Burundi 2015a,b).

Biomass is the main energy resource used in Burundi and the country is no longer using biomass for electricity end use. Biomass is mainly used for cooking by the rural and urban population. Biomass for cooking in form of firewood and charcoal accounts for the largest part of household energy consumption and hence has more impact on health and environment. Then, the limited access to electricity is a huge barrier to the development of the country, which imports additional electricity from SNEL and SINELAC (MEM 2012), two electricity companies based in DR Congo. SNEL is the DR Congo's national electricity company while SINELAC is a regional electricity company gathering DR Congo, the Republic of Burundi and the Republic of Rwanda. The lack of enough electricity has been a big challenge up to now for the country and is the main cause of several power failures. The country needs to increase the accessibility to electricity by initiating several small hydropower projects which have more impact on the socio-economic development of rural areas. But there are insufficient studies or tools that could be taken as reference in the energy sector development. Therefore, one purpose of this paper is to collect maximum data for all primary energy resources that could help the country to increase its electricity production. The collected data will allow us to produce an energy flow diagram in Burundi which could serve as reference for future research or activities in the energy sector. According to IEA (2014), a Sankey energy flow diagram aims to balance the energy production and importation versus the total final consumption. Other Sankey energy flow diagrams can make comparison between the final total energy consumption and the consumption by sector. A second purpose of this paper is to show the interest of the Banki-Michell turbine in small hydropower in Burundi.

After this brief introduction, our paper is structured into two main parts: the methodology used to build a Sankey energy diagram for Burundi and the perspectives in which we describe the test bench of a prototype of Banki-Michell turbine which could be used under the real conditions of Burundian rural areas.

2. Methodology

2.1. Energy Resources in Burundi

The purpose of this paragraph is to collect all data on the production and consumption of the country's energy resources. The latter data will be used to construct the first Sankey energy flow diagram for a chosen year. The Burundian climate, relief and vegetation meet the favourable conditions for developing hydropower, solar, wind and biomass energy. Given that Burundi is listed among the poorest countries in the world, electricity production remains insufficient.

According to the *Cadre stratégique de Croissance et de Lutte contre la Pauvreté* (CSLPII 2012), although the rural population represents 90 % of the population, the electrification rate in rural areas is still very low (in the order of 2.6 % in 2011). In the same year, the electrification rate of urban areas was about 45.7 % (African Development Bank 2009). However, the households are provided in firewood and charcoal for cooking purposes. The main primary energy sources present in Burundi are composed of fossil fuel and renewable energy in which hydraulic plays a major role in electricity production. Fossil fuel is mainly used in transport while hydropower is used in electricity. Therefore, less accessibility to electricity implies a lower development level for the country.

2.1.1. Fossil Fuel

According to Savary (2011), Burundi has an important potential of oil reserves along Lake Tanganyika which are not well known and for which concerted efforts must be made between the partners of Eastern African countries for explorations in the region. For instance, studies have already been made in order to establish a common basis of geological data.

Figure 2 shows the map of oil exploration in Burundi. The exploration area is divided into four research zones along the Lake Tanganyika basin and Rusizi: A (793.1 km^2), B (697.1 km^2), C (664 km^2) and D (813.4 km^2). Block A is on Rusizi basin, which is onshore, while B, C and D are offshore in Lake Tanganyika basin from north to south respectively. The exploration of Lake Tanganyika requires enormous financial resources that the country does not have and this is why the government of Burundi continue to encourage oil companies to invest in petroleum exploration which could raise numbers of available studies on petroleum products. In a recent conference (EAPCE 2017), it was shown that there were no undergoing studies on the exploration of Lake Tanganyika, which means that the country is not visibly involved in research of petroleum products. However, Burundi is no oil producer; the country is obliged to import and transport petroleum products, which is a big challenge. Transportation costs a lot to Burundi and influences oil prices at the pump. Three corridors are used to transport and supply oil products. A north corridor links Mombasa harbour to Bujumbura, a middle corridor connects Bujumbura to Dar es Salaam harbour and a south corridor connects Bujumbura to Dar es Salaam via Kigoma harbour. The last one uses Lake Tanganyika from Kigoma harbour to Bujumbura (Savary 2011). So, the main products of oil consumed in Burundi are diesel, gasoline, lamp oil and kerosene. Methane, propane, butane and other hydrocarbons are not much used in Burundi. A part of the amount is used for electricity production while the rest is used for transport and lighting. Table 1 shows the quantity of oil imported to Burundi from 2010 to 2015.

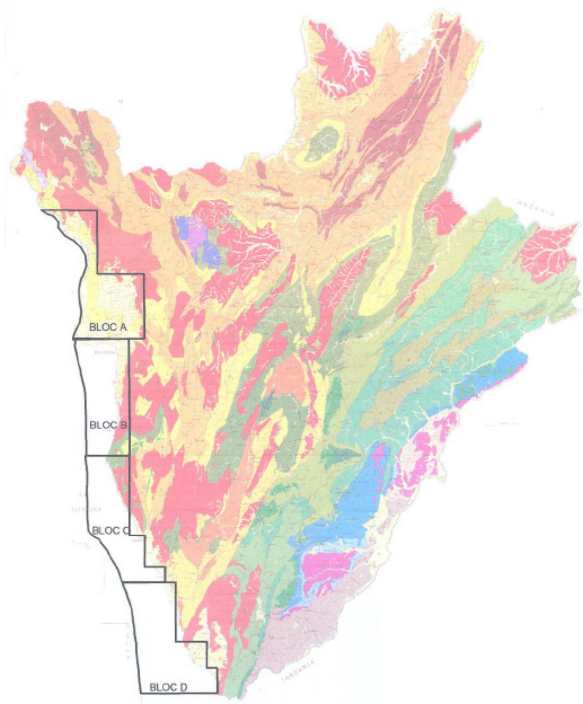


Fig. 2. — Map of the oil potential of Burundi (Savary 2011).

Table 1
Quantity of oil imported to Burundi from 2010 to 2015
(Office burundais des Recettes 2015)

	2010	**2011**	**2012**	**2013**	**2014**	**2015**
Gasoline	43,644,544	52,806,159	66,530,724	67,496,255	67,745,766	68,862,511
Kerosene	5,095,060	4,746,149	4,591,839	5,088,440	5,188,719	3,632,785
Diesel	57,877,341	79,726,535	64,539,821	70,663,133	77,374,811	68,783,205
Lamp oil	3,380,810	3,532,417	2,889,576	3,440,333	1,583,573	738,933
Others	251,552	299,712	527,039	360,242	385,013	253,202
Total (litres/year)	**110,249,307.0**	**141,110,972**	**139,078,999.0**	**147,048,403**	**152,277,882.0**	**142,270,636**
Total (GWh/year)	**1,102.5**	**1,411.1**	**1,390.8**	**1,470.5**	**1,522.8**	**1,422.7**

According to peat resource (MEM 2012, 2013), Burundi has an important potential of peat reserves of six hundred million tons of which fifty-seven to fifty-eight million tons are exploitable (MEM 2012, 2013). This quantity is equivalent to 279,870 and 284,780 GWh. The use of peat has a huge negative environmental impact. For instance, the peat production shared by Index Mundi

(2013) states a peat production of 93.3 GWh, which represents a huge amount of CO^2 emissions of 35,916.65 t CO^2. This value takes into consideration the extraction and combustion of peat. By definition, peat is a heterogeneous mixture of decomposed plants that have accumulated in water-saturated environment and in the absence of oxygen. Due to the lack of national data on peat production, we have used the data shared by an international platform named Index Mundi. This platform keeps the world informed of the global country statistics, charts and maps compiled from multiple sources in order to give a good understanding of complex information on hydrocarbons in general (fig. 3). However, based on statistical data given by Index Mundi (2013), the global peat production of Burundi from 2003 to 2013 is shown in figure 3.

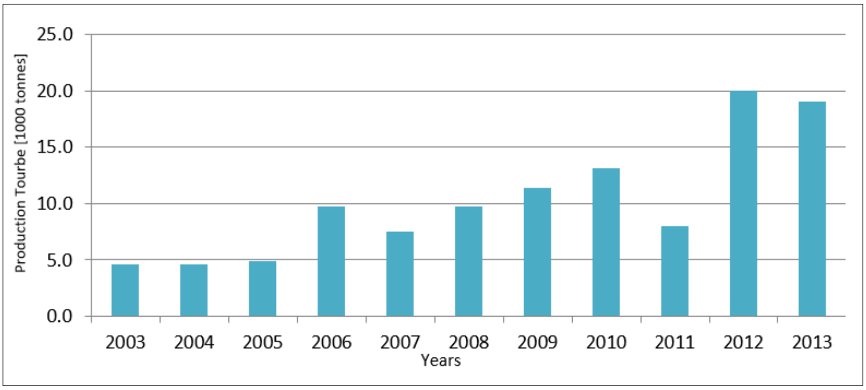


Fig. 3. — Global peat production in Burundi from 2003 to 2013 (Index Mundi 2013).

The management of peat is ensured by a public institution named *Office national de la Tourbe* (ONATOUR). In fact, peat cannot be used in households for two main reasons. It produces unpleasant smell for cooking and its combustion causes harmful smoke. So, peat is not indicated for household use. For this reason, it is mainly used by collective institutions such as hospitals, military camps and prisons for cooking purposes.

2.1.2. Solar Energy

The assessment of solar energy capacity for a typical site is based on two important parameters, *i.e.* global radiation and the duration of radiation per day. Referring to figure 4, solar radiation in Burundi varies between 1,200 and 1,650 kWh/kWp/year. We have maximum radiation in the lowest altitude regions during the dry seasons and we have minimum radiation in the highest altitude regions during the wet period. For instance, the country has one hundred and fifteen photovoltaic installations of 72.8 kWp in total (MEM 2012).

Electricity produced by photovoltaic cells is used in public services such as schools and telecom infrastructures (Liu *et al.* 2013). Note that the installed solar capacity for private households is still unknown. The country has no reliable data and needs more investigation in this field. There is no available study made to characterize the solar potential in Burundi.

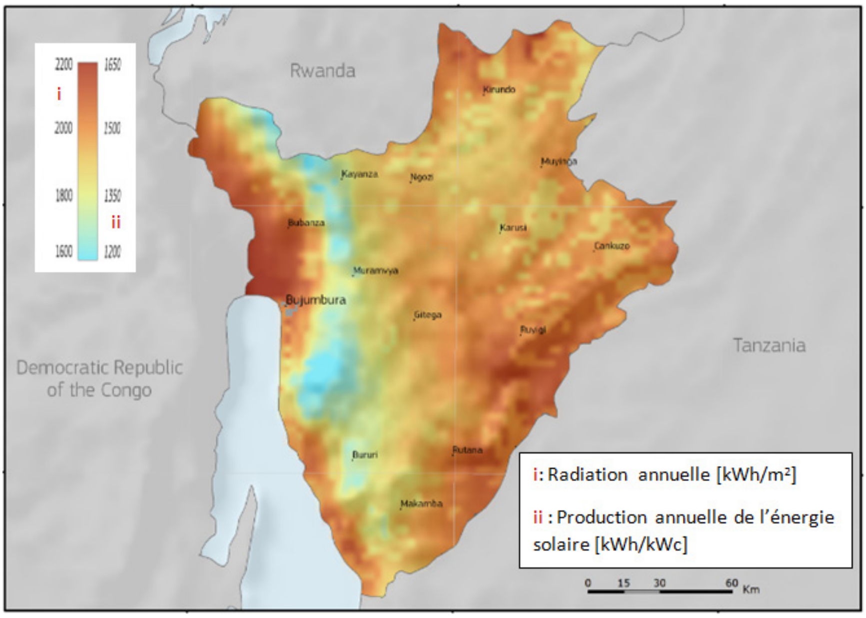


Fig. 4. — Global radiation and solar electricity potential in Burundi (Huld *et al.* 2012).

2.1.3. Wind Energy

Wind energy is not much used in Burundi. There are no feasibility studies available in the sense of future wind energy projects. There are only two existing mechanical wind turbines for several years in the plain of Imbo which are now out of use (MEM 2012).

2.1.4. Biomass

Biomass is the set of biological materials that are used as fuel for the production of heat and electricity. In Burundi, biomass is used at large scale for cooking under the form of firewood and charcoal. Moreover, biomass is used to generate electricity on a limited scale by the Sosumo (*Société sucrière du Moso*) in the form of *bagasse* (MEM 2012). *Bagasse* is wasted residue from sugarcane after juice extraction, which is used to produce electricity by the Sosumo during the period when sugar is produced. Sosumo is the company in charge of producing sugar from sugarcane in Burundi. There is no available data for electricity production from *bagasse*. However, firewood and charcoal are used in rural and urban households, in industries and in some cases, they are exported to the neighbouring countries (tab. 2) (Bararwandika 1999a,b; Nkurunziza 1999).

Table 2a

Firewood consumption in Burundi from 1994 to 1998 in kg (Nkurunziza 1999)

	1994	**1995**	**1996**	**1997**	**1998**
Rural households	7,227,793	7,451,333	7,681,787	7,912,242	8,149,609
Urban households	3,683	3,797	3,915	4,033	4,153
Industries	14,855	15,158	15,468	15,777	16,092
Public services	30,484	31,754	33,078	34,401	35,770
Craft industries	3,268	3,405	3,547	3,689	3,836
Exportations	19,843	20,248	20,662	21,075	21,496
Total	**7,299,926**	**7,525,695**	**7,758,457**	**7,991,217**	**8,230,956**
Total (GWh/year)	**25,549.7**	**26,339.9**	**27,154.6**	**27,969.3**	**28,808.3**

Table 2b

Charcoal consumption in Burundi from 1994 to 1998 in kg (Nkurunziza 1999)

	1994	**1995**	**1996**	**1997**	**1998**
Urban households	36,637	38,163	39,754	41,344	42,997
Rural households	8,573	8,660	8,748	8,835	8,923
Exportations	1,474	1,504	1,535	1,566	1,597
Public sector	104	105	107	108	109
Total (tonnes/year)	**46,788**	**48,432**	**50,144**	**51,853**	**53,626**
Total (GWh/year)	**224.6**	**232.5**	**240.7**	**248.9**	**257.4**

Since the population of Burundi is more rural than urban, wood is the most widely used energy (in the order of 94.5 % in 2011) (tab. 2a). The country must develop more projects that would reduce the quantity of wood used for cooking.

For instance, the use of improved cookstoves is a good technology which would contribute to the socio-economic development and to the protection of the environment. In fact, the main goal of improved cookstoves is:

- To reduce the wood used as fuel;
- To improve combustion efficiency;
- To reduce the time spent in cooking;
- To make household cooking more comfortable and save money.

Figure 5 shows a cookstove used in Burundi and made locally. The heat exchange is made by radiation, convection and conduction.

The choice of the stove has to take into account some features such as its material, its form, its efficiency and its price. The cookstove is mainly made of aluminium metal or steel and terracotta. Metal increases quickly the temperature.

Fig. 5. — Improved cookstove used in Burundi (Ministry of Energy and Mining – MEM).

The main fuel is wood or charcoal. However, wood is characterized by its coefficient of moisture (equation 1) and by its calorific value:

$$H = \frac{Gross\ weight - Anhydrous\ weight}{Gross\ weight} \tag{1}$$

Complete combustion of wood can be summarized in equation 2. One kilogram of wood associated to one cubic metre of oxygen produces a heat of 19 MJ:

$$1\ kg\ wood + 1\ m^3 O_2 \ \rightarrow 1 m^3 CO_2 + \ {}^2/_3\, m^3 H_2O + 19\ MJ\ of\ heat \tag{2}$$

The heat is supplied by the flame and by the heating of combustion gas. Good combustion then involves high temperature and good air mixture.

In the end, the goal of the improved technology is evaluated through a good efficiency. Combustion efficiency is computed by the ratio between the heat produced over the heat consumed by wood (equation 3):

$$Efficiency\ of\ combustion = \frac{heat\ production}{heat\ consumption} \tag{3}$$

Total thermal efficiency of improved cookstoves is then computed taking into account the total heat exchange by the pot over the total heat generated by the combustion from the starting phase to the boiling phase (equation 4) (Ministère du Plan et du Développement communal & PNUD 2011). Boiling phase of the cooking process is featured by high heat power:

$$\eta_{tot} = \frac{[M_o(T_b - T_i) + M_o^{cook}(T_2 - T_{cook})]C_p + (M_v^b + M_v^{cook})h_v}{(M_w^b + M_w^{cook})P_c} \tag{4}$$

where η_{tot} = total thermal efficiency; M_o^{cook} = water mass at the start [kg]; T_2 = water temperature before boiling phase [°C]; T_{cook} = water temperature at the start of cooking [°C]; M_v^{cook} = vaporized water mass during cooking [kg]; M_v^b = mass of vaporized water at boiling phase [kg]; C_p = heat coefficient (4.18 kJ/kg); hv = latent heat of water vaporization (2,257 kJ/kg); M_w^{cook} = mass of wood before boiling phase [kg]; M_w^b = mass of wood consumed at boiling phase [kg]; P_c = lower calorific value of wood (18,000 kJ/kg).

JOREZ (1992, p. 173) simulated the heat exchange of an improved cookstove (fig. 6). The entrance of Air I represents the inlet of air at the start of combustion while the entrance of Air II is the air contributing to the complete combustion when wood is supplied. The power involved in cooking is the one supplied to the cooking pot which is composed of heat supplied by radiation, by the flame and by the convection of heated gases.

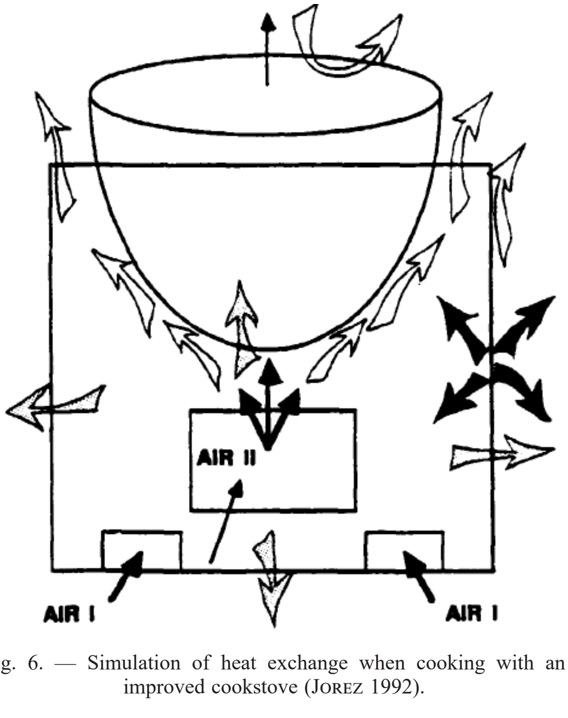


Fig. 6. — Simulation of heat exchange when cooking with an improved cookstove (JOREZ 1992).

In addition, a part of the heat is lost through the contact of the cooking pot with the soil, by convection of the heated gases, by natural cooling and by radiation of the wall of the cooking pot. To sum up, the design of improved cookstoves implies good combustion, high efficiency of heat exchange, reduced heat losses, long duration and good resistance against mechanical and thermal stress. We can also find biomass in liquid form. This kind of biomass is called biogas and it has been well known in Burundi since the 1980s. Biogas is a mixture of natural gas and other components such as carbon dioxide. Biogas is used either for electricity or for heating use. In the context of Burundi, biogas has been used in remote high schools and hospitals as a way of cooking and lighting.

Three multilateral projects were carried out between Burundi, Belgium and China as part of a study on the digesters to adopt in Burundi (WAUTHELET *et al.* 1989). This study resulted in the adoption of five types of digesters for Burundi: dome digester (German), digester bell (German), elongated modular digester (Belgian), and the Chinese digester and the batch square digester (Belgian). In November 1988, Burundi had one hundred and thirty-six identified digesters and most of these are currently out of use due to lack of maintenance (WAUTHELET *et al.* 1989). The country needs to make another survey on biogas use in order to get more reliable information. There is no saved data on energy production and consumption about biogas.

2.1.5. Power Generation by Diesel Generators

In 2009, the government of Burundi set up the first thermal power station with a capacity of 5.5 MW and under the responsibility of REGIDESO. Until June 2017, the total electricity production by diesel generators was in the order of 20.5 MW of which a capacity of 10 MW was supplied by a local private company named Interpetrol with a contract to operate over six hours per day. In September 2017, Interpetrol got a new contract of 20 MW totalizing 30 MW to operate eighteen hours per day. The 10.5 MW power station managed by REGIDESO operates rarely for lack of fuel. Figure 7 shows the electricity mix of Burundi of which 44.6 % is supplied by generators (September 2017).

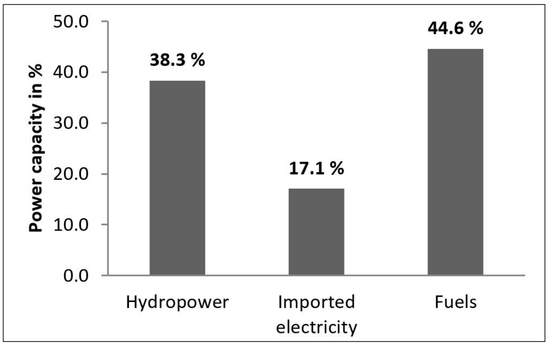


Fig. 7. — Electricity generation in Burundi (REGIDESO 2016).

2.1.6. Hydroelectricity

Electricity production from hydropower plants is grouped into two categories: domestic production and imported electricity. Table 3 shows the electricity production from hydropower from 1996 to 2014. There has been no significant variation in terms of electricity production since the first hydropower was commissioned. The country has one large hydropower plant with a capacity of 18 MW. Except for Mugere power station with a capacity of 8 MW, the rest of small hydropower plants produce electricity with a capacity lower than 3 MW.

Table 3
Hydropower production from 1996 to 2014 (REGIDESO 2016)

Years	Hydropower (GWh)	Electricity imported (GWh)
1996	83.6	1.2
1997	73.4	45.8
1998	98.8	31.7
1999	89.7	50.3
2000	87.7	45.4
2001	123.8	40.6
2002	117.5	39.9
2003	96.1	51.1
2004	84.6	70.4
2005	93.1	84.6
2006	86.3	58.8
2007	111.4	70.3
2008	111.8	90.0
2009	116.5	85.0
2010	124.5	99.4
2011	128.4	104.1
2012	138.8	104.3
2013	137.9	103.2
2014	140.4	91.3

In fact, the electricity supplied by hydropower plants depends largely upon domestic production from Rwegura and Mugere power stations, which totalize a capacity of 26 MW, and the imported electricity from Ruzizi I & II with a total capacity of 15.5 MW. The electricity supplied by small hydropower plants is still not sufficient for the electricity demand from rural areas.

2.2. SMALL HYDROPOWER DEVELOPMENT

2.2.1. Installed Power

In the 1980s, a study made by Lahmeyer (1983) established that there were forty-one potential hydropower sites in Burundi with a capacity of 1,731 MW of which 294 MW were economically and technically feasible (MEM 2012). All hydropower plants were commissioned in the 1980s and at the beginning, the entire electricity consumption in Burundi was produced by hydropower plants in which a part of electricity consumption was imported from the Democratic Republic of Congo (3.5 MW) and the rest from a multinational hydropower plant named SINELAC managed by Burundi, Rwanda and DR Congo (12 MW). Except for the Rwegura hydropower plant with a capacity of 18 MW, the rest of hydropower plants are classified into small hydropower schemes and totalize a capacity of 16.8 MW (tab. 4). According to the report made by REGIDESO (2016), 0.63 MW is produced by private investors of which a capacity of 0.466 MW is out of operation.

Table 4
Installed small hydropower capacities in Burundi

Plants	**Installed capacity (Mw)**	**Operators**	**Years**
Mugere	8	REGIDESO	1982
Nyemanga	2.8	REGIDESO	1987
Ruvyironza	1.5	REGIDESO	1980
Gikonge	1	REGIDESO	1982
Kayenzi	0.8	REGIDESO	1984
Marangara	0.28	REGIDESO	1986
Buhiga	0.47	REGIDESO	
Six stand-alone plants (ABER)	1,345	ABER	
Twelve private plants	0.63	Private	
Total capacity	**16.8**		

Source: monthly report on electricity production by REGIDESO (2017).

The study made by SHER Engineering s.a. (2013) pointed out a hydropower potential of a capacity of 414 MW, which is technically and economically feasible, of which 198 MW can be exploited for small hydropower schemes. Figure 8 illustrates the small hydropower potential of Burundi with respect to the current installed hydropower capacity.

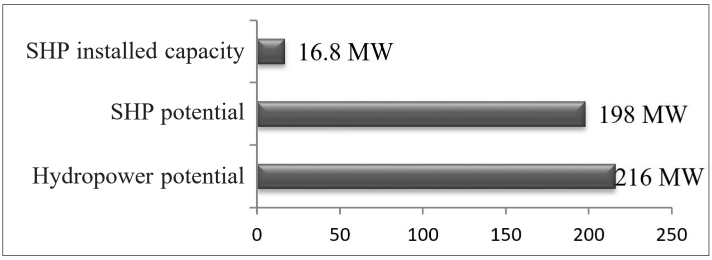


Fig. 8. — Small hydropower potential in Burundi (SHER Engineering s.a. 2013).

In comparison with large hydropower schemes, small ones present many advantages such as:

- Improvement of the socio-economic level of rural population;
- Reduced impact on climate change;
- Less founding and less time for their implementation;
- Less surface construction.

2.2.2. Electricity Production (1996-2014)

In Burundi, the main available sources of energy are biomass, hydroelectricity, oil, peat, wind, solar and geothermal energy (African Development Bank 2009, MEM 2012). According to the Ministère du Plan et du Développement communal & PNUD (2011), the country has a rural and urban population of about 89.9 % and 10.1 % respectively. In comparison with the other energy resources, the biomass used in 2011 was about 94.5 % of the energy production and it was used in the form of wood and charcoal for cooking. Although hydropower is used in the electricity field, oil is more used in the transport sector. Hydropower includes both domestic and imported electricity. A report made by REGIDESO (2016) shows that hydroelectricity is the most widely used source of energy in Burundi.

Figure 9 illustrates an evolution of electricity production from small hydropower for the period 2005-2014. In fact, since the political conflict broke out in 1993, a few small hydropower plants have been destroyed so that the electricity shared from them was much lower up to 2005. For instance, the Ruvyironza and Gikonge power stations were refurbished in 2005 and this refurbishment of existing small hydropower plants was an attempt to raise the electricity production up to 2014. Unfortunately, electricity produced from hydropower is still low and the government intends to raise the electricity production from diesel generators. As the population and cities are steadily growing, the electricity demand is increasing. The situation causes an unbalance between demand and production, which is at the origin of several outages within the national grid. As seen in chapter 2.1.5, the government intends to increase power generation by introducing new power plants producing electricity through diesel generators. The electricity produced from diesel power stations is sometimes limited due to some outages of the current generator units and to lack of fuel.

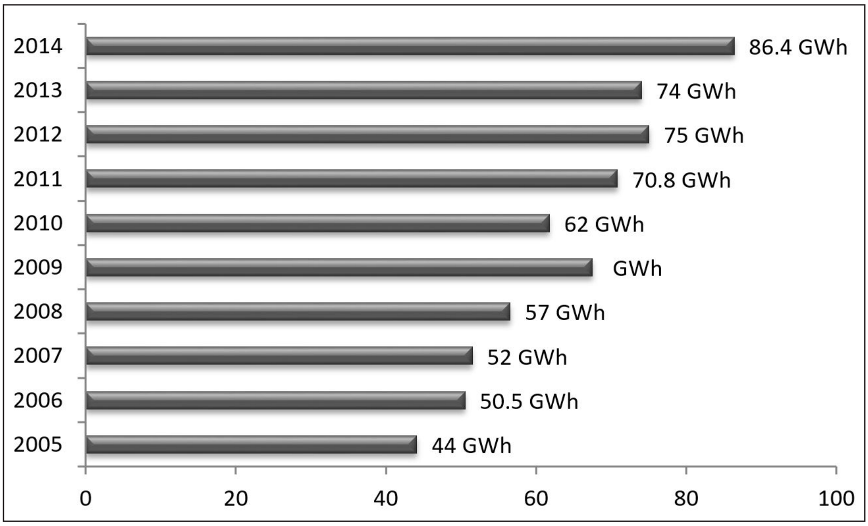


Fig. 9. — Evolution of electricity production from small hydropower (REGIDESO 2016).

2.2.3. Burundi Energy Projection

Table 5 shows the projection of electricity production and demand from 2015 to 2024. As can be seen, the electricity demand is increasing rapidly in Burundi. Starting in 2015, the predicted demand is calculated on the basis of the growth of both urbanization and electricity demand which amounts to 6.8 % (REGIDESO 2016). The increase in energy demand is caused by the growth of cities, the extension of existing cities and the increase in industrial consumption.

Table 5

Projection of electricity production and electricity demand made by the REGIDESO (2016)

Year	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
Production (MW)	46	46	51	61	158	209	244	304	504	600
Lower demand (MW)	65	70	75	80	85	91	98	104	112	119
Peak demand (MW)	86	92	99	106	113	121	129	138	147	157
Power losses (MW)	-40	-46	-48	-44	45	89	115	166	357	443

In order to face this increase in electricity demand as shown by the projection, the government needs to develop new projects of electricity production, such as domestic and regional projects. Funding for the electricity projects is mainly supplied by the World Bank, European Bank institutions (Germany and France mainly), the African development Bank and the Republic of China. In fact, the government intends to raise by 2030 the electrification of rural and urban areas so that the household electrification rate would then be about 43 % (fig. 10). The aim of this plan is to ensure that the business community and households have access to reliable electricity, and consequently to reach the target that about one third of rural households would be linked to the national electricity grid by 2030 (African Development Bank 2009). Unfortunately, the political crisis in 2015 has ruined all projects in the energy sector. The ongoing projects have been temporarily suspended such as the solar project for instance.

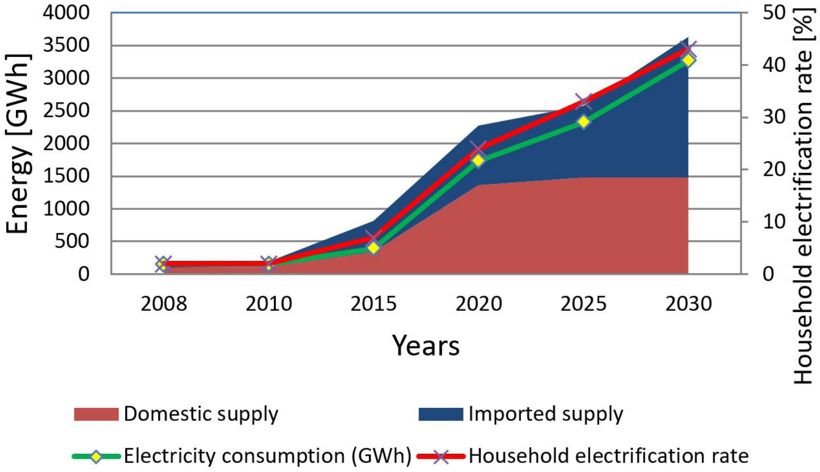


Fig. 10. — Electricity demand and supply in Burundi (African Development Bank 2009).

2.3. Developing a Sankey Diagram

A Sankey diagram is a graph that is used to visualize flows like energy flows which are represented as arrows. The width of the arrows is proportional to the size of the represented flow. In the energy sector, a Sankey diagram is a tool used to balance the energy produced and imported versus the total final energy consumption (IEA 2014, Soundararajan *et al.* 2014). Moreover, the Sankey diagram is also used to analyse the balance between the final energy consumption and the energy consumed by sectors such as industries, roads, etc.

The energy used in Burundi is supplied from three main resources: biomass, hydraulic and hydrocarbons. According to table 6, biomass energy from wood accounts for more than 94 % of the total final energy produced. Both rural and urban population use wood and charcoal for cooking purposes. Biomass is much used by rural population in the form of firewood while charcoal and firewood are used for cooking by urban population. As there is no available data about wood production and consumption from 1999 until today, the consumption of firewood and charcoal for the next few years was found according to the main assumptions we made. These assumptions take into account both the population growth rate — about 2.4 % (République du Burundi 2012) — and its consumption rate from 1996 to 1998. The consumption rate is different from firewood to charcoal. For instance, the rate of firewood for rural households is about 3.1 % against 4.2 % for urban households.

According to table 6, electricity is supplied from hydropower plants and the diesel generators mainly for lighting purposes and represents only 0.8 % of the total energy production in 2011. The transport sector accounts for 4.6 % of the final energy production and includes the imported one. Peat is used for cooking by public services such as the army and schools and represents 0.1 % of the total energy production. As said before, the lack of data in the field of energy is a big handicap in the development of Burundi and the country does not have useful reference tools for future planning in the energy sector. Only hydroelectricity data are available and updated each year.

Table 6

Energy production flow in 2011

Energy production	**2011 (GWh)**	**2011 (%)**
Wood	29,243.8	94.5
Domestic hydro	128.4	0.4
Electricity imported	104.1	0.3
Diesel generators	43	0.1
Oil imported	1,411.1	4.6
Peat	39.3	0.1
Total	**30,939.6**	**100.0**

Source: Index Mundi 2013, Nkurunziza 1999, Office burundais des Recettes 2015, REGIDESO 2016.

Figure 11 shows an evaluation of energy consumption based on the total production of 30,933.3 GWh in which the residential sector consumes more energy (94.2 %) than others. The major part of energy consumption consists of firewood and charcoal which are used for cooking. The energy consumed by industries is still much lower than 1 %, which shows that Burundi is a non-industrial country. However, the part of energy produced in the form of electricity is still lower than 1 % (tab. 6), which shows that access to electricity remains a big challenge for Burundi and that electricity consumption represents a minor part in the final energy consumption.

Ignoring the other sources of energy loss, global energy losses take into account the losses generated by national networks and those generated through the diesel power generation.

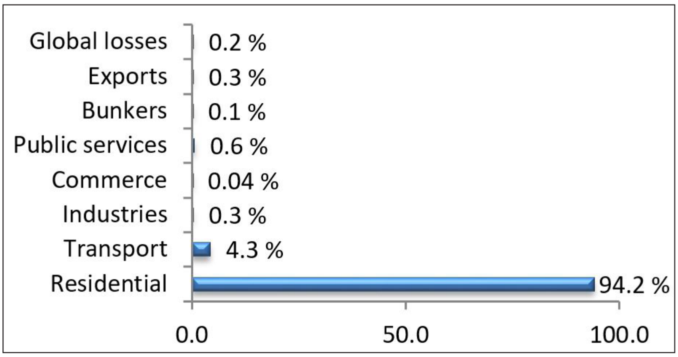


Fig. 11. — Assessment of energy consumption (in GWh) in 2011 (Index Mundi 2013, Nkurunziza 1999, Office burundais des Recettes 2015, REGIDESO 2016).

In fact, the absence of documentation and the absence of tools do not facilitate any study and any planning in the energy field, which is a big obstacle to the country's economic development. The aim of this paper is to give a useful contribution by creating a typical energy flow diagram for Burundi in 2011, which will be taken as a reference.

Figure 12 shows an energy flow diagram which was made by using a free open source tool named "Sankey Diagram Generator". As a reminder, the Sankey diagram is a tool used to balance the energy flow between energy production and the final energy consumption. In the case of Burundi, the energy input of the diagram is represented by the biomass, hydroelectricity, oil and peat resources. This is the total energy production in 2011. The right side of the diagram shows the final energy consumption consisting of residential users, commercial, industrial, public services, air/road transport, amount of energy exported and energy losses. The biomass branch alone represents 2,924.8 GWh, which accounts for 94.5 % of the total energy production. For clarity, the flow of biomass is omitted on the diagram because the latter flow is larger than the ones of other resources. So, a Sankey diagram is a balance between the total energy production and the total final energy consumption.

In Burundi, electricity is produced from both hydro and diesel power plants. Any energy transformation results in energy losses which are negligible in hydropower generation. In the case of diesel power stations, electricity production is accompanied by 30 to 40 % of power loss. So, the Sankey diagram in figure 12 is constructed on the basis of 30 % power loss in diesel generators.

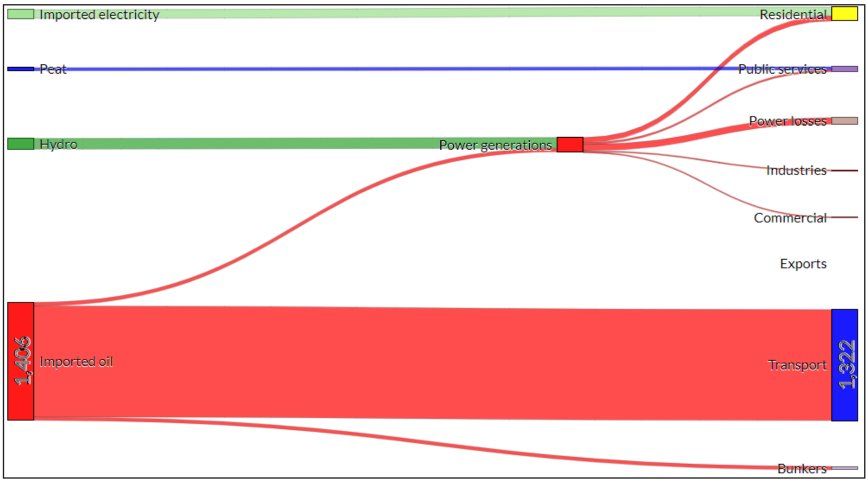


Fig. 12. — Burundi energy flow diagram in 2011.

2.4. Sankey Diagram’s Discussion in the Context of Burundi

Normally, energy can be transferred usefully, stored or dissipated. It cannot be created or destroyed. Energy Sankey diagram is a type of diagram in which the width of arrows is proportional to the energy flow, such as energy generation, energy loss and final energy consumption. The side of the flow shows how much is the quantity of energy from the production side to the final consumption. For instance, biomass production is larger than the others (fig. 12). The diagram points out in the context of Burundi that the major part of the population use more biomass for cooking.

In fact, flowing energy such as transportation and distribution of electricity gives additional power loss which is subtracted to the total electricity production. However, this Sankey diagram takes into account the final energy when ignoring the efficiency involved in the energy services. The national electric grid shows around 20 % power loss (Paish 2002) and the imported electricity goes straight to the final electricity consumption through the electricity national network.

Regarding the imported oil, the major part is used in road and air transport while a small quantity is used in electricity production in order to improve it. The additional electricity produced from diesel generators contributes to the reduction of frequencies of load shedding per day.

So, the Sankey energy flow diagram gives an economic picture of the country. Burundi is still an underdeveloped country where most energy consumption comes from firewood and charcoal. This is an indicator of poverty. Burundi has neither fossil energy sources nor nuclear power to produce electricity. Even though the country has a huge potential of renewable energy, it has limited financial resources to fund such projects of electricity production on the basis of renewable sources (biomass, wind, solar and hydro). Burundi can focus on small hydropower to improve the population well-being in rural areas. Furthermore, the less the electricity consumption of a country, the less developed it is.

3. Perspectives: Banki-Michell Turbine Test Bench at ULB/ATM Laboratory

3.1. Banki-Michell Turbine Description

The Banki turbine is composed of two main parts, a nozzle and a turbine runner. The sectional area of the nozzle is shaped as rectangular and discharges the water jet of the runner over its full width. According to Mockmore & Merryfield (1949), the angle at the entrance of the wheel is approximately sixteen degrees with the tangent to the periphery of the wheel. In figure 13, the water strikes the blades on the rim of the wheel, flows over the blade, leaving it, passing through the empty space between the inner rims, enters a blade on the inner side of the rim, and discharges at the outer rim. The wheel is said to be an inward jet wheel and the flow is essentially radial. In fact, the diameter of the wheel is practically independent of the amount of water impact and the required width of the wheel can be given independently of the available quantity of water.

In figure 13, velocity diagrams give an indication of the magnitude and direction of water velocity. There is no loss assumption through the inside of the runner which gives equal diagrams at the outlet of the first stage and inlet of the second one (Walseth 2009).

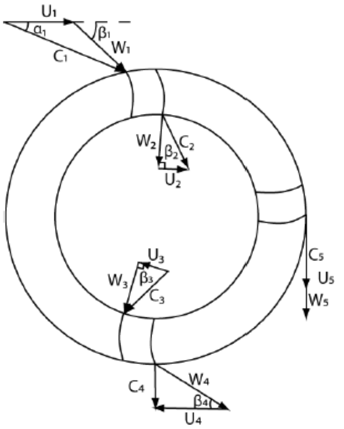


Fig. 13. — Path of water through turbine (C = absolute velocity in m/s; W = relative velocity in m/s; U = peripheral velocity in m/s; β = angle between the tangent of the blade and the runner periphery, or the angle between W and U in rad; subscript 1, 2, 3, 4 & 5 = respectively water entering the first stage, water leaving the first stage, water entering the second stage, water leaving the second stage and the entrained water leaving the runner) (Walseth 2009).

3.2. Importance of Turbines for Burundi

Burundi is listed among the less developed countries. Despite the importance of its hydroelectricity potential (SHER Engineering s.a. 2013), the country has no possibility to invest in large hydropower plants due to the large investment required with respect to studies, planning, design, development and civil works. A good idea for Burundi is to adopt strategies leading to small hydro turbines such as the Banki-Michell turbine. Small hydro turbines have several advantages against large ones, such as improving the socio-economic conditions of rural population, which represents the majority of Burundian population (around 90 %). Since a turbine is composed of two main parts (injector and runner), this geometry has several advantages for the benefit of underdeveloped countries such as Burundi. A turbine is easy to design, construct and repair and there is no need for highly-qualified engineers to maintain it. Moreover, the rotor of the turbine can be divided into two parts depending on the conditions of the site. This geometry makes the turbine insensitive to any flow variation that may arise during its operation and its efficiency characteristic is flat-shaped (fig. 14).

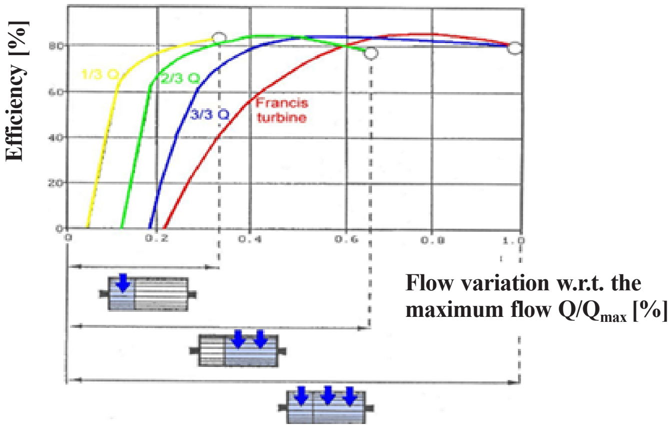


Fig. 14. — OSSBERGER turbine's efficiency at different loads (http://www.ossberger.de/cms/pt/hydro/ossberger-turbine/).

3.3. Purpose and Description of the Test Bench

The test bench of the turbine is installed at ATM laboratory of ULB and aims to analyse the performance of the turbine in order to check whether it operates under the real conditions of rural areas in Burundi.

$$\eta_t = \frac{P_{méca}}{P_h} \qquad (5)$$

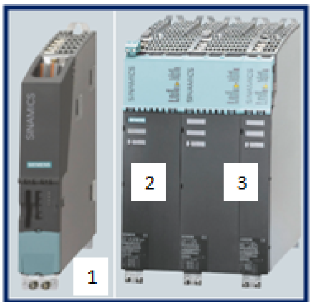
where η_t = turbine efficiency; $P_{méca}$ = mechanical power of the turbine (kW); P_h = hydraulic power of water (kW).

Equation 5 gives the calculation of turbine efficiency which is found by the ratio between mechanical and hydraulic power. Several measurements are required in order to find further parameters involved in the equation, such as the discharge, mechanical torque, rotational velocity and instantaneous net head during the test:

- Flow measurement will be done by an ultrasonic flow metre along a straight PVC pipe; avoiding any turbulence is required during measurement;
- Torque measurement will be done by a torque sensor coupled to the shaft of the turbine;
- Rotational speed will be given by means of an induction sensor attached to the shaft of the turbine;
- Instantaneous net head will be measured by means of a pressure sensor attached to the intake duct of the turbine.

Figure 15 shows the control unit which is made by a frequency variation. The frequency variation aims to set the speed at which each test will be done. Surplus energy will be dissipated through a resistor. The frequency variation is mainly composed of:

- A double motor module driving both the gear motor and the braking resistor. If the generator produces energy that cannot be consumed by current users, the voltage level on the intermediate circuit will increase. If the voltage exceeds a certain threshold, the motor module will work as a brake chopper and send the energy to the resistor.
- The control units that perform communication, control and regulation for the motor module and the line module.
- A smart line module which is a power supply and recovery unit, switched by the network with 100 % of permanent power recovery.
- A sensor module (SMC30) required for processing sensor signals mounted on the motor.



1 : Control unit 320

2 : Line module

3 : Double module

Fig. 15. — Control unit 320, line module and double motor module.

3.4. Components of the Test Bench

Except for the channel, the tank, the PVC pipe and the measurement devices, the test bench is composed of the following elements (fig. 16):

- A turbine JLA 29, which is a prototype of Banki-Michell turbine manufactured in Belgium. The turbine is built to operate with a head in the range of 2.5 to 80 m, discharge water of 30 to 600 l/s and power range of 2 to 120 kW at rotational speed range of 200 to 1,100 rpm.
- A gear motor to load the turbine.
- A braking resistor to vary the load.
- The frequency inverter to control the motor.

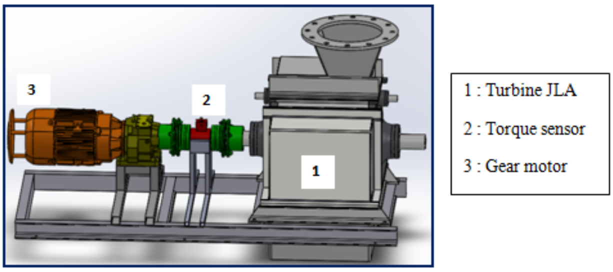


Fig. 16. — 3D design of JLA turbine, torque sensor and gear motor coupled with KTR coupling.

4. Conclusion

The energy Sankey diagram is a tool to represent energy balances focused on both energy production and energy consumption. The Sankey diagram models the input side comprising biomass, hydro, peat and imported oil. The output shows that biomass contribution is more dominant within the global energy flow in the country.

Firewood and charcoal are the most widely used sources as primary energy sources (94.2 % in 2011). The big challenge is that in the energy end use, electricity is less represented (lower than 1 %). This is a big issue for the country to achieve its economic development looking backward when the first hydropower plant was implemented (1980s).

The future of Burundi means the need to update each year its own energy Sankey diagram, which will help identify the needs in the energy sector. In addition, the test bench of the turbine built at ULB-ATM will help the country to exploit Banki-Michell turbines which will bring benefit to the mainly rural Burundian population (around 90 %).

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Fuel Cells and Hydrogen for Emerging Countries: Flexible Devices for the Production of Sustainable Electricity in Africa

by

Jean-Luc Delplancke[*]

Keywords. — Hydrogen; Fuel Cells; Sustainability; Renewables.

Summary. — Africa is a continent extremely rich in renewable energy sources (RES) but these resources are currently poorly exploited by the African emerging countries. Some of the reasons for this low exploitation lie in the absence of transnational high-voltage electric infrastructure, in poor energy production infrastructures and in the absence of local investment in RES. The objective of this poster is to highlight the potentials of hydrogen generation from renewable energy sources in combination with electricity and drinkable water production by means of fuel cells for the local and international development of African emerging countries.

Introduction

The International Renewable Energy Agency (IRENA) provides on-line simulation tools to visualize RES resources in the world. Figure 1a[**] highlights and compares the wind resources for Africa and Europe. Wind is more abundant in the north, south and east parts of Africa than on the European continent.

Figure 1b clearly shows that solar irradiation in Africa is at least as high as in Spain, the European country with the highest annual solar irradiation (except maybe in the equatorial part of the continent).

Moreover, the central equatorial part of the continent, where wind and solar powers are limited, is very rich in water resources with some of the most important rivers of the world (fig. 2).

These RES are nowadays poorly exploited in Africa. There are many reasons for this low exploitation. Some of them are listed below:

- Limited local electric power generation infrastructure;
- Limited local and transnational electric power distribution infrastructure;
- Absence of investment in RES;

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[*] École polytechnique de Bruxelles, Unité de recherche *Materials Engineering, Characterization, Synthesis and Recycling* (4MAT), Université libre de Bruxelles, avenue F. D. Roosevelt 50, B-1050 Brussels (Belgium).

[**] *Cf.* figures at the end of the text.

— Absence of investment plans for rural electrification.

These limitations are combined in general with poor road, train or maritime transport infrastructures and with a very inhomogeneous population density. As a result, Africa (except for some specific locations) is the continent with the lowest electrification rate, particularly in rural areas. Hydrogen production from RES and utilization of fuel cells could help remedy this situation.

Hydrogen

Hydrogen is not only the most abundant element in the universe but also an essential energy carrier, should mankind set the target to limit climate global warming and to achieve the ambitions of multiple international agreements like the COP21. Hydrogen can be stored for a long duration in large quantities and offers a clean, sustainable and flexible solution to a low-carbon economy when produced by water electrolysis (a robust well-known technology) and renewable energy sources (RES). Hydrogen transport at scale and over large distances, *e.g.*, from areas with a high potential for renewable power generation to areas with a high demand of energy can become an economically attractive option for emerging countries, substituting the transport of electricity via high maintenance cost power lines by the transport of hydrogen. Hydrogen can be transported as a gas (in zeppelins), as compressed gas (in tube trailers, in ships or trains equipped with gas vessels), as a solid (hydrogen is reversibly adsorbed or absorbed in specific materials) or as a liquid (Liquid Hydrogen Organic Carrier or LHOC). This diversity of hydrogen transport solutions contributes to the selection of the best economic option based on local infrastructure.

Fuel Cells

Fuel cells, discovered by Schönbein and Grove in 1838, correspond to an old technology with a very complex history. They are efficient electrochemical generating power devices invented more than forty years before the classic dynamo generators, combustion engines or gas turbines. But they were more or less completely forgotten until the launch of the NASA Gemini and Apollo development programmes in the 1960s. There is today a renewed interest in this technology generated by the concept of "Hydrogen Economy" and sustainable growth. A fuel cell is a static and compact electrochemical device transforming a fuel (natural gas, biogas, hydrogen,…) and an oxidizer (oxygen or air) into electricity, heat and pure water. Fuel cells allow a very efficient use of fossil or renewable energy sources, do not generate greenhouse gases (if powered by hydrogen), NOx, SOx, particulates or noise and are highly modular with power ranging from 1 W to tens of MWs. Fuel cells are particularly useful for electricity micro-generation for distributed residential use or off-grid locations, medium power plants for co-generation, industrial processes, malls, hospitals, airports and large power plants (the largest one in 2016 is located in South Korea – 59 MW).

Conclusion

Hydrogen and fuel cells must be considered in the future plans for the electrification of Africa. The production by water electrolysis of hydrogen from renewable energy sources like hydroelectricity from the Inga dam (RDC), wind farms or solar energy from the many favourable locations in Africa, its storage, even for long durations and its transport as a gas, a liquid or a solid contribute to making hydrogen one of the most sustainable, flexible and economic energy carriers. Fuel cells with power ranges adapted to the local needs of the population will consume this hydrogen and provide rural electrification without the deployment of high maintenance cost electric power lines. Hydrogen-powered fuel cells generate energy without any noise, greenhouse gases and pollutant emissions and can be used as a local provider of drinkable water (every two grams of hydrogen generates eighteen grams of water).

FIGURES

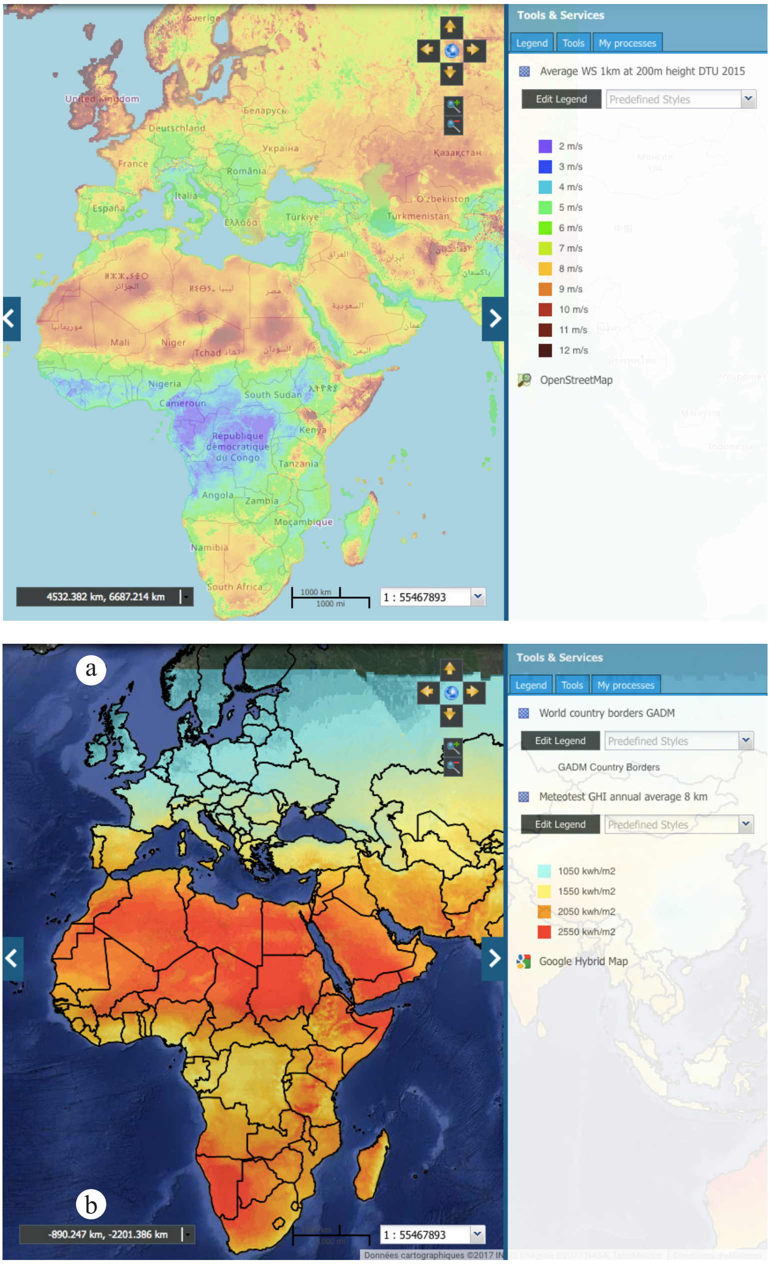
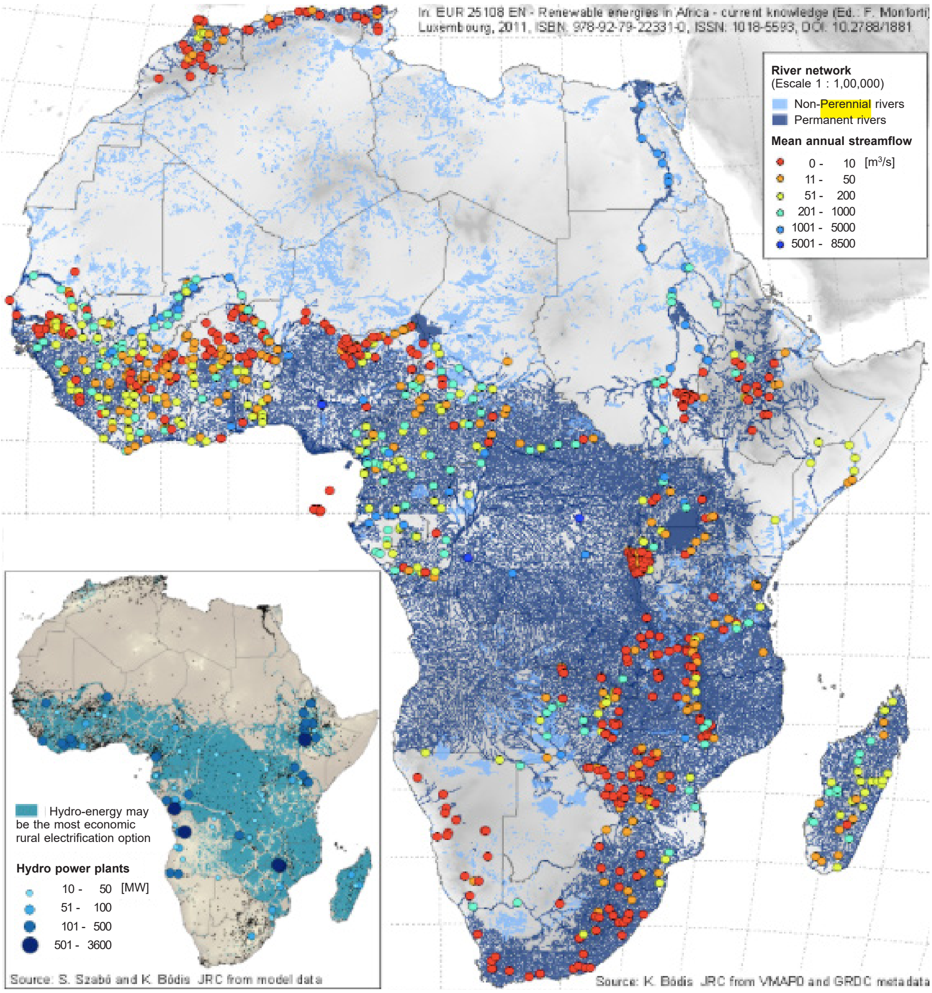


Fig. 1. — Comparison of the African and European continents in terms of renewable energy sources: (a) wind speed at 200 m height; (b) solar irradiation in kWh/m^2.


In: EUR 25108 EN - Renewable energies in Africa - current knowledge (Ed.: F. Monforti)
Luxembourg, 2011, ISBN: 978-92-79-22331-0, ISSN: 1018-5593, DOI: 10.2788/1881

Source: S. Szabó and K. Bódis JRC from model data

Source: K. Bódis JRC from VMAP0 and GRDC metadata

Fig. 2. — Modelling of pico- and mini-hydro resources and geographic location.

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Concentrated Solar Power, Battery Storage for Solar Photovoltaic (PV) Flexibility, Solar PV for Water Pumping and Biomass Applications: Solution for Sustainable and Flexible Power

by

Jean-Michel WAUTELET*, Sébastien BORGUET**
& Fabrice DELFOSSE***

SUMMARY. — The involvement and high motivation of John Cockerill to contribute to African sustainable energy improvement, throughout its technologies, products and activities together with local communities and workforce are presented here. Some of John Cockerill's major achievements and technologies are outlined below.

Central Tower Solar Thermal Electricity – Storage by Molten Salt

On central tower solar thermal power plants, the solar field consists of thousands of heliostats (mirrors on mounting poles with tracking capability) located on the ground, each of them individually controlled to concentrate the solar rays towards a receiver placed at the top of a tower. The heat flux reaching the receiver can exceed 1,000 kW/m², which represents more than a thousand times the natural solar flux at the most exposed places on earth. The receiver consists of vertical heat exchanger tube panels through which a heat transfer fluid (water or molten salt) absorbs the energy of the concentrated solar flux.

Thermal energy is used to generate electricity through a thermodynamic process, typically by generating superheated steam to feed a steam turbine that drives a generator as in the classic process of most power plants.

This thermodynamic process is specific to solar thermal electricity and much more efficient than any photovoltaic process. Furthermore, the possibility to economically store thermal energy gives a serious advantage to solar thermal power plants compared to most renewable energy sources (fig. 1).

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[*] John Cockerill Solar, av. Greiner 1, B-4100 Seraing (Belgium).

[**] Mechanical Engineering Group Leader Hydrogenics, University of Liège, place du 20 août 7, B-4000 Liège (Belgium).

[***] John Cockerill Balteau (Cockerill Maintenance & Ingénierie SA), rue de la Légende 63, B-4141 Sprimont (Belgium).

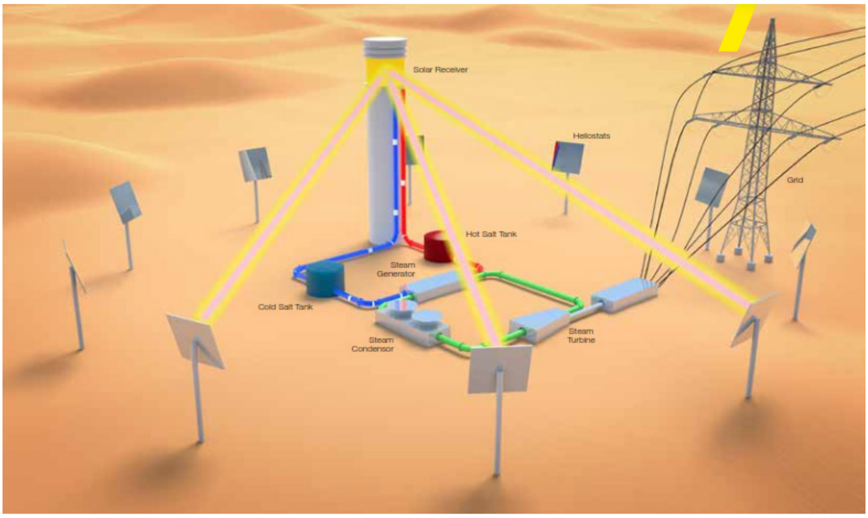


Fig. 1. — Concentrated solar tower schematic.

The strengths of power tower technology are the following:

- — Higher concentration ratio allows higher temperatures, and thus better efficiency.
- — The receiver is capable of withstanding high pressures. This enables direct production of high pressure superheated steam (up to one hundred and eighty-five bars) in the receiver (in the case of direct steam generation).
- — A short and mostly vertical piping layout allows fast and easy drainage of the heat transfer fluid and makes the receiver the safest arrangement for molten salt plants.
- — No need for dangerously flammable and polluting thermal oils used in parabolic trough plants, which limits the generated steam temperature to below 400° C, with a negative impact on the plant efficiency.

Dispatchability and Overnight Power Generation

Wind and sun energy sources are uncontrolled; they induce a fluctuating electricity production. The network must therefore adapt quickly and efficiently to compensate any power drop to avoid outages. Solar thermal power plants represent one of the best efficient energy sources as they do not generate power fluctuation. They can feed the network anytime instantaneously by adapting their production to the demand. This is what we call a “dispatchable” electricity production. Solar thermal electricity plants therefore contribute to the stability of the network like any conventional power plant. They also allow an electricity generation twenty-four hours a day.

The best way to provide dispatchability or even overnight electricity production is to store the absorbed solar energy in molten salt: a low-cost, flame-proof and non-polluting fluid.

The solar receiver first converts the absorbed solar energy into thermal energy by heating molten salt, which is stored in the hot molten salt storage tank. Steam can then be produced on demand by pumping the hot molten salt through a steam generator. Cold molten salts are returned to a cold molten salt tank, from which they are sent to the solar receiver to be heated again.

Molten salts freeze if their temperature goes below around 230° C. It is one of the main challenges with molten salt plants. Thanks to their short and vertical piping layout, allowing fast and easy drainage, central towers are the safest solution for a direct heating of molten salts in the receiver.

JOHN COCKERILL'S MOLTEN SALT RECEIVER

Located at the top of very tall concrete towers, John Cockerill's receivers (fig. 2) collect the concentrated solar energy and transfer it into molten salt. The main challenges come from the very high energy fluxes involved: above 1,000 kW/m², *i.e.* several times more than what is reached in conventional-fired boilers. This leads to metal temperature locally exceeding 700° C, requiring to use special materials like stainless steel and nickel alloys. High temperatures induce thermal expansion, stresses, creep, fatigue, etc. John Cockerill's expertise as a boiler designer allows to control these phenomena and mitigate their effects. Calculation methods had to be refined to verify the lifetime of the equipment, which operates under highly fluctuating conditions. A major operational risk for the receiver is to have it overheated due to a locally excessive incident flux. This might cause the destruction of a receiver panel in a few seconds. To mitigate this risk, John Cockerill has developed a system to closely monitor the thermo-mechanical behaviour of the panels thanks to a network of infrared cameras (fig. 3). The system also evaluates in real time the thermal stress at every point of the panels. In case the maximum acceptable stress is locally approached, a signal is sent to request an adjustment of the energy directed towards the receiver. This allows to always operate at the maximum capacity without any risk of damaging the receiver.

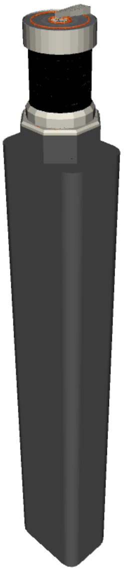
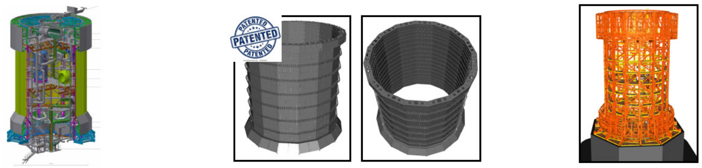


Fig. 2. — Example of John Cockerill's molten salt receiver.

Key features include:

- Patented insulated airtight casing;
- Designed to be erected on the ground and lifted in one piece to the top of the tower;
- Patented IR temperature and stress real-time monitoring system;
- Patented maintenance system.



Architect engineering **Pre-insulated bolted casing** **Bolted structure, allowing one piece lifting**

Thermo-mechanical behaviour software by John Cockerill **IR monitoring** **Maintenance solutions**

Fig. 3. — Technical features of John Cockerill's solar receiver.

THE ATACAMA SOLAR PLANT IN CHILE

The Atacama plant, located in the remote Atacama desert in the north of Chile, has the highest level of solar radiation in the world. This region is thus quite suitable for concentrated solar power plants. This new solar thermal plant will mainly supply electricity for local mines. In addition, the Atacama I solar complex will feature a photovoltaic plant with a capacity of 100 MW.

In July 2014, John Cockerill Energy was awarded its first order for the design and supply of a molten salt solar receiver. It will be installed at the top of a concrete tower in the Atacama I power station (fig. 4).

With its 110 MWe, the Atacama power plant will be the largest molten salt power plant in the world and the most powerful solar plant on the South American continent. Thanks to its ability to store enough energy for 17.5 hours of operation, it will be able to supply electricity twenty-four hours a day. With a height of 32.4 m, the John Cockerill's receiver will be installed at the top of a 217-metre-high tower. Made up of sixteen identical panels forming a polygon of 18.4 m in height, it will be topped by a thermal shield which prevents the sun rays from damaging the equipment.

Fig. 4. — Atacama I power station under construction.

Although the process for this type of equipment is simpler than for a classic solar receiver (no need for an evaporator or superheater), the solar flow is much more concentrated than for direct steam generation. Metal temperatures are much higher as a result (700° C instead of 600° C), which represents the main challenge.

It is therefore necessary to select materials that can resist high temperatures while limiting the corrosion risks linked to the use of molten salts. Another challenge for this technology is the fact that molten salts start freezing below 230° C. Therefore, they have to be permanently kept at a temperature above 290° C. This requires to empty the receiver each time there is insufficient sunlight and to reheat the unit before injecting the salts and begin start-up.

The power plant is designed for base load. Electric production has to be uninterrupted even when the sun does not shine. The use of molten salts enables a large energy storage capacity, which is a major asset for electricity production.

The main technical parameters include:

- Nominal power: 110 MWe;
- Annual electricity production: ~940 000 MWh;
- Storage ability for 17.5 hours of operation;
- Thermal efficiency: up to 90.5 %.

Battery Storage for Solar Photovoltaic (PV) Flexibility

In order to actively support the "Energy Transition", John Cockerill has entered the activity of energy storage coupled with intermittent renewable energy such as solar PV and wind.

Most African countries have the chance to have abundant sun resources. But many regions have no or limited transmission network. Therefore, for the rural or remote electrification, the challenge is to set up a system with solar PV to ensure a flexible electricity supply after sunset and before sunrise, with a robust, heat-resistant, safe and low-cost energy storage system.

John Cockerill has proposed the best match, especially by the use of Redox flow batteries, a type of battery adapted to longer-time storage, safe, and inflammable, for long lifetime. This flow battery is specially adapted to the African continent thanks to a high ambient temperature resistance (thus no need for an air-conditioning unit), its inflammability — high level of HSE (Health, Safety and Environment) —, a lifetime typically over twenty years [thus, same lifetime as solar PV and much longer compared to lead-acid battery (three to five years) and lifetime of lithium-ion battery (around six to eight years)], and an easy dismantlement and recycling of the system.

A flow battery is composed of two tanks of electrolyte which determine the duration of energy storage, and a stack which is the core system for charge and discharge of the power, thus corresponding to the power rate. This means that the system can be designed in a flexible manner, and can offer long duration for evening and morning time consumption. The system is in continuous circulation and does not require overhaul or major maintenance for over twenty years, which implies lower maintenance cost.

The MiRIS Project

John Cockerill collaborates with key technological partners and constantly works on the system integration, supply, installation and O&M matters. In order to get to know all the different technologies, John Cockerill is currently building the largest European industrial energy storage pilot plant at its headquarters in Belgium. This project, MiRIS, is based on a PV installation of 2 MW peak output (enabled by 11,000 m^2 of PV) and a storage capacity of over 4 MWh through three different battery technologies (fig. 5). This is active development work for opportunities to help African populations and industries in remote or off-grid areas.

In order to ensure optimized energy use from the electricity generation to consumption throughout the battery storage system, John Cockerill is also working on the Energy Management System (EMS) in close collaboration with both industrial and academic partners. This software will act as a real brain of the whole installation, integrating the weather forecast, battery charging/discharging status and optimization, and user's energy consumption profile, with self-learning function.

Fig. 5. — PV and batteries project.

Water Pumping by Solar PV for Off-Grid Rural Areas

In many developing countries, the pumps feeding water to the communities are driven via diesel generator sets (gensets). A lack of money to pay for the fuel may lead to stop water supply. In addition, standard gensets have constant speed, which means constant flow of pumped water: this leads to water waste if the tank is full, or to defuse pumping if the level in the well goes down.

John Cockerill has developed a concept of water pumping that prioritizes renewable energies over diesel (fig. 6). A solar PV installation supplies power to drive the pump at variable speed. The same variable speed drive is connected to the diesel, which can back up the power when needed (during the night or when sunlight is not sufficient). This product was first designed for a project in Kenya.

Fig. 6. — Water pumping technology.

KAJIADO WELL PROJECT: WATER FROM THE SUN

As mentioned here above, John Cockerill has installed over fifty deep water wells in the Kajiado region in Kenya. The wells have a depth up to 200 m and a capacity ranging from 1 to 3 m^3 per hour. These wells were installed to provide water to populations and cattle. Kajiado is a rural and semi-arid area with very limited access to water and electricity.

Biomass Power with Feedstock Torrefaction through a Multi-Hearth Furnace

John Cockerill has developed a solution called NESA Solution® which consists of a special multi-hearth furnace (fig. 7). The NESA Solution (developed by John Cockerill Environment) has five main fields of application among which the transformation of biomass through its torrefaction. This process is particularly well-suited for sub-Saharan Africa as many countries on the continent have rich biomass feedstock resources.

There are two principal uses for the feedstock obtained after treatment, the so-called roasted biomass. First, the fuel generated can be used in the existing installations which operate with coal, with no modifications or specific adaptations, *i.e.* an energy transition from coal to biomass to reduce the environmental footprint. Secondly, the fuel can also be used in new installations, whose investment costs are reduced thanks to the density and the homogeneous nature of this new fuel.

Fig. 7. — Multi-hearth furnace.

Last but not least, John Cockerill has an utmost engagement to contribute to improving the African people's quality of life. For that, John Cockerill is actively working with multilateral financial institutions in order to bring financial support to materialize the power, water, industrial and environmental projects in Africa.

But what exactly does roasting mean? Roasting is a 'soft' thermo-chemical treatment at the interface of drying and pyrolysis, whose objective is to eliminate the water contained in wood and to modify part of the organic matter of the biomass in order to break the fibres down. With roasting, the reaction takes place between 250 and 300° C in an oxygen-starved atmosphere, as the time spent in the reactor is very short (less than thirty minutes). Roasting retains the calorific value of wood energy virtually unchanged. Ninety-five percent of the calorific value of the raw wood are conserved. So, this thermal treatment of refined biomass feedstock turns a renewable energy into a reliable, steady and high-quality fuel.

In June 2017, John Cockerill was awarded a substantial contract to equip the largest industrial unit in Europe for the production of roasted pellets from wood energy in France (fig. 8). The annual environmentally-friendly fuel production will represent an energy potential of 250 GWh.

Fig. 8. — Unit for production of roasted pellets.

Besides being used in the already existing coal-power plants, this innovative feedstock is suited to be used in John Cockerill's designed power plants as the company has a long experience in solid biomass-fired power plants and Combined Heat and Power (CHP) installations. These power and CHP generation facilities rely on John Cockerill's historical engineering, boiler experience which have achieved the world lowest NOx and CO^2 emission level.

John Cockerill is now actively working in the unconventional biomass power plant project in Ivory Coast. The feedstock is a mix of agricultural residues with a different caloric density and combustion ability. As a consequence, the boiler capability to adapt its temperatures and pressures should be highly controlled and John Cockerill is one of a few companies which can comply with.

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Concentrated Solar Power (CSP) Technologies for Electricity Generation in Harare, Zimbabwe: Comparison of Two Options, Solar Tower (ST) and Parabolic Trough (PT)

by

Luckywell SEYITINI*

KEYWORDS. — Concentrating Solar Power; Parabolic Trough; Solar Tower.

SUMMARY. — Concentrating Solar Power (CSP) technologies become more attractive in the world for electricity generation at large scale. This is because of their potential to integrate the solar thermal power plants with thermal energy storage systems. This study seeks to investigate how CSP technologies can perform under the Zimbabwean conditions. The 'System Advisor Model' (SAM) is used to simulate solar power plants based on CSP technologies of both types, solar tower (ST) and parabolic trough (PT), at a site in Harare. Simulation results including annual energy production output, capacity factor, land requirements, levelized cost of energy and plant installation costs have been analysed and compared in order to determine which CSP technology performs better and can be recommended for implementation.

Background

The need to promote the use of renewable energy systems at the expense of fossil fuels is being prioritized worldwide. Different nations are coming together to empower international organizations, global and regional financial institutions to drive the agenda of sustainable energy in the whole world. Various efforts aimed at increasing the capacity utilization of renewable energy technologies are currently underway as evidenced by activities including: financing renewable energy projects, feasibility studies on renewable energy systems, research on improving performance and reducing costs of renewable energy technologies as well as capacity-building programmes.

The technology of using Concentrated Solar Power (CSP) for electricity generation has already been proven to be viable as evidenced by several CSP power plants which are already operational worldwide as well as various CSP power projects that are under construction (TESKE *et al.* 2016). Of all the CSP technologies, parabolic trough and solar tower technologies are currently leading in large-scale electricity generation systems on the international market,

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* Department of Physics, Geography and Environmental Science, Great Zimbabwe University, P. O. Box 1235, Masvingo (Zimbabwe).

with the parabolic trough being the most commercially matured technology (Teske *et al.* 2016). Ongoing research activities on components of solar tower power plants suggest that solar towers appear to have greater potential for cost reductions and since they operate at high temperatures, this makes the technology to have high efficiency; hence looking into the future, this technology is expected to have a greater contribution in the global energy mix (IRENA 2013).

However, the use of these technologies is still scarce in most developing countries despite the abundance of the solar resource in some of these regions, including Zimbabwe. Among the various factors that hinder the uptake of solar energy technologies, is the lack of feasibility studies that can inform potential investors and policy makers on both technical and financial performances of solar energy systems. This study therefore seeks to analyse the feasibility of implementing CSP technologies in Zimbabwe by considering the following objectives:

- To simulate solar thermal power plants based on parabolic trough and solar tower technologies of different rated power outputs;
- To analyse the viability of technical and financial performances of power plants;
- To provide technical and financial information to potential investors.

Methodology

A software called 'System Advisor Model' (SAM) was used in this study. This software was developed by the National Renewable Energy Laboratory (NREL) of United States and is based on a set of thermodynamics, heat transfer and other mathematical equations. It uses meteorological data together with other technical and financial input parameters to determine the expected technical performance of renewable energy systems as well as the associated financial costs. Solar and weather data for a site in Harare were obtained from the website of the International Weather for Energy Calculations (IWEC). Technical input parameters for all major components of the two solar thermal power plants, including solar fields, power blocks and thermal energy storage systems, were carefully chosen to optimize the power plant designs. Parabolic trough and solar tower power plants of different rated power outputs were simulated and their results were analysed.

Results and Discussion

Simulation results for all the plant power capacities considered in this study are summarized in table 1.

Table 1

Comparison of expected performances of parabolic trough (PT) and solar tower (ST) power plants

	Type of technology	**Plant capacity (MW)**		
		50	**100**	**150**
Annual energy production (kWh)	PT	85,141,656	172,648,592	258,071,184
	ST	88,255,496	179,718,832	262,040,928
Gross to net conversion (%)	PT	88.40	88.8	89.2
	ST	83.64	83.25	82.56
Capacity factor (%)	PT	19.60	19.60	19.70
	ST	19.00	19.20	19.70
Levelized cost of energy ($)	PT	35.74	35.58	35.71
	ST	31.33	29.86	29.20
Net capital cost ($)	PT	375,832,928	758,530,688	1,137,722,880
	ST	378,081,696	740,096,320	1,103,680,896
Total land use (acres)	PT	416	841	1,257
	ST	1,754	3,424	5,760

Results indicate that for all different power plant capacities considered in this study solar tower power plants produce about 3 % more energy annually than the parabolic trough power plants as seen in figure 1.

Results also show that for a lower power plant capacity, parabolic trough technology is slightly cheaper in terms of net capital costs, but for higher plant capacities, solar tower technology performs slightly better as illustrated in figure 2.

In addition, levelized cost of energy produced by solar technology is lower for all the simulated plant sizes as shown in figure 3, with energy from parabolic trough technology costing at least 14 % more. It was also observed that the levelized cost of energy for solar tower technology gets lower for the larger plant capacities while for parabolic trough technology the cost of energy is almost constant as shown in figure 3.

However, solar tower technology requires much more land compared to parabolic trough technology as observed from table 1, which is consistent with the findings of the National Renewable Energy Laboratory (NREL) of United States

(Ong *et al.* 2013). This is due to the space-consuming layout of solar field for ST power plants.

Capacity factors of all designed power plants are almost the same, with all in the range of 19 % and the gross to net efficiency for all the power plants considered is also comparable even though parabolic trough technology performs slightly better with about 6 %. Generally, the results obtained were consistent with what was found by other researchers at different sites (Pidaparthi *et al.* 2016, Muye *et al.* 2015).

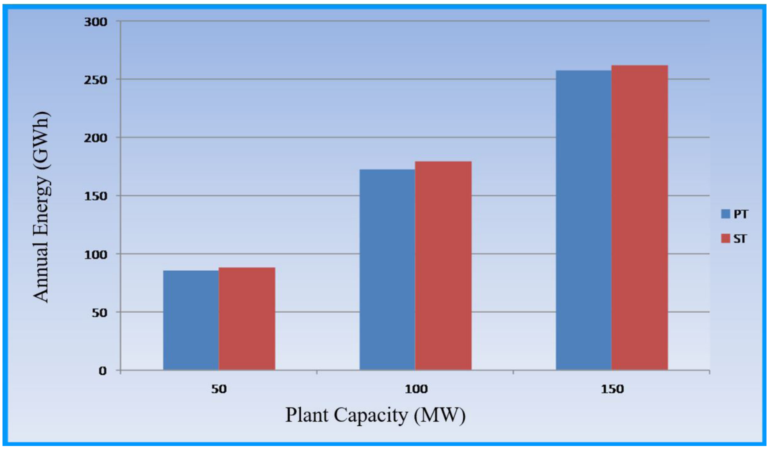

Fig. 1. — Annual energy production from PT and ST power plants at various plant capacities.

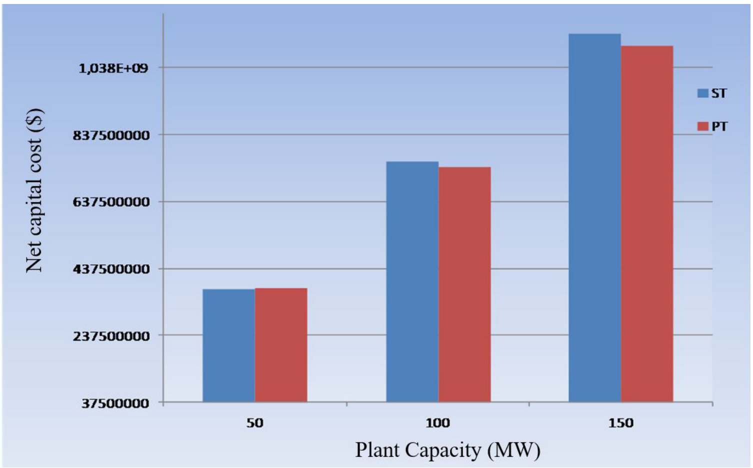

Fig. 2. — Variations of capital costs for PT and ST power plants of different rated power outputs.

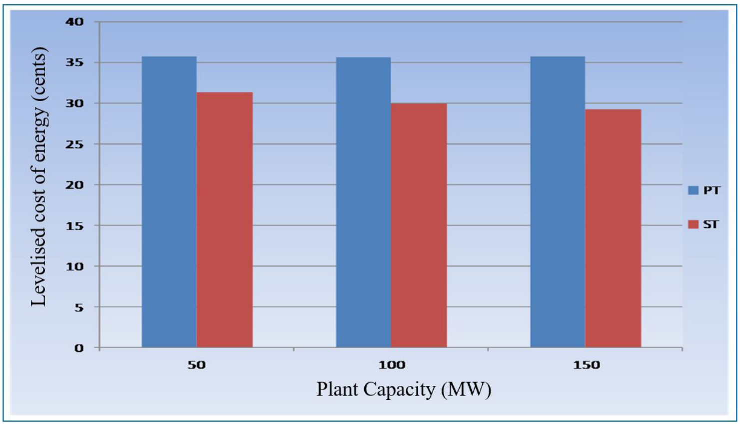

Fig. 3. — Levelized cost of energy produced from PT and ST power plants of different plant capacities.

Conclusion

Results suggest that solar tower technology generally performs better from both technical and economic assessments. It can therefore be concluded that potential investors and policy makers should recommend investments in solar tower power plants at a Harare site in Zimbabwe. The cost of energy from both CSP technologies discussed in this study is higher compared to the current cost of electricity which is about US 10 cents per kWh. However, there are other sites in Zimbabwe that receive better solar resources and have potential of producing electricity at a price more comparable to current market prices.

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PV Generation Optimized for Remote Households in Central Africa

by

Maarten Vergote[*] & Nathan Windels[**]

Keywords. — Solar PV Panels; Remote Households; Central Africa.

Summary. — In this contribution, we summarize the results of a case study concerning a photovoltaic (PV) electricity production installation that meets a realistic demand profile of an average family, living isolated on a remote location with sufficient direct sunlight in the tropical band around the equator. Cooking is supposed to be done by using other primary energy sources.

The study focuses on the realistic gain that can be expected by tilting — once or twice a day — the solar PV panels around a north-south axis. This increments, for the same installed capacity (Wp) of PV panels, the daily production easily with 20 %. The conclusions can be used to lower further the minimal capacity of PV panels to be installed in order to provide electricity for meeting living standards in Central Africa.

Introduction

More than half a billion people, increasingly concentrated in rural areas of sub-Saharan Africa, will still be without access to electricity in 2040 (IEA 2016), as predicted by the International Energy Agency (Paris). The reason behind this is — most probably — the rather moderate demand of electricity in these areas, making the investments for grid extension extremely expensive. This last statement follows directly from figure 1, taken from Szabo *et al.* (2011), where one can see the very rarely branched electric networks in Central Africa (on all levels, *i.e*. high, medium and low voltage). The resulting distance from the grid is therefore very high for a large fraction of the population.

In this paper, an optimization technique will be proposed for stand-alone PV installations, although the reasoning can be applied as well to any other converter based on solar irradiance.

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[*] Department of Physics, Royal Military Academy, Renaissancelaan 30, B-1000 Brussels (Belgium).

[**] Mathnasium of Saskatoon, 705 Central Ave # 10, Saskatoon, SK S7N 2S4 (Canada).

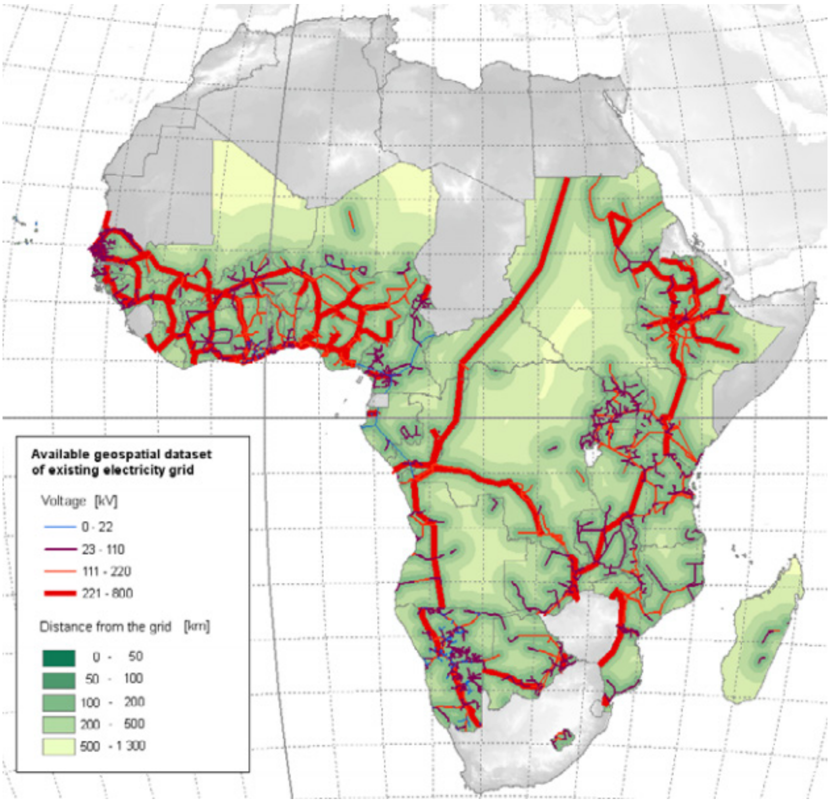


Fig. 1. — Available geospatial dataset of existing electricity grid and distance from the grid, taken from Szabo *et al.* (2011).

Motivation

As seen on figure 2, the price of solar photovoltaic (PV) panels decreases continuously towards levels that are almost negligible compared to a grid-connected system. The so-called costs for the Balance-of-System (BoS) are much lower or even absent in stand-alone "off-grid" installations. This directs the development in electrification more and more towards these off-grid stand-alone PV converters delivering electricity to individual users, remote households or mini-grids. The photovoltaic conversion seems to be a logical choice for sub-Saharan Africa because the solar influx in that region is — on average — twice the influx as, for instance, in Central Europe.

We are searching to further increase the yield of a given panel in this region of Africa, or to further decrease the installation cost per kWh of produced electricity, making electrification even more affordable.

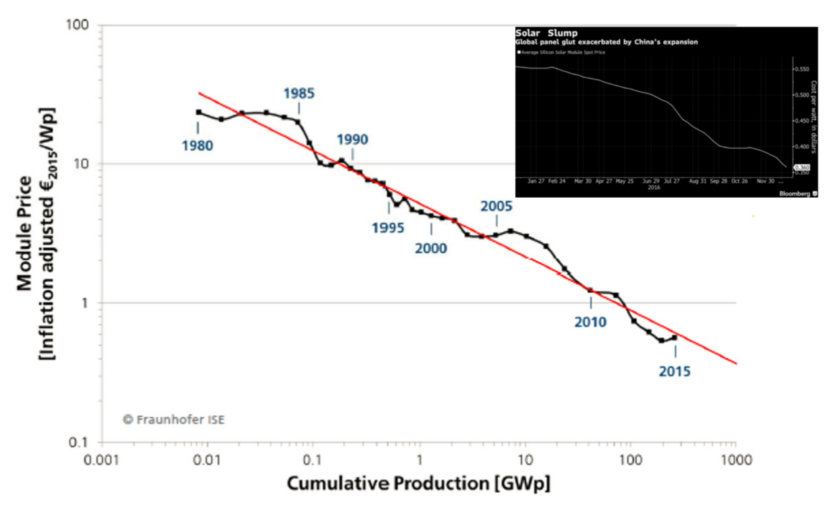


Fig. 2. — Price learning curve for PV, taken from Fraunhofer ISE and Bloomberg's Average Silicon Solar Module Spot Price in 2016. These numbers need to be compared to BoS costs of ~ 1 USD/Wp in 2016 (Taylor 2016).

Basic Idea

With the continuous decrease of the unit price for PV panels themselves, the BoS costs become relatively more important (this effect is even more pronounced for grid-connected PV systems). Here, we focus on stand-alone (off-grid) PV systems, installed in order to deliver supplementary DC electricity during the economically most active hours over a day: daytime hours. The need for batteries is in that case minimized. The aim is to increase the DC output for the same installed capacity in Wp. A certain number of application areas can be envisaged: Solar Home Systems (SHSs), PV irrigation pumps, a PV food dryer or a PV Telecom tower plant.

The idea is to optimize the orientation of the PV panel during the day without paying extra investment for an automated tracking system (fig. 3). The tracking system is thus mimicked with human intervention. The projection losses on a fixed panel, which are due to the apparent north-south variation (declination angle) of the sun during the year, are very limited for the region around the equator, covering all sub-Saharan Africa. A simple man-powered tilting mechanism can then mimic very well the remaining single axis tracking around a north-south directed pivot.

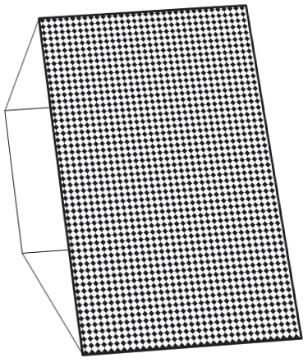


Fig. 3. — Picture of PV panel with an orientation angle allowing the increase of its yield.

Tropical Latitude

In the tropical band around the equator, the latitudinal part of projection losses is almost negligible (fig. 4).

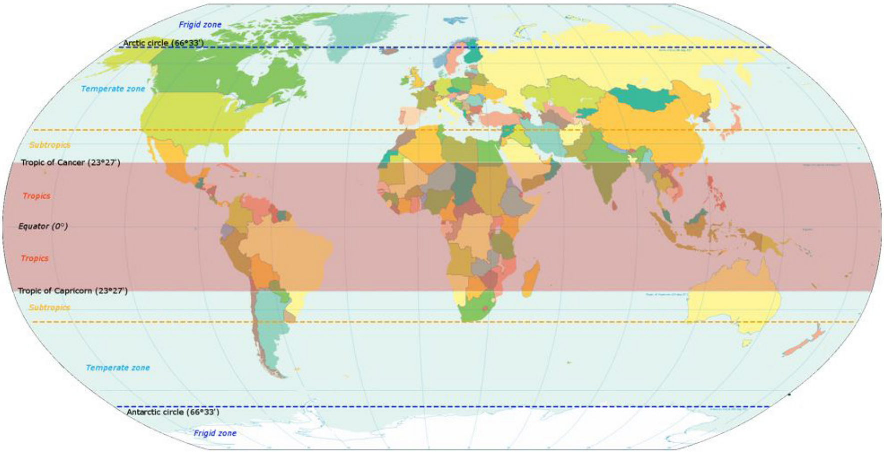


Fig. 4. — Map showing the possibility of installing panels between the Tropic of Cancer and Tropic of Capricorn.

To get an idea about these losses, consider for instance the average cosine of the declination angle α

$$\langle \cos\alpha \rangle = \frac{\int_{-23^\circ}^{23^\circ} \cos\alpha . d\alpha}{\int_{-23^\circ}^{23^\circ} d\alpha} \approx 97.5\%$$

We can conclude that for locations on the equator (or close to the equator, say within the tropical latitude band) there is no need for a two-axis tracking system. A single axis tracking system, making the solar panel to pivot around a north-south directed axis, captures the biggest part of projection losses during the day-time variation throughout the complete year. We will compute the yield of a reference panel, laid down horizontally on the equator (FIXED), of the same panel tracking the sun by using a two-axis tracking system and of the panel being tilted ONCE or TWICE a day around the north-south pivot (fig. 5).

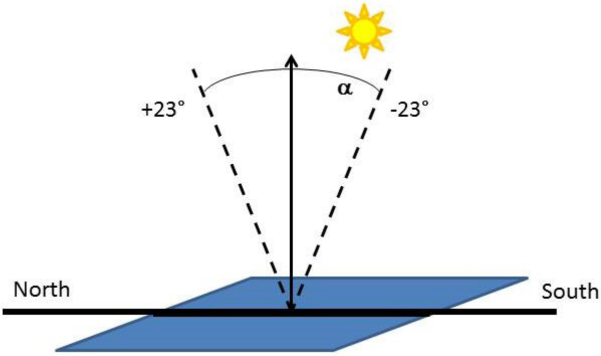


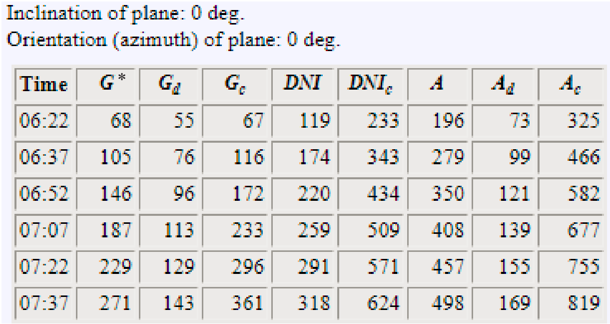
Fig. 5. — Variation of incoming solar rays' direction at noon for a PV panel laid down horizontally on the equator.

Database: PVGIS

This calculation was made by using the Photovoltaic Geographic Information System (PVGIS) database (JRC & EU Commission 2012), which is based on solar radiation data from HelioClim-1. The database contains daily global horizontal irradiation values for the period 1985-2004 with a spatial resolution of ~30 km at the equator. The database gives the possibility to simulate solar PV production: yearly figures per month or daily figures per fifteen minutes (for every average day in each month). Also, one has the possibility to choose the slope and azimuth OR to optimize these in a FIXED position. In order to give an idea about the figures from PVGIS, we show in table 1 the irradiances in Lokandu (RDC) during the first six periods (fifteen minutes time interval) of an average day in January on a FIXED horizontal panel.

Table 1

A snapshot of the output from PVGIS for a FIXED panel in Lokandu (RDC)



Inclination of plane: 0 deg.
Orientation (azimuth) of plane: 0 deg.

Time	G^*	G_d	G_c	DNI	DNI_c	A	A_d	A_c
06:22	68	55	67	119	233	196	73	325
06:37	105	76	116	174	343	279	99	466
06:52	146	96	172	220	434	350	121	582
07:07	187	113	233	259	509	408	139	677
07:22	229	129	296	291	571	457	155	755
07:37	271	143	361	318	624	498	169	819

* G: global irradiances on a fixed plane (in W/m^2, Gd = diffuse, Gc = clear sky); DNI: direct normal irradiance (in W/m^2, DNIc = clear sky); A: global irradiance on two-axis tracking plane (in W/m^2, Ad = diffuse, Ac = clear sky).

The relative importance of projection losses (early in the morning) is seen by comparing the columns G and A.

Computation

The aim of the paper is to mimic a single axis tracking mechanism (along the north-south axis) by tilting the PV panel through human intervention once or several times a day. The axis of rotation is N-S (fig. 6) and we will compute yields of the same panel for different values of θ.

We have compared the daily electricity production of an horizontally PV panel (FIXED) with respect to:

- A panel that is tilted ONCE a day (from the morning (AM) to the afternoon (PM) position);
- A panel that is tilted TWICE a day (from the morning (AM) over the midday (NOON) position towards the afternoon (PM) position).

The time of tilting towards the new position is determined by the moment when the new position delivers more electricity than the former one. Various angles θ of the tilting angle were tested in order to find the optimum value: this is the angle with the highest yearly production.

Optimum: Tilt TWICE a Day

We have searched for optimum solutions for the cases of tilting ONCE and TWICE. The results of the yearly yield can be compared with respect to the production of the two-axis tracking system. The latter system gives an increase of the yield with respect to the FIXED panel of about ~ 30 %.

Tilting the panels ONCE a day (@ 12:00) is optimized for $\theta \sim 35°$. The increase in yearly production with respect to the FIXED panel is 19.0 %. Tilting the panels TWICE a day (@ 10.40 – 13.20, local time) is optimized for $\theta \sim 48°$. The increase in yearly production with respect to the FIXED panels is 22.5 % (see fig. 6).

Of course one can construct polyhedrons with multiple intermediate positions between the morning and evening positions. In the limit of an almost continuous sequence of very small tilts $\Delta\theta$ per day, one has a human equivalent of a single-axis tracking system. In order to limit the time consumption of the tilting operation, we choose the tilting TWICE procedure as being sufficiently optimized giving three quarters of the gain that a very expensive two-axis tracking system delivers.

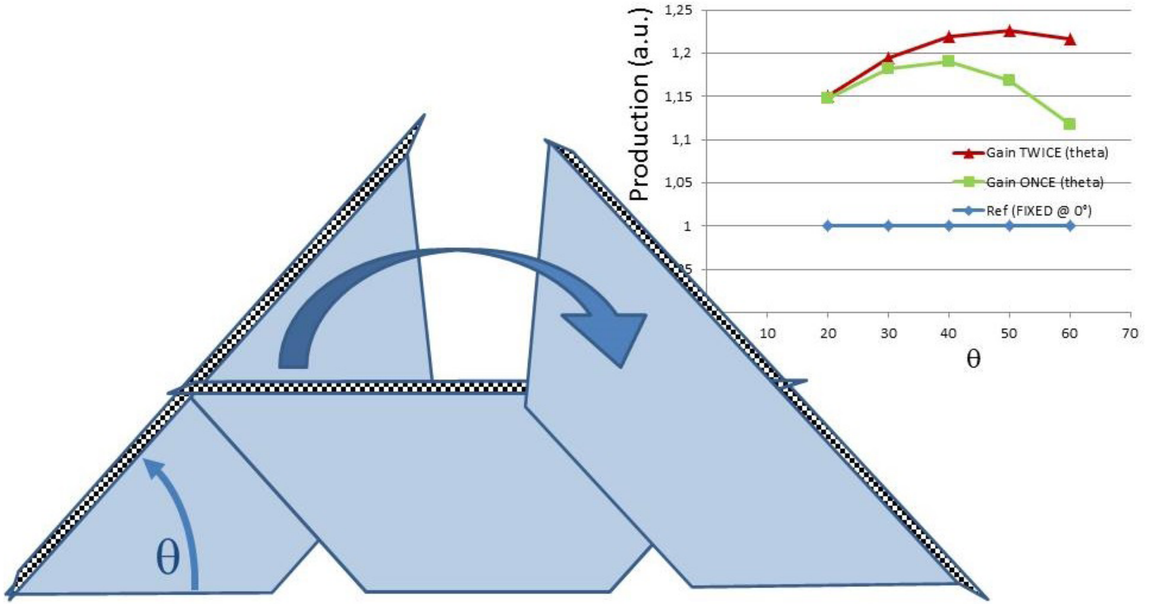


Fig. 6. — PV panel with backing support to be tilted TWICE a day. On the top-right panel, one finds (for varying angles of θ) the production of the ONCE and TWICE simulations, compared to the FIXED position of the panel.

Conclusion

For solar home systems in remote households or other applications that need in the first place electricity during daytime, it is worthwhile providing a tilting mechanism to tilt PV panels twice a day. This reduces the capacity that needs to be installed through an increase of the production per day per panel. There are a number of nice side-effects of this tilting mechanism. For example, an increased commitment of the owner due to the responsibility of making these tilts gives in turn a regular visual inspection of the whole system and allows the rain to do its work and clean the panels.

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Science and Diplomacy in Central and Western Africa: Remarkable Achievements and Challenges

by

César Kapseu[*] & Liliane D. T. Atoukam[**]

Keywords. — Science; Diplomacy; Central and Western Africa; Research; Conference; Project.

Summary. — Cameroon is the interface between the regions of Central and Western Africa. In this respect, it can play a role in scientific diplomacy. One of the assets of this "Africa in miniature" also concerns languages: English and French are the two official languages. Cameroon is bordered by five countries (Nigeria, Chad, Central African Republic (CAR), Congo and Equatorial Guinea). Two neighbours have insecurity problems (Nigeria and CAR). The aim of this paper is to identify cases related to science and diplomacy within the limits of our knowledge in Central and Western Africa. Research diplomatic agreements contribute to social, local and sustainable development by technology transfer.

Introduction

The Republic of Cameroon is a central-African state, located at the bottom of the Gulf of Guinea between the second and thirteenth degrees of north latitude and the ninth and sixteenth degrees of east longitude. GDP (Gross Domestic Product) was estimated at 18.3 billion US$ in 2006 by the World Bank. The growth rate has recently been on an upward trend, since it was observed after reaching the completion point that it had increased from 2.5 % (before) to 3.5 % in 2006 with the cancellation of certain debts. In 2007, it was 4.2 % and today it is around 6 %. Even if the share of the industrial sector in GDP remains a little weak (17 % in 2009) and a little higher today (Nkue & Njomo 2009). The agricultural sector accounts for 21 % of GDP and is divided between active food production, exported partly to neighbouring countries, and cash crops (cotton, rubber, palm, cocoa and banana). Cameroon shares borders with six countries (Nigeria, Chad, Central African Republic, Congo, Gabon and Equatorial Guinea) and has 400 km of coastline. It is therefore an interface between Central and West

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[*] Department of Process Engineering, University of Ngaoundere, BP 455, Ngaoundere (Cameroon).

[**] Faculty of Arts, Humanities and Social Sciences, University of Ngaoundere, BP 455, Ngaoundere (Cameroon).

Africa. As a result, it can play a very important role in scientific diplomacy. One of the highlights of this “Africa in miniature” is bilingualism: French and English are the two official languages. Two of its neighbours have security problems which cannot leave Cameroon indifferent. Our goal is to identify the cases of science and diplomacy within the limits of our knowledge in Central and West Africa.

Diplomatic and Scientific Agreements between States and/or International Universities

There are many diplomatic agreements between states in the world. The agreement presented here is a research and scientific agreement concerning Western and Central Africa.

Cameroon has signed several agreements with a number of international organizations, such as UN-Unicef, the Francophone International Organization (OIF), the Commonwealth, the African Union, CEMAC (*Communauté économique et monétaire de l’Afrique centrale*), etc. Cameroon is already a member of other organizations: the Francophone University Agency (AUF, Paris-France), the Commonwealth (UK), the World Academy of Sciences for the Advancement of Science in Developing Countries (TWAS, Trieste-Italy), DAAF (Munich-Germany). These agreements concern diplomatic science usually with a network representative in the world. For example, we have the TWAS ambassador of science (fig. 1), the ANSOLE (African Network for Solar Energy) representative or the African commission for the Future of the Earth representative for Central Africa.

The mission of the ambassadors of these structures gives full meaning to this cooperation with diplomacy. As proof of this, the TWAS ambassador of science for the Central-African region declared as mission: “to advance issues at the interface of science and diplomacy, and to do so at the regional level, especially in developing countries, as is the case in Central Africa, to organize projects aimed at strengthening regional cooperation and networking between TWAS members and their countries, and increase the capacity of the Ministries of Foreign Affairs, International Cooperation Divisions within Ministries and Research Organizations to Establish Scientific Partnerships”.

Within the framework of these cooperations, several scholarships from the sub-region’s countries were awarded in Cameroonian universities. For example, countries like Chad, Congo, and the Democratic Republic of Congo received among other lessons, those related to young people in a difficult situation and in post-conflict situation supported by the Francophone University Agency and the Association of African Universities.

Fig. 1. — Assignment of the function of ambassador of science for Central Africa (Trieste-Italy, 2013) (*source*: Journalducameroun.com, 27/12/2013).

Science and Diplomacy at the Service of Sustainable Development

Sustainable development is focused on:

- Improvement of the quality of life;
- Maintenance of permanent access to natural resources, whether renewable or non-renewable;
- Reduction of waste or pollutant emissions so as to avoid any persistent environmental damage (Tchouate Héteu 2003).

It was in this context that a sub-regional and international conference was organized at Ngaoundere University of Cameroon on July 21-23, 2015 (fig. 2).

This event aimed at:

- Valuing residues from industry and agro-pastoral and forestry activities in the Central-African region, particularly through the production of bio-energies;
- Developing organic compost, bio-ethanol, biogas, bioplastic and energy from waste;
- Enhancing non-timber forest products;
- Training young people on climate change issues and setting up small waste processing units;
- Strengthening regional cooperation in research and education.

Projects such as the one presented in that conference aimed to promote common research schemes between the countries of the sub-region. At the last conference in Cameroon (see fig. 2), the participants came from Chad, Congo and the Democratic Republic of Congo. This was thanks to the revitalization of laboratories and the publication of research results and consequently grade change at university. As a result, several Chadian and Congolese research teachers had the opportunity to move from assistant to lecturer. As an example, let us mention a Burkinabe researcher who at the end of the conference became minister in his country.

Fig. 2. — International conference of Ngaoundere, Cameroon.

Other seminars were organized, such as the one in Yaounde which focused on “renewable energies and cogeneration for sustainable development in Africa” in 2002 together with the University Development Cooperation (CUD) of Belgium. The overall objective of this seminar was to analyse the potential contribution of energy production technologies to the sustainable development of the energy sector in the African context.

The organization of international conferences plays an important role in common research for the development and training of young researchers. Such events further promote diplomacy through science in the Central-African, western and beyond sub-regions. International conferences with sub-regional representations such as ANSOLE (fig. 3), the African Commission for the Future of the Earth, the French-speaking network of researchers in the field of agro-food processes, and the Research and Innovation Network contribute to strengthening solidarity links between scientists. Evidence of this is the cooperation initiated between the Cameroonian municipality of “Ngaoundere III” and the Italian municipality of Trieste on the occasion of Ngaoundere international colloquia. The aim is the use of “scientific cooperation to solve the problems of citizens in the two partner municipalities and finally, to put people in touch for creating a synergy of actions and exchange of experience”.

Fig. 3. — International conference organized by ANSOLE (Cameroon-Bamenda, 2017).

At the end of these conferences, collective books (proceedings) between states and participating scientists were published on sustainable, social and local development topics.

One of the most salient events of the international conference of Ngaoundere “Biodiversity and Global Changes: Valuation of Effluents from Industries, Agropastoral Residues and Forestry” was recognized as a contribution during the international conference on the dry zones in Alexandria in Egypt in August 2016 (fig. 4).

This book was published as the symposium proceedings with the support of the ambassadors of France, Germany, Belgium and research and development partners such as AUF (Canada), IRD (France) and TWAS (Italy).

Fig. 4. — Presentation of the proceedings of the international conference of Ngaoundere (2015).

The results of these seminars have crossed sub-regional boundaries and gone beyond the simple scientific framework. We would like to witness the participation of housewives at the Ngaoundere conference in 2015 and the recognition of the coordinator two years later as man of the year on the occasion of the day dedicated to them – the International Women's Day (fig. 5).

Fig. 5. — a. Consecration as home of the year on the occasion of the International Women's Day (March 2017); b. Women exhibition at the Ngaoundere conference.

Conclusion

This paper deals with the development of inter-state cooperation through scientific research. We have presented some organizations whose vocation is to support development and some results of scientific meetings. We have shown that due to its geographical location, Cameroon can host and serve as a relay for the development of scientific cooperation. For a global development, the sub-regional conferences with the support of partners represented in the sub-region are unavoidable. As a perspective, further to these seminars, we should support young innovative project leaders through sub-regional incubators.

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Use of Distributed Generation to improve Operation of Overloaded Grids in Africa

by

Marien OKANA NSIAWI OTIIN[*], Laurent KITOKO[**],
Pascal KAMABU TSONGO[*] & Ali ATUNDEZI GAHUMA[***]

KEYWORDS. — Distributed Generation; Renewable Energy; Induction Generator; Synchronous Generator; Solar Panels; Power Distribution.

SUMMARY. — Power systems in Central Africa are most of the time unable to meet the demand. In many cases, they are overloaded and load-shedding programmes are established to protect them. Instead of upgrading the whole electrical system, this paper proposes the integration of distributed generation (DG) units in distribution grids to improve their operation.

The paper investigates the benefits of the proposal by simulating the integration of various types of electrical power sources in the low-voltage (LV) grids of Kinshasa city. Load-flow calculations done with DIgSILENT Power Factory 15.2 show that distributed generation is a good solution to improve operation of overloaded grids.

Introduction

Facing the new challenges in power system development, scientists and engineers are constantly reflecting on and developing new and original solutions. Distributed generation is one of them (SHORT 2004).

In Central Africa, distributed generation could be a solution to improve:

— Access to electricity;
— Operation of overloaded distribution grids.

The benefits of distributed generation on distribution grid operation in Central Africa have been investigated by simulating, with DIgSILENT Power Factory 15, the integration of various DG units in the grids of Kinshasa city.

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[*] Laboratoire de Génie électrique, Département d'Électricité, Faculté polytechnique, Université de Kinshasa, B.P. 255, Kinshasa XI (RD Congo).

[**] Director SNEL (Société nationale d'Électricité), avenue de la Justice 2831, Kinshasa Gombe (RD Congo).

[***] NTIC-Acteurs RDC, avenue Parc de Virunga 14, Q/Righini, Commune de Lemba, Kinshasa (RD Congo).

Issues of Distribution Grid Operation

Many areas in Central Africa have an electrical system unable to meet the power demand. As a consequence, grid components are most of the time overloaded and load-shedding programmes are established to keep voltage within an acceptable range and to protect cables and transformers.

For example, in figure 1 showing a portion of Kinshasa city's medium-voltage (MV) distribution grid, load-flow calculations show that:

— Loadings of the main cables and transformers under study are above 105 %;
— LV busbar voltages are below 0.95 p.u.

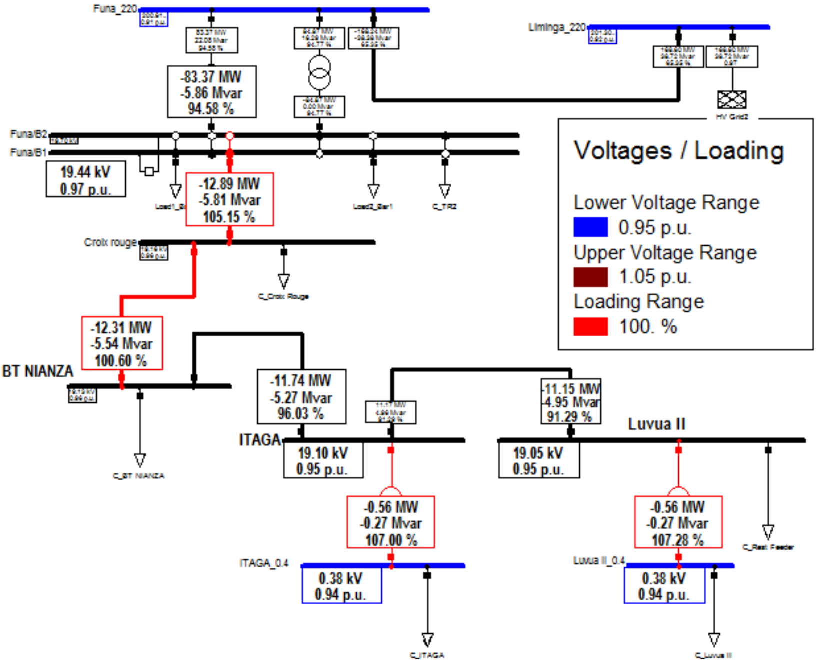

Fig. 1. — Load flow in a portion of Kinshasas's distribution MV grid.

To lower loadings below 100 % and have voltage of LV buses above 0.95 p.u., 660 kW must be removed from the grid shown in figure 1.

Integration of Distributed Generation (DG) in Distribution Grids

The traditional way to improve operation of such overloaded grids is to build new power plants, to build new transmission lines or reinforce the existing ones, and to install new transformers and cables (MV and LV) in the distribution grid.

Instead of upgrading the whole electrical system, a local solution can be found to improve grid operation by installing DG units in distribution grids.

Among the various DG technologies, small hydro, solar PV, internal combustion and stirling engines are the most suitable in Central Africa according to IRENA (2013) and Knazkins (2004).

To assess the impact of DG integration on distribution grid operation, the three following types of sources have been investigated:

- Induction generators (IG);
- Synchronous generators (SG);
- Photovoltaic arrays (PV).

Results, Summary and Discussion

Load-flow results presented in table 1 and on figure 2 show that integration of DG units in distribution grids has the following impact:

- Reduction of MV cables and MV/LV transformer loading (greater loading reduction for SG and PV, and smaller one for IG);
- Improvement of voltage level at LV buses under study.

Table 1

Simulations results for main cables and substations

Study cases	Main cable loading (%)	Itaga MV/LV substation		Luvua II MV/LV substation	
		Transformer loading (%)	LV bus voltage (p.u.)	Transformer loading (%)	LV bus voltage (p.u.)
Initial situation	105.15	107.0	0.94	107.3	0.94
Induction generator without compensation	102.15	90.4	0.93	90.6	0.93
Induction generator with compensation	100.27	60.9	0.95	52.5	0.96
Synchronous generator	99.75	49.2	0.97	49.3	0.96
Photovoltaic array	99.98	52.2	0.96	52.3	0.96

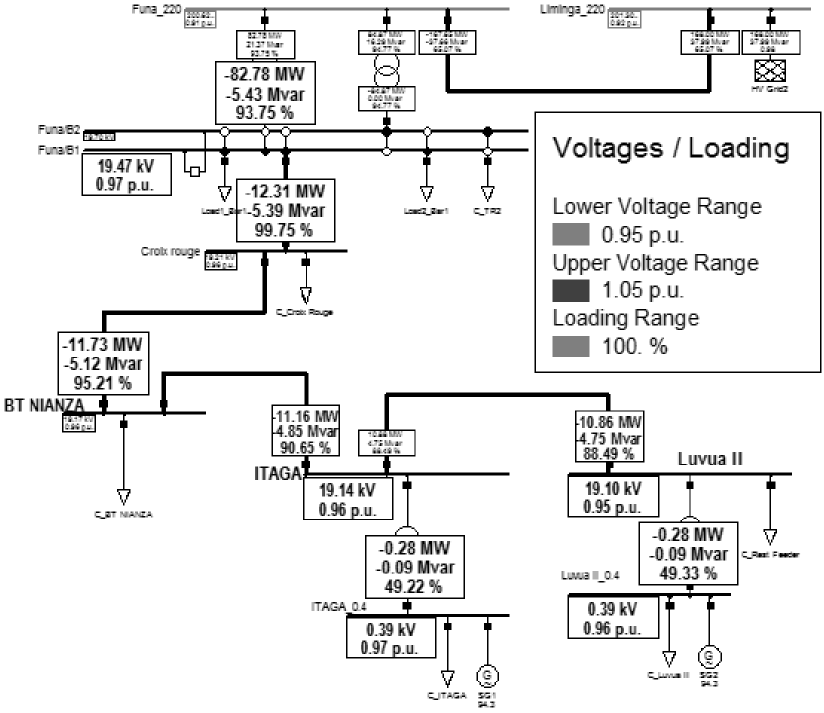

Fig. 2. — Load-flow results after integration of SG in the grid.

Conclusion

The impact of distributed generation on distribution grids in Central Africa has been analysed in a part of the distribution grid of Kinshasa. Load-flow calculations have shown that integration of generators in the distribution grid enhances its parameters and improves grid operation: improve voltage level, reduce loading of equipment and so the need for load shedding.

Analysis has shown that systems using synchronous generators and PV arrays have a greater benefit on grid operation than those using induction generators. The latter seem to be not suitable for overloaded grids.

The results of grid simulations have shown also that distributed generation offers opportunities for small independent producers (<1 MW) to actively participate in the generation system.

Therefore, in Central Africa, there is a need for further research on the subject: short-circuit, power quality, stability, monitoring and management issues.

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Closing Remarks

by

Jozef Smets[*]

Eminent Professors,
Ladies and Gentlemen,

Let me first of all say that Mr Didier Reynders, Belgian Deputy Prime Minister and Minister of Foreign Affairs, has asked me to send you his best regards as well as a clear message of support to this international conference organized by the Royal Academy for Overseas Sciences of Belgium on such a prominent theme as “Sustainable Energy for Africa”…

Minister Reynders is at this very moment in Africa, more precisely in Ivory Coast where he takes part in a great Belgian trade mission composed of more then two hundred businessmen, with the participation of the three regions of Belgium and presided by HRH Princess Astrid.

Together with Prime Minister Charles Michel, Minister Reynders is also preparing for a high-level Belgian participation in the European Union/African Union Summit which this time will have as prominent theme: “Youth”…

Ladies and Gentlemen,

More Belgian initiatives are being taken these days, which is a proof of our continuous focus on Africa and of a strong African commitment of the government, but also of other prominent actors, and here I should of course refer to our universities and research centres, many of them being represented here today.

In this regard, I would like to mention the “African Diamond Conference” due to take place on 13 and 14 November 2017 both in Brussels and in Antwerp, a joint initiative of the Antwerp diamond sector and of the Ministry of Foreign Affairs, aiming at the promotion of sustainability in that field, the impact of a responsible supply chain on profit margins and the benefits and challenges of industry self-regulation and best practices of rough diamond valuation mechanisms.

Ministers of Mining of the main diamond-producing African countries have confirmed their presence.

Joint action to strengthen sustainable management of natural resources is one of the prominent flagships as listed out in the ‘Joint Communication for a

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[*] Ambassador, Director Sub-Saharan Africa, Belgian Ministry of Foreign Affairs, rue des Petits Carmes 15, B-1000 Brussels (Belgium).

Renewed Impetus of the Africa-EU partnership', adopted in May 2017 by the EU. This Joint Communication is in fact a strategy document, a follow-up of the 'Joint Africa Europe Strategy' (JAES), which was launched a few years ago.

In the new ambitious document, adopted this year, a range of flagships are listed with the aim of guaranteeing concrete deliverables, which will be also prominent guidelines for the coming summit EU/AU in Abidjan (Ivory Coast).

Out of this list, another prominent flagship is the following: "to launch a new EU-Africa Research and Innovation Partnership on climate change and sustainable energy". And I think that all the participants of this conference will take note of this with great interest.

Preparing for the summit all EU member states are currently collecting relevant information with regard to these flagships. Belgium is one of the countries that is now pursuing this important exercise and sustainable energy will have a prominent place in such a context.

Ladies and gentlemen, throughout my different mandates in Africa — three years as a *consul général* in Lubumbashi (DRC), four years as an ambassador to Nigeria and later to Burundi — I could observe from nearby the huge challenges and problems but also the high potential in the sector of sustainable energy and what we call here "a sustainable energy mix".

By the way, going through the programme of this international conference my attention was immediately drawn to specific contributions on these three countries, made by native prominent experts and scholars.

We were also present when, just two weeks ago, the former president of Nigeria, Olusegun Obasanjo, and three prominent researchers presented in Brussels their book "Making Africa Work". They outlined for each economic sector (agriculture, mining, manufacturing, services and technology) what they called "Five steps for success"…

Going through these steps, I could notice that the "sustainable energy" factor was very present in most of them.

I have also appreciated in this book the field-based experience with dozens of examples relating to various African countries and the fact that the book does not focus on the mistakes of the past, but gives a sober *status questionis* followed by suggestions and perspectives for the future.

I understand that this is also the approach and philosophy of this conference!

We have to look at the African continent in a different and innovative way, and this must be reflected at all levels, including the level of EU-African relations, a fast-evolving framework where my country is a prominent actor.

It is within this context that we are also looking these days at the future of the Cotonou agreements while the debate on "Post-Cotonou" is going on and the stakes are high.

Do we opt from 2020 onwards for a relationship between the EU and the ACP countries (of which Africa is by far the most important pillar), which is restricted to migration and security issues? Or instead, do we opt for the continuation of an ambitious relationship, including trade aspects, investment, market access issues, development cooperation but also an intense policy dialogue between the EU and their different partners from the South (we call it the article 8 dialogue)?

I can tell you Belgium is one of the EU member states in favour of the continuation of an ambitious relationship between Europe and the ACP countries, whereby we would like to see the three regional pillars (the Caribbean, the Pacific and Africa) to become more prominent.

For us, the African pillar would be a priority. So, we want to move towards a legally-binding, ambitious and at the same time more efficient and adapted partnership. The debate is going on among Europeans and within the ACP group, and soon the countries from the North and from the South will go into more final negotiations…

Ladies and gentlemen, there have been throughout this three-day conference many outstanding contributions on sustainable energy for Africa.

The signal I would like to give is that we will try at decision-making levels to promote the priority of a sustainable energy strategy for the African continent. This has to happen at the UN level — and please allow me to mention here the specific ambitions of Belgium: besides being an active partner in the UN system, we are a candidate for a seat of non-permanent member in the Security Council for the period 2019-2020, and I can assure you that if we get this seat, we will be very sensitive to African priorities. But it should also happen as part of the EU-Africa relation, and again I am referring here to the upcoming summit in Abidjan (29-30 November 2017) and the post-Cotonou debate.

Furthermore, the sustainable energy dimension has to be reflected throughout our bilateral cooperation programmes, more precisely with our thirteen partner countries in Africa (Benin, Burkina Faso, Burundi, DR Congo, Guinea, Mali, Morocco, Mozambique, Niger, Rwanda, Senegal, Tanzania, Uganda), but of course also with all the other countries with which we maintain intensive relations in the policy field, as well as in the fields of trade and research.

Finally, I would like to plead in favour of the drafting of a short policy document that would reflect the main conclusions of this conference, thus providing guidelines to our governments and policy makers.

For our part, we would commit to raising awareness on such a document and its conclusions and to sharing it with our European partners. We could even organize together a follow-up round table.

Ladies and gentlemen, I would like to congratulate once again the Royal Academy for Overseas Sciences and all the prominent experts and scholars who have taken the floor all along this three-day conference.

This being said, we are ready to make the link between research level and the level of Belgian and European policy makers on this very prominent matter of sustainable energy for Africa.

International Conference
Sustainable Energy for Africa
Royal Academy for Overseas Sciences
Brussels, 23-25 October 2017
pp. 255-291

Summary and Tentative Conclusions

by

Georges Van Goethem[*]

Specific Challenges dealt with in the Conference

To set the context of this conference SE4A 2017, it should be recalled that the concept of "sustainable development" originally refers to both intergenerational sustainability and poverty eradication in the world. The concept was first developed in the mid-1980s in the famous G. H. Brundtland's "Report of the World Commission on Environment and Development: Our Common Future" (United Nations, 1987). As a follow-up of the UN Millennium Summit in 2000 and of the subsequent discussions in 2014 around the seventeen Sustainable Development Goals (SDGs), UN came up in 2015 with the "2030 Agenda for Sustainable Development". The SDGs and associated targets in this UN 2030 Agenda include economic, social and environmental aspects and recognize their interlinkages in achieving sustainable development in all its dimensions.

Energy is one of mankind's basic needs. Access to energy is a prerequisite for reaching many of the SDGs. Electricity, even though it only accounts for around one fifth of the world's final energy consumption, plays a key role in economic development in emerging as well as industrialized countries.

The timing and location of this conference were quite appropriate.

First, special mention should be done of the reference report by the OECD/IEA (Organisation for Economic Co-operation and Development/International Energy Agency), located in Paris, namely the "Africa Energy Outlook 2014 – a Special Report" published in 2014 in the World Energy Outlook series with focus on energy prospects in sub-Saharan Africa – SSA (in short, IEA WEO 2014, 242 pp.). Here is an excerpt:

> Sub-Saharan Africa's energy sector can be improved to unlock a better life for its citizens. This report describes one of the most poorly understood parts of the global energy system, offers an authoritative study of its future prospects — broken down by fuel, sector and sub-region — and shows how investment in

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[*] Member of the Academy; co-organizer of the conference "Sustainable Energy for Africa" (23-25 October 2017); European Commission – Euratom Research, Innovation and Training in nuclear fission and radiation protection (Italy and Belgium).

> the sub-Saharan energy sector can stimulate rapid economic and social development across the region.
>
> The “Africa Energy Outlook 2014” report:
>
> - Explores how quickly modern energy might be brought to the huge population currently deprived of it.
> - Highlights key actions in the energy sector that can unleash more rapid economic and social development in sub-Saharan Africa.
> - Evaluates the role of renewables in the region’s energy future, and how important mini- and off-grid solutions can be in providing access to electricity.
> - Examines how existing and emerging oil and gas producers can maximise the value of their resources for economic development.
> - Identifies the benefits that greater regional integration of the energy sector can bring, as well as mapping the future role of SSA in the global energy system (https://www.iea.org/publications/freepublications/publication/WEO2014_AfricaEnergyOutlook.pdf).

Secondly, a number of important EU-Africa summits took place during the previous decade (Cairo in 2000, Lisbon in 2007, Tripoli-Libya in 2010). The fourth and most recent EU-Africa summit took place in Brussels on 2-3 April 2014. On the EU side, two DGs of the European Commission, namely DG DEVCO (in particular, the Technical Assistance Facility (TAF) for the “Sustainable Energy for All” initiative West and Central Africa) and DG RTD (in particular, the current EU Research and Innovation programme 2014-2020, called Horizon-2020), have played a key role. Regular High-Level Policy Dialogues (HLPD) and expert level meetings ensure the implementation of the “road map”, such as the reference group on Infrastructure, or the EU-Africa HLPD expert group on Science, Technology and Innovation (STI). The fourth meeting of the latter group took place in the EU premises in Brussels on 17-18 October 2017. The meeting took stock of the first results of the first STI partnership on “Food and Nutrition Security & Sustainable Agriculture” launched in 2016. Moreover, a roadmap on “Climate Change and Sustainable Energy” (CCSE) was adopted by the member states as the second priority for the STI partnership between both continents (http://ec.europa.eu/research/iscp/pdf/policy/ccse_roadmap_2017.pdf). The fifth EU-Africa summit is scheduled to take place in Abidjan, Ivory Coast, on 28-29 November 2017.

Thirdly, the OECD/IEA issued recently another remarkable report (144 pp.) focussing on access to energy, namely “Energy Access Outlook 2017 – World Energy Outlook Special Report”.

> This IEA 2017 report, released in Rome on 19 October 2017, explores the close links between energy and development, assessing today’s global picture for access to modern energy, the strategies and technologies that can enable countries to achieve energy for all by 2030, and the ways in which reliable energy can move communities to meet the UN Sustainable Development Goals.

A chapter (pp. 75-101) is dedicated to SSA, namely “Energising development in sub-Saharan Africa”, focussing on (1) sub-Saharan Africa energy outlook,

(2) access to electricity, (3) access to clean cooking and (4) impact of modernizing agriculture (https://www.iea.org/publications/freepublications/publication/WEO2017SpecialReport_EnergyAccessOutlook.pdf).

The focus of the RAOS conference "Sustainable Energy for Africa" was on three specific challenges, all related to UN goal SDG 7 (*i.e.*, "ensure access to affordable, reliable, sustainable and modern energy for all"):

- Universal energy access: energy is the golden thread connecting economic growth, increased social equity, and an environment that allows the world to prosper. Without access to modern energy, it is not possible to achieve the SDGs, whether reducing poverty, improving health, or broadening the reach of education for all.
- Renewable energy: hydro, geothermal and bio-energy have long been competitive where resources are available, and wind and solar are also economically attractive in many locations. If supported by strong enabling policies and robust investment, renewable energy could supply a much larger share of the world's energy by 2030.
- Energy efficiency — getting more from existing resources (*i.e.*, circular economy) — increases global resource productivity, supports economic growth, and reduces costs for all citizens. The savings from energy efficiency could help make modern energy services available to those who lack it. They also can make energy more reliable while creating new jobs.

The aim of the three-day conference was to provide an interdisciplinary and multisectorial forum, enabling synergy between (1) decision-makers (*e.g.*, in industry and ministries) and opinion leaders (*e.g.*, media and civil society), (2) SESH (Social and Economical Sciences as well as Humanities) experts and (3) the STEM (Science, Technology, Engineering and Mathematics) research community. A number of high-level experts belonging to various countries (from both Africa and European Union) and originating from various horizons (scientific and technical, political and socio-economic) were invited to discuss opportunities and challenges related to sustainable energy in Africa.

One of the most important driving forces of any development in Africa of course is demography: demographic trends are creating major challenges, particularly in terms of migration, security and employment. The population of Africa is growing rapidly. The continent already has a population of 1.21 billion people and is expected to have 2.37 billion people by 2050 (IEA source). Under these conditions, economic development poses a series of challenges, especially regarding access to energy, food and water (nexus approach needed).

Summary of the 27 Invited Lectures and 36 Scientific Posters

Here is the summary of the RAOS "Sustainable Energy for Africa" conference, which was structured around three main topics.

Topic 1 – Energy is Crucial for achieving the UN Sustainable Development Goals

Energy poverty is exemplified by the fact that one billion people worldwide lack access to electricity and that 95 % of these people live in sub-Saharan Africa or developing Asia. More than six hundred twenty million people in sub-Saharan Africa alone (total population of nine hundred ninety-five million in 2016), *i.e.* 62 %, live without access to electricity and nearly seven hundred thirty million people use hazardous, inefficient forms of cooking, a reliance which affects women and children disproportionately (International Energy Agency 2016).

Electricity demand in Africa was 605 TWh (terawatt-hours) in 2012, with North Africa accounting for around 40 % of the total. In SSA, total electricity demand has increased by 35 % since 2000 to reach 352 TWh in 2012, just 70 % of the level of Korea, which has a population of fifty-one million people (*i.e.*, 5 % of the size of SSA). Reference can also be made to Spain (population of forty-six million): in 2012 they consumed 261 TWhe of electricity. On a per capita basis electricity demand in sub-Saharan Africa has remained largely unchanged for the last decade, *i.e.* close to 400 kWhe (*source*: IEA WEO 2014).

On-grid power generation capacity in 2012 was 158 GW (gigawatts) in Africa, including 90 GW in SSA, with around 45 GW in South Africa. Coal-fired generation capacity is 45 % of the sub-Saharan total, followed by hydropower (22 %, both more evenly spread), oil-fired (17 %), gas-fired (14 %, mainly Nigeria, also Mozambique and Tanzania), nuclear (2 %, today only South Africa, tomorrow maybe Ghana, Kenya, Namibia and others) and renewables (less than 1 %, solar particularly in South Africa and Nigeria, and geothermal particularly in East Africa).

As for the future (IEA WEO 2014), by 2040 the economy in SSA will quadruple in size, the population will nearly double (to 1.75 billion) and energy demand will grow by around 80 %. The sub-Saharan energy system will expand rapidly by 2040, with generation capacity quadrupling to 385 GW. The power mix becomes more diverse, with coal and hydropower (all regions) being joined by greater use of gas, solar and geothermal. The share of renewables in total capacity more than doubles to 44 %. Sub-Saharan Africa makes only a small contribution to global energy-related CO_2 emissions, accounting for merely 3 % of the total in 2040, but is on the front line when it comes to the potential impacts of a changing climate. In particular, hydropower prospects can be affected by changing patterns of rainfall and surface run-off, which is the primary cause of urban flooding.

NB on solar power: Africa is particularly rich in solar energy potential, with most of the continent enjoying an average of more than three hundred and twenty days per year of bright sunlight and experiencing irradiance levels of almost 2,000 kWh per square metre annually. Solar PV is much more competitive in off-grid or mini-grid applications, where the main alternative at present is generation fuelled by diesel or gasoline. Potential solar power generation far exceeds electricity demand today and into the foreseeable future, though vast areas of land or rooftops would be required. *NB*: solar irradiance for several locations: Northern Germany: 1,220 kWh/m^2/a (@36 degrees inclination); Southern Spain: 2,100 kWh/m^2/a (@32 degrees inclination); Northern Africa: up to 2,700 kWh/m^2/a (@18 degrees inclination).

NB on hydropower: Africa has an estimated potential of 300 GW, and only 8 % of this has been tapped with the aim of driving regional interconnection and grid expansion. The countries with the most hydroelectric generating capacity installed in the region include Ethiopia (2,552 MW) and the Democratic Republic of Congo (2,495 MW). Much of the capacity developed in Ethiopia provides electricity for export to neighbouring countries and regions. Ethiopia is developing several large projects, including the ‘Grand Renaissance Dam’ (6,000 MW) and ‘Gilgel Gibe III’ (1,870 MW). The large hydropower potential in DR Congo has long been a focus of policy makers, both in terms of the planned Inga III project (4.8 GW) and the several phases of the long discussed Grand Inga project (around 44 GW) which, if constructed, could transform the African power supply picture.

As a conclusion of this topic, the emphasis of EU-Africa collaboration in the energy field should be not only on ambitious joint research and innovation programmes but also on the improvement of standards and regulations (to be adapted to each country), thereby creating the desired enabling environment needed for untapping the existing energy potential and developing modern energy infrastructures.

Introductory Session: Three Keynote Speeches

TOPIC 1 – ENERGY IS CRUCIAL FOR ACHIEVING THE UN SUSTAINABLE DEVELOPMENT GOALS

Monday morning 23 October

10:00 **Welcome Message**, Georges VAN GOETHEM (conference chairman, member RAOS)

10:15 **Opening Speech**, Carole MAMAN, Chief Investment Officer, Belgian Investment Company for Developing countries (BIO), representing Alexander De Croo, Deputy Prime Minister and Minister of Development Cooperation and Digital Agenda

10:35 **The Demography of Africa: Impacts on Economy, Energy, and Governance**, Dr John F. MAY, Population Reference Bureau in Washington, DC, Visiting Scholar

10:55 **African Universities and Science Diplomacy in favour of Alternative Sources of Energy**, Prof. Wail BENJELLOUN, President Mediterranean Universities Union (UNIMED), former president of the Conference of Moroccan University Presidents

Selected Pieces of C. Maman's Keynote Speech

> The Belgian Investment Company for Developing Countries (BIO) has participated along with other development agencies in the financing of various hydro, solar, wind, geothermal projects across the three continents. On a yearly basis, they invest 50 M/60 M€ in renewable energy. […] Pushing the agenda on regional interconnections could also significantly improve energy access and distribution and reduce reliance on one kind of energy. Eventually, governments could promote more effective energy measures. […] We, development agencies, have a role to play in building human capacity in the host countries to accompany the development of sustainable energy through education and through academic cooperation.
>
> List (non-exhaustive) of projects that are currently being deployed:
>
> — Hydro projects: at BIO, we see many projects being developed in Ethiopia, Uganda, Ivory Coast and Kenya without mentioning Inga in DRC.
> — Wind projects in Kenya, Morocco, South Africa.
> — Geothermal in Kenya, Ethiopia and possibly Uganda.
> — Sustainable forestry projects in South and East Africa.
> — Methane extraction from Lake Kivu for electrification: a project in which BIO participated.
> — Solar projects are being developed on-grid as well as off-grid. What started in South Africa and Morocco is now being rolled over in Rwanda, Senegal, Namibia, Burkina Faso, Benin, Zambia and soon Ethiopia. Solar home systems are being sold on a pay-as-you-go basis continent-wide to help households shift from diesel and candles to electricity.

Selected Pieces of J. May's Keynote Speech

The huge population increase in Africa will have far-reaching consequences on many development sectors. First and foremost, African population will migrate and urbanize rapidly, fuelling the current megacities and their slums. The formation of human capital (education and health) will be another major challenge. Last but not least, SSA will need to create over the next quarter of a century eighteen million new jobs every year — this is about the current population of Burkina Faso.

Three dimensions will need particular attention. First, should fertility decline more rapidly, active people would become relatively more numerous than their dependents and this could generate a production surplus (*i.e.*, a first demographic dividend). Secondly, the rapid population growth will have a major impact on the energy needs of the continent, and countries will have to accelerate their energy transition. Last but not least, in order to capture a demographic dividend and to plan for their energy requirements, SSA countries will need to improve their governance. This will be a *sine-qua-non* condition for countries to be able to charter the way forward and seize the potential opportunities.

NB: "Africa's Population: In Search of a Demographic Dividend" (title of his most recent book), *i.e.*, the SSA region could take full economic advantage of a larger labour force as the labour force grows with fewer dependents as fertility rates in the region fall. This will entail a true vision and determination on the part of African leaders and their development partners.

Selected Pieces of W. Benjelloun's Keynote Speech

At the climate change conference in Marrakesh (COP22, 7-18 November 2016), participants adopted a Joint Official Declaration of African Academies of Science and Presidents-Rectors of African Universities recommending actions to be undertaken in the academic and scientific areas to face the challenges of climate change in Africa. The declaration insisted on the necessity for the United Nations, decision-makers in the developed world and international organizations to set up a special fund to financially support initiatives that need to be implemented in Africa, including support for research. […] The Marrakesh proclamation, adopted by the heads of state and government at the end of COP22, included these recommendations.

Invited Lectures

TOPIC 1 – ENERGY IS CRUCIAL FOR ACHIEVING THE SUSTAINABLE DEVELOPMENT GOALS

Monday morning 23 October (continuation)

11:15 **Energy for Sustainable Development in Africa: Success, Challenges and Possible Way Forward**, Dr Emmanuel Kofi ACKOM, J. A. HASELIP & G. A. MACKENZIE, UNEP, DTU Partnership (UDP), Technical University Denmark (DTU), Copenhagen

11:35 **The Main Challenges for Financing Sustainable Energy in Africa: Lessons from the Past and New Opportunities for PPP, viewed from a European Point of View**, Paul FRIX, Senior Economist, specialized in international relations and development, Hon. DG Belgian Development Cooperation and CDE/CDI, Counsellor CBL-ACP

11:55 **Governing Decentralized Energy Provision: Exploring the Role of Local Governance in Articulating Nexus Approaches to Energy Transitions**, Prof. Ed BROWN, UK Low Carbon Energy for Development Network, Jon CLOKE, John HARRISON & Richard SIEFF (all at Dept of Geography, Loughborough University, UK)

Selected Pieces of E. K. Ackom's Speech

Africa is rich in energy resource, yet poor in energy access – 'the 66 % issue':

— 66 % of SSA population have no access to electricity;
— 66 % of energy investments in SSA are for export rather than internal utilization (IEA WEO 2014).

Challenges for sustainable energy development in Africa:

— The seemingly lack of a strong political will to bridge the rural-urban access gaps;
— Lack of well-designed and implemented policies targeted at strengthening the institutional structures to promote expanding energy access;
— Lack of private sector involvement (uncompetitive tariff regimes – enabling framework is essential);
— Rural electrification and connecting the last mile (decentralization of energy systems holds good promise);
— Strengthening the existing grid;
— Electrification in informal settlements in peri-urban communities (a considerable and ever-growing population in developing countries).

Selected Pieces of P. Frix's Speech

Financial needs: (1) according to a 2015 McKinsey report "it would take US$ 490 bn to generate power and US$ 345 bn for transmission and distribution to meet the needs of the SSA region in the next 15 years"; (2) the AfDB estimates that it could cost $ 60 bn per year to achieve its target of providing universal electricity access by 2025. [...]

At EU level, up to now, the support has been channelled mainly in the framework of the Yaoundé (1963), Lomé (1975) and Cotonou (2000) conventions, in particular through the 'Energy Facility' financed by the European Development Fund and managed by DG DEVCO, and the 'Investment' and 'Infrastructure' facilities located at the EIB. [...]

Worth mentioning at African Union level is their Agenda 2063, the first ten-year implementation plan of the AU, approved in 2015 in Addis Ababa, with three objectives:

- To raise by at least 10 % the share of renewable energy (wind, solar, hydro, bio and geothermal) in total energy production;
- To reduce by at least 20 % proportion of fossil fuel in total energy production;
- To increase by at least 50 % electricity generation and distribution.

The fifth Africa-EU summit due to take place in November 2017 in Abidjan provides a critical opportunity to develop the Africa-EU partnership, particularly in the strategic fields of investment promotion in clean energy and energy efficiency.

Moreover, pros and cons of 'debt-for-development swaps' were discussed. These are financial transactions in which a portion of a developing nation's foreign debt is forgiven in exchange for local investments in development projects. The principle is as follows: a cooperation country undertakes to provide funding for development projects within its own borders; in exchange, the donor country grants debt relief for at least the equivalent amount. Debt swaps enable donor countries to target and foster measures and processes in the cooperation countries that make good sense in development terms. Debt swaps have proven to be an important instrument of development policy. *NB*: debt-for-nature swaps also exist; they usually focus on environmental conservation measures.

Selected Pieces of E. Brown's Speech

Issues treated within the context of 'nexus thinking' across water, food and energy sectors:

- How the various scales of governance interact with the energy, water and food sectors;
- How they might be most effectively coordinated;
- How institutional disconnect, power imbalances and the increasing complexity of greater cross-sector integration might be resolved.

Decentralization and energy: a 2009 UNDP study is the only significant work connecting the two areas. This study explored decentralization policy in over sixty countries and found explicit mention of energy issues in only four cases. Local governance of energy is clearly important and local authorities clearly do have important roles in relation to energy across the globe.

The challenge in decentralization is to think about the different energy needs of people at local level, *e.g.* household and institutional cooking and lighting needs, and not only large-scale electricity generation programmes and projects.

As far as practical experience with renewable energy and political decentralization is concerned, the focus was predominantly on Kenya, one of "the most rapid and ambitious devolution processes in the world" (World Bank 2015). *NB*: Kenya has a new Constitution since 2010 with new strong county governments.

TOPIC 2 – ENERGY MIX: TOWARDS ROBUST, EQUITABLE AND SOCIALLY ACCEPTABLE ENERGY SYSTEMS

Access to energy is not only related to availability of primary energy resources and secondary energy sources. Efficient technologies also should be made available to exploit these energy sources, particularly through modern infrastructures and equipment. Finally, specific energy services should be developed.

A number of lectures were dedicated to strategies and concrete achievements in Africa in connection with the energy value chain which is characterized by various conversion stages:

- Primary energy sources (*i.e.*, renewable, fossil and fissile);
- Secondary energy forms that humans can readily use (*i.e.*, energy carriers, such as electricity, refined oil products, charcoal, hydrogen);
- Infrastructures and, in particular, electric grid systems and electric equipment;
- Energy services for meeting the needs of a demanding and continually growing population.

Primary Energies

The pros and cons of each primary energy source in the requested energy mix were discussed in various lectures devoted to:

- Renewables (in particular, solar and wind power sources which are intermittent, unpredictable and non-dispatchable);
- Fossil fuels (*i.e.*, sources with limited reserves in time and space, and CO^2 emissions);
- Nuclear fission (subject to constraints such as robust regulatory framework for long-term operation and technical improvements regarding load following capacity).

Remarkable achievements referring to the above UN objectives were presented in the fields of renewable sources (intermittent as well as continuous such as hydropower and biomass), fossil fuels (in particular, gas) and nuclear fission (in particular, small modular reactors).

Secondary Energies (i.e., Energy Carriers)

Facts and figures were presented regarding electricity, refined fuels, charcoal and hydrogen (the latter in the long term).

Infrastructures, particularly Electric Grid Systems

Electricity systems require infrastructures in connection with production, transmission, distribution and retail. Several issues were debated at the Conference, such as:

- Decentralized ("small is beautiful") < = > centralized ("big is efficient");
- Rural areas < = > urban areas (megacities of over ten million inhabitants!);
- Domestic use < = > big industry.

Energy Services

A lot of attention was devoted to basic needs such as cooking, home comfort, lighting, transport, communication, etc.

Of particular interest in any access to electricity strategy is the issue of scales. Three increasing levels of energy access can be distinguished based on services made accessible, namely:

- Households and meeting basic human needs:
  - Electricity (50-100 kWhe/pers/yr): lighting, education, health and communication;
  - Modern fuel (580-1,100 kWhth/pers/yr): cooking and heating.
- Meeting the needs of productive use and economic activity:
  - Increasing the productivity of activities such as agriculture, trade, transport, etc.
- Meeting individual and collective needs in modern societies:
  - Home comfort (refrigeration and heating), sanitation, travels (2,000 kWhe/pers/yr).

> Reminder: electricity demand in sub-Saharan Africa is close to 400 kWhe/pers/yr. For comparison, the EU-wide consumption average in 2012 varied greatly between countries: from Romania (2,109 kWh/capita) to Finland (14,951 kWh/capita). Electric power consumption in Belgium in 2014 was reported at 7,709 kWhe/pers/yr (*source*: "Facts & Figures, ENERGY ACCESS, CURRENT SITUATION, CHALLENGES AND OUTLOOK", July 2014, ENEA Consulting (company providing energy transition and sustainable development consulting services to industry) [http://www.enea-consulting.com/wp-content/uploads/2015/05/ENEA-Consulting-Energy-access.pdf]).

In parallel to the above three increasing levels of energy access, a distinction should be made between off-grid, mini-grid or major grid:

- Off-grid systems at the scale of a household (< 500 We): appropriate for small populations living in remote rural areas distant from existing electrical grids (*e.g.*, solar home systems);
- Mini-grid systems at community level (30-500 kWe): appropriate for communities of a dozen to several thousand households in a rural area, partic-

ularly if the grid is far away from the target populations (*e.g.*, biomass power plants);

— Major grid systems needed for industrialized societies (up to several hundreds of MWe) are generally preferred in highly-populated urban and peri-urban areas, where population density allows economies of scale (*e.g.*, thermal power using fossil fuels or hydropower).

As a conclusion of this topic, access to energy is not only related to availability of primary energy resources and secondary energy sources which are just the front end of the value chain. Emphasis should be on the back end of the value chain (*i.e.*, energy services). What matters in any robust, equitable and socially acceptable energy system is the quantity and quality of energy services which are supplied to domestic and industrial users. Of particular importance in the selected energy mix is the triple challenge of: (1) security of supply (24/7/365) of usable energy, (2) which is physically and economically accessible to all, and (3) whose environmental impact is limited.

Invited Lectures

Topic 2 – Energy Mix

Monday afternoon 23 October

14:00	**Centralized and Decentralized Energy Solutions for Africa: Cutting-edge Technologies Supported by and Co-developed with the African Actors**, Bruno Bensasson, ENGIE, CEO Africa Business Unit, Paris
14:20	**Digital Solutions for Growth**, André Bouffioux, CEO Siemens Belgium-Luxembourg (also responsible for Algeria, Morocco, Tunisia and West-Central Africa) & François-Xavier Dubois, Head of Power Generation Large Projects, Siemens S.A./N.V., Brussels
14:40	**Integrating Climate into Strategy for an Oil & Gas Company: Focus on Africa**, Valérie Quiniou, Vice-President Climate-Strategy-Innovation, TOTAL S.A., Paris
15:00	**Sustainable Energy Mix for Africa and MENA Region Countries**, Prof. Idris Eisa El Tayeb, PhD Univ. of Reading (UK), National Energy Research Center, Khartoum, Sudan & Prof. Dr Mustafa El Tayeb, President of The Future University, Sudan, former director Division for Science Policy & Sustainable Development, UNESCO, corresponding member RAOS

Selected Pieces of B. Bensasson's Speech

Installation of centralized power will have to provide the competitive, low-carbon solutions Africa needs for its economic growth. We also see a role for the growth of natural gas in Africa in large LNG-to-power projects, but also small-scale LNG (liquefied natural gas) and gas distribution. African economies need energy services that will make their businesses more competitive, thanks to expert externalization. Development of decentralized innovative solutions will bring power — and beyond power, many applications: water, mobility, etc. — to rural Africa. As the access to power in rural Africa progresses, there will be a real need to also help larger cities tackle the challenges of a sustainable growth through the deployment of cutting-edge technology.

'Solar Home System' is the fastest and cheapest solution to meet the basic electricity needs in isolated areas. Beyond the drop in cost, the emergence of pay-as-you-go models is transforming the market. They enable customers to pay the upfront cost of a solar home system in affordable instalments over time and increase consumer confidence by shifting the risk of faulty technology to the supplier. This system allows households to start climbing the 'Solar energy ladder' (as their income rises, families and small businesses can afford larger systems).

Selected Pieces of A. Bouffioux' Speech (given by F.-X. Dubois)

The world has never been as closely connected — or as digital — as it is today. After electrification — the backbone of all industrial development — automation is making it possible to boost the effectiveness and reliability of industries across all sectors. And digitalization is opening up new perspectives towards yet unexplored business models. Remember the historical evolution towards Industry 4.0: industrial revolution no. 1 (= mechanics), no. 2 (= electro-mechanics), no. 3 (= automation) and no. 4 (= digitalization, integration and enhanced flexibility).

'MindSphere' (the cloud-based, open operating system for the Internet of Things (IoT) from Siemens) is one of their major business drivers in the years to come: it's not about technology, it's about a 'Mindset'. MindSphere is a centre-piece of a powerful ecosystem with data analytics and connectivity capabilities, tools for developers, applications and services.

NB: EconoFlex TM: 'Small-Scale Combined Cycle' (minimum 50 MW, 38 % efficiency) = flexible combined cycle power plant + suited as back-up to renewable power sources in the grid + 10-minute start, frequent starts and stops, fast load-following, employs a modular design, suitable for decentralized location in smart grid development.

Selected Pieces of V. Quiniou's Speech

TOTAL S.A. published after COP21 (Paris, 30 November – 12 December 2015) a high-level strategy document called "Integrating Climate into Our Strategy / Access to Energy – Focus on Africa", May 2017 [http://www.total.com/sites/default/files/atoms/files/integrating_climate_into_our_strategy_va.pdf].

One of the most ambitious objectives is to improve the carbon intensity of their current production mix (nearly 60 % gas in their production mix in twenty years' time). Following measures are announced: exiting the coal business; deploying an assertive strategy in gas, while strictly limiting methane emissions; selecting and developing safe, environmentally-responsible competitive oil and gas projects; innovating and expanding in carbon capture, utilization and storage technologies; publicly supporting the implementation of carbon pricing mechanisms; encouraging sector initiatives and collectively engaging to address climate issues.

The TOTAL Group strategy incorporates the challenges of climate change, using as a point of reference the 2 °C scenario of the International Energy Agency and its impact on energy markets. TOTAL's challenge is to increase access to affordable energy to meet the needs of a growing population, while providing concrete solutions to help limit the effects of climate change and supplying its clients with an energy mix featuring a progressively decreasing carbon intensity. Since 2011, the Group has been developing its off-grid solar product offering, and consequently has contributed to improve the lives of more than ten million people in some forty developing countries, chiefly in Africa.

Selected Pieces of I. E. El Tayeb's Speech

The International Renewable Energy Agency (IRENA) issued a report in 2015: "Africa 2030: Roadmap for a Renewable Energy Future" (in short, REMAP 2030). Several African countries have already succeeded in taking the necessary steps to scale up renewables, such as adoption of support policies, investment promotion and regional collaboration. The following success stories are mentioned: feed-in-tariff in Kenya; Tanzania's policy and regulatory framework to support small power producers; private participation in Rwandan hydropower development; solar water heater programmes in Tunisia; South Africa's solar water heater programme; biofuel blending in Mozambique.

Four success stories of renewable energy installations are worth reporting:

— Morocco: Ouarzazate Solar Power Station (OSPS), also called Noor Concentrated Solar Power (CSP) Station, is planned to produce 580 MW at peak when finished (the largest CSP in the world, covering an area of 30 km^2, total cost: \$9 billion). Phase 1 (Noor 1 CSP) has an installed capacity of 160 MW (connected to power grid in 2016, expected to deliver 370 GWh per year). The plant is a CSP of parabolic trough type with a molten salt storage for three hours of low-light producing capacity.

— Kenya: Lake Turkana Wind Power project (LTWP) is the single largest private investment in Kenya's history. The park will include three hundred and sixty-five wind turbines with 850 kW of unit power. The wind farm covers 162 km^2 and aims to provide 310 MW to Kenya's national grid, equivalent to approximately 17 % of the country's current installed electricity-generating capacity (completion by end of 2017).

— Egypt: planned to be one of the biggest wind farms in Africa, the Gulf of El Zayt Wind Farm project (200 MW) is being built on an area of 35 km^2 and is expected to be commissioned by the end of 2017. The wind farm will consist of a hundred wind turbines of 2 MW each (rotor diameter c.100 m) and is co-funded by the EU.

— Burkina Faso: Zagtouli solar photovoltaic power plant of 33 MW, located in a suburb of Ouagadougou (55 ha, started in November 2017). The solar plant is made up of one hundred thirty thousand polycrystalline silicon panels with a peak unit power of 260 W (maximum sunshine: 2,200 KWh per square metre per year), one thousand eight hundred structures of seventy-two modules inclined at fifteen degrees, and thirty-two one-MW inverters. These inverters are used to transform direct current into 33-kV (kilovolt) alternating current.

A 17-MW expansion is also planned for this site, financed by the European Investment Bank. Once operational, Zagtouli will be the largest photovoltaic power station in West Africa with an overall production capacity of 50 MW (poised to cover 5 % of national consumption).

Scientific Posters related to above Lectures on Topic 2

Private Sector Involvement in Energy Production: Experiences of the Belgian Development Agency from Rwanda and Mozambique, Muriel Lambert de Rouvroit, Frederik Van Herzeele, Benoît Legrand (as unit coordinator) & Paul Verlé (as head of department), all in Infrastructure and Environment Unit, Belgian Development Agency (BTC)

Collaboration between Northern and Southern Organizations with the Aim to Facilitate and Analyse Technology Impact on Society, Prof. Dr. Ir. Jean-Pierre Raskin (École polytechnique, UCL) & Stéphanie Merle (Louvain Coopération)

Barriers to the Uptake of Renewable Energy in the East Africa Region: An Enabling Environment, Access to Finance, Awareness and Access to Technical Support Services, Prof. Izael Pereira Da Silva, Deputy Vice Chancellor, Strathmore University (Kenya)

Mapping of the European Portfolio of Energy Development Cooperation on behalf of the EU Energy Initiative, Fiona D. Wollensack, EU Energy Initiative-Partnership Dialogue Facility (EUEI-PDF), Brussels, & Niklas Hayek, Africa-EU Renewable Energy Cooperation Programme (RECP) and EUEI-PDF, c/o Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Eschborn (Germany)

Agoria's Views and Technology Contributions for Energy and Sustainability in Emerging Countries (in particular, Africa), Christian Dierick, Lead Expert, Energy Technology Solutions, Agoria ("Development through technology"), Multisector Federation of the Technological Industry (Brussels)

Development of Advanced Energy Technologies in Africa: Success Stories obtained and Challenges left from both Technological and Managerial Points of View, Peter Koninckx, Director Power Generation for Belux, North Africa and West and Central Africa, Siemens n.v./s.a., Beersel (Belgium)

Modern Energy Strategy Implementation in Africa: Success Stories and Challenges left in terms of Central and Decentralised Power Generation, Integration of Renewable Energies, and Power Systems Interconnections, Joseph Dubois, Product Director of Tractebel (ENGIE)

Growth, Energy and Climate: Squaring the Circle, Philippe Charlez, Mining Engineer, Senior Technical Advisor, Energy Expert, Institut Sapiens, Paris (France)

Role of Renewable Energies in the Fight against Global Warming: The Context of Africa, Prof. Yezouma Coulibaly, International Institute for Water and Environmental Engineering (2iE), Ouagadougou (Burkina Faso)

Invited lectures

Topic 2 – Energy Mix (continuation)

Tuesday morning 24 October

BACKGROUND

09:00 **Towards a Global Partnership regarding Mineral Resources and Energy Production: Contribution to Sustainable Development with Focus on Africa**, Prof. Jean-Pierre Tshibangu Katshidikaya, Faculty of Eng., Mining Eng., UMons (Belgium), member RAOS

09:20 **Sustainable Energy Transition: An Operations Research Perspective**, Prof. Per Joakim Agrell, Co-Director “Center for Operations Research and Econometrics” (CORE), UCLouvain (Belgium), Prof. Anthony Papavasiliou, ENGIE Chair UCLouvain in Energy Economics and Energy Risk Management, & Ignacio Aravena, Senior Researcher

09:40 **On Power System Paradigm: Opportunities and Challenges**, Aymen Chaouachi, PhD, EGI (Elia Grid International, Brussels), Power System Operations & Security

10:00 **Energy Poverty in Africa: Focus on Challenges and Solutions related to Electric Power and to Energy for Cooking**, Prof. Samuele Furfari, Geopolitics of Energy, École polytechnique, ULB (Belgium)

10:50 **Renewable Energy Deployment in Africa: Opportunities, Challenges & Perspectives**, Dr Eng. Pépin Tchouate Héteu, Managing Director DEECC Consulting (Energy, Environment, Climate change mitigation)

11:10 **Steel: A Key Resource for a Sustainable and Circular Economy in Emerging Countries**, Carl De Maré, Vice-President ArcelorMittal, Group CTO, Head of Technology Strategy

Selected Pieces of J.-P. Tshibangu's Speech

The global demand for mineral resources and its economic impact has been growing at a high rate for about two decades (http://minerals.usgs.gov/minerals/pubs/mcs).

Successful industrial production involves the development of facilities to produce energy in such an amount as to comply with the level of activity.

The economic activity of African countries relies mostly on the production of raw materials from natural resources: agriculture or mining.

Specifically, the production of mineral resources and their transformation implies the use of large amounts of energy: power supply to mines, crushing and milling, smelting in furnaces, electrowinning in metallurgy,...

The mining sector has to face different challenges: (1) the increase of world population and the need to improve the living standards; (2) the limited high-grade resources (producing one tonne of metal then needs more energy); (3) the variability of prices on the global market.

Raw Materials Initiative in Europe – Relationship with Africa: EU is strongly dependent on imports for Critical Raw Materials (CRMs) for metals, industrial minerals and fuels. For example, Europe's dependency on metal imports in 2010 = 100 % for antimony, cobalt, ilmenite, molybdenum, Platinum Group Metals (PGMs), rare earth elements, rutile, tantalum and vanadium; = 70 to 90 % for most other metals.

EC report 2017: http://ec.europa.eu/growth/sectors/raw-materials/specific-interest/critical_fr

Conclusion: in a partnership with energy, the mining activities can play a triple role: as end-user, as producer and as actor in the development of renewable technologies (*i.e.*, lithium and cobalt for batteries). A sustainable development of Africa must include mining activities. The continent has a huge potential for mining development and is a major actor in the global mining economy. Despite big recent progress, investments in exploration and development remain limited for several reasons.

Selected Pieces of P. J. Agrell's Speech

Operations research for transitioning to future power systems in Africa: how do we expand the transmission grid to accommodate new projects and assess future demand? Transmission – Expansion – Planning (TEP) is a combinatorial problem: for one hundred candidate transmission lines, there are two thousand one hundred different possible decisions.

Case study – Scheduling solar energy storage in Burkina Faso: in September 2017, Burkina Faso commissioned the largest solar installation of West Africa, poised to cover 4 % of the country's national consumption. Solar power is only available in a cyclical and uncertain pattern, backed up with conventional generators, batteries. Using storage optimally can reduce CO^2 emission, reduce operation costs and improve reliability. The problem is similar to hydrothermal coordination: uncertain production (rainfall/cloudiness), storage (dams/batteries) and backup. Approach: using hydrothermal coordination algorithms (Stochastic Dual Dynamic Programming or SDDP) to schedule energy storage.

NB: hydrothermal coordination (HTC) means determination of thermal and hydro power in such a way that total system generation cost is minimum while meeting the system constraints.

Conclusion: operations research can be an enabling tool in the transformation of the African energy grid in the next ten to fifteen years: upgrading the current grid, operating the future power grid; operations research algorithms can provide significant advantages over heuristic decision policies.

Selected Pieces of A. Chaouachi's Speech

The electric power system is facing increasing stress due to fundamental changes impacting both supply and demand dimensions. On the supply side, a sustained shift from large synchronous generators to scattered smaller distributed energy resources, increasing penetration of non-synchronous power injection (HVDC or power park modules) and variable uncontrollable resources (wind and solar farms). To meet the demand, the EIA's 2016 Energy Outlook expects the total electricity generation to increase by 69 % by 2040 (predominantly in non-OECD countries). Furthermore, new concerns in terms of environmental impact stress the need to integrate higher shares of Renewable Energy Sources (RES), which still present major challenges with respect to investment, operational costs as well as their controllability.

Where to head for?

- External constraints: extreme growth in power demand; impressive demographic growth; need for access to electricity and higher living standards; lack of attractiveness for investors; limited financial resources; tariff reduction and loss of revenue; climatic challenges and scarcity of conventional resources; need for transparency and long-term vision.
- Internal constraints: low grid reliability and lack of generation adequacy; lack of usage of interconnections; management of both old and brand-new infrastructures; missing observability and information; high diversity of existing and new infrastructures; large territorial areas lacking harmonization; need for electrification of rural areas.
- Possible visions: (1) Bulk System Development: asset management strategy; cross-border interconnection; HVDC-based backbone network; energy market and balancing integration (cost-efficient system adequacy/benefit from high RES potential regions/social welfare maximization); (2) Decentralized System Development: asset management strategy; production closer to demand; smaller RES integration; micro-grids dominant electrification vector (cost-efficient RES integration/cost-efficient rural electrification/rural economic development),...
- Sustainable electricity: sustainability goes well beyond environmental considerations as it covers reliability and affordability all over the long term.

Selected Pieces of S. Furfari's Speech

A part of humanity is suffering from ‘energy poverty’. The situation is particularly dramatic in Africa. There is in the world 1.3 billion people who have no access to electricity. It is estimated that 2.5-3 billion have intermittent access. Few hours a day of electricity is infinitely better than those who have none at all. The average rate of access to electricity of sub-Saharan Africa is 35 %. In South Sudan, only 5 % of the population has access to electricity, in Burundi 7 %. In DRC it is 16 % while hydropower that could be produced on the Inga River would suffice for much of Africa.

But there is worse than the lack of electricity! After all, if we want to do without comfort we can do without electricity. But we cannot go without food. Cooking is therefore a necessity.

There are 2.7 billion humans who eat meals prepared with renewable energy only (wood, green wood cut by women and children, dried dung), sometimes with plastic bottles. This causes severe respiratory disease and premature death which are largely documented by WHO. Should Burundi deforestation continue at the current rate in order to obtain the necessary energy, its forests will disappear in twenty-four years.

These countries must grow and get out of this extremely precarious energy situation. Therefore, it is urgent that citizens, academics and policy makers get aware of this injustice and act quickly to end the scourge of fuel poverty in Africa.

Selected Pieces of P. Tchouate Héteu's Speech

Africa's energy poverty is a paradox:

— Gas: Africa is a NET LNG exporter;

— Oil resources are abundant: world = 2.6 trillion barrels; Africa = 0.23 => Share Africa = 8.8 %;

— Solar PV: average sun irradiation = 2,000-2,500 kWh/m²/y (as a result, 100-300 kWhe/m²/y on 47 % of SSA and 75-200 kWhe/m²/y elsewhere);

— Hydro: 280 GW, 10 % world resources [main rivers: Congo-Grand Inga (44 GW), Gabon (> 10 GW), Cameroon (> 20 GW), Nile-Ethiopia (> 30 GW); Zambezi-Angola (> 18 GW), Mozambique (> 12 GW); Niger-Nigeria (> 10 GW)].

Despite a quarter of the world's population estimated to live in Africa by 2050, only 25 % of the hydropower potential is expected to be tapped.

NB: Grand Inga requires about $ 50 bn, *i.e.*, 50 million shares @ $ 1,000 or 5 million shares @ $ 10,000 or 1 million shares @ $ 50,000 or 500,000 shares @ $ 100,000 + … …

Why will mini-grids play an important role in electricity access in Africa? Because they will tap into Africa's enormous renewable energy resources; allow faster deployment, more reliable than grid expansion; highlight real cost of electricity; drive new electrification policies and partnerships; stimulate electricity demand and productive use of electricity (PUE) in rural areas; drive economic development; prepare the ground for future grid expansion. NDLR-PUE can be found in agriculture (*e.g.*, irrigation, grain milling, electric fencing), manufacturing (*e.g.*, carpentry, tailoring, welding, and looming), and the service sector (*e.g.*, bars and restaurants using electric lights, sound systems, refrigerators, charging stations for mobile phones). Common applications include electricity used for drinkable water, public lighting, education, health (*e.g.*, refrigeration of vaccines and anti-venom), etc.

Selected Pieces of C. De Maré's Speech

— Steel is a key enabler for circular economy and cross-sectorial collaboration;

— Steel and climate: steel is responsible for 6 % of global emissions.

Practical example of sustainable steel industry in Brazil = ArcelorMittal Bio-Florestas (30 MWe plant): 'Mini-mill plants' for steelmaking: sustainable production of charcoal as fuel source while taking care of environmental and social issues in forest plantations.

Initiatives in energy efficiency (every thousand tons of charcoal produced can generate 1 MWe) and other sustainability pillars, such as social responsibility, especially for communities.

Three energy efficiency improvement projects:

— Smoke burner: combustion chamber to burn the carbonization residual gases by transforming methane into CO^2 (which becomes a renewable waste heat at 900 °C).

— Wood dryer: residual heat is recovered to decrease wood moisture, which reduces the need for energy during the carbonization process of charcoal.

— Energy cogeneration: benefits from residual heat generated by the smoke burner. A stove uses this residual heat and atmospheric air for superheating in an adapted gas turbine.

Carbon credit projects also are important. Three of them are now in progress: credit for forests planted to small and medium-sized farmers; credit for the replacement of coke by charcoal in blast furnaces; and credit for burning methane into production of charcoal.

Scientific Posters related to above Lectures on Topic 2

'Mini-Mill Plants' for Steelmaking: Sustainable Production of Charcoal as Fuel Source while Taking Care of Environmental and Social Issues in Forest Plantations, Paula Almado DE ROOSEVELT, Health and Safety, Environment and Forest Research Manager, ArcelorMittal BioFlorestas Ltda., São Geraldo, Martinho Campos (Brazil)

Industrial Waste Heat Recovery: Innovative Solutions for Steel Industry, Thomas STEINPARZER, Alexander FLEISCHANDERL, Manfred HASELGRÜBLER & Paul TRUNNER, Primetals Technologies, Linz, Austria GmbH (joint venture of Siemens, Mitsubishi HI and Co.)

Hydrocarbon Resources in the Democratic Republic of Congo: A Potential Source of Development for the Country?, Bernard RESPAUT, CEO European Copper Institute, Brussels

Invited Lectures

Topic 2 – Energy Mix (continuation)

Tuesday afternoon 24 October

HYDRO

14:00 **Hydro-electricity in Africa: Remaining Economically Exploitable Capacity and Impact Assessment Study (including Social Acceptance)**, Henri Boyé, USAID Electrification Advisor, & Michel de Vivo, General Secretary International Commission on Large Dams

14:20 **Inga: A Necessary Mega-Project that still needs to mature**, François Misser, journalist, independent researcher

14:40 **Using Small Low Cost, Robust and Easily Maintained Decentralized Hydraulic Power Stations in Central Africa**, Prof. Patrick Hendrick, Head of Department Aero-Thermo-Mechanics, École polytechnique, ULB (Belgium)

Selected Pieces of H. Boyé's Speech

Our planet Earth is increasingly in need of water and energy because of population growth and consumption, especially in developing countries. After COP21, the increased use of renewable energy is a necessity reinforced by the Paris Agreement. Among all renewable energies, hydropower is the most economic as it is competitive without expensive subsidies, and without intermittency or storage problems for power system operators. It also offers unique advantages for power grid management (frequency and voltage adjustment).

In addition, the need for freshwater, drinking water and irrigation will also increase with the expected climate change. Without water, there is no life on our planet. Freshwater resources are limited and poorly distributed. There are areas where water provision determines any improvement in living standards, currently too low, and even the survival of existing communities, as well as the satisfaction of the ever-increasing demand resulting from the rapid growth of their population. In these regions, the contribution of dams to the use of water resources cannot be dispensed with. We will have to increase our water resources and build new dams.

Water storage infrastructure is seen as an indispensable tool for both sustainable development and adaptation to climate change.

However, the development of dams is controversial in both North and South, because of potential impacts, and new projects often face strong opposition.

The social acceptability of dams is therefore a very important issue, and this speech attempts to provide some answers and reflections in terms of raising awareness on environmental and democracy issues, with examples of actions in developing countries.

Selected Pieces of F. Misser's Speech

The largest single hydropower site in the world, Grand Inga (planned final configuration: six plants with fifty-one units; total power: 42,000 MW; yearly energy production: 340 TWh) in DR Congo, has been endowed with a total potential of 40 to 44 GW, which accounts for about 40 % of the country's huge hydroelectric potential estimated at 100 GW. This huge potential has been explored since 1885, namely by a Belgian geographer called Alphonse-Jules Wauters (see also report in 1955 by Pascal Geulette, member of the Royal Academy of Colonial Sciences, *Considérations sur l'aménagement hydro-électrique du fleuve Congo à Inga*). So far, only a tiny share of the potential has been exploited with the construction of Inga 1 (351 MW, completed in 1972) and Inga 2 (1,424 MW, completed in 1982).

In 2013, the DRC and South Africa signed an international treaty for the development of Inga 3 Lower Fall (to be finalized by 2025), which included a power-sharing agreement (not yet accepted by the civil society): 2,500 MW for the main off-taker ESKOM (South Africa); 1,300 MW for Katanga province and the mining industry; 1,000 MW for the national utility SNEL. Total cost was then estimated at $ 11 billion by the World Bank including the transmission lines.

The government decided recently to double Inga's capacity. In July 2017, the Agency for the Development of Inga (ADPI) announced that the capacity of Inga 3 would be scaled up to 10,000 MW or 12,000 MW. ADPI's director, Bruno Kapandji, also announced that the two consortia, which bided for Inga 3, would merge and submit a common offer. Those are respectively: (1) a Chinese-led consortium called *Groupement Chine d'Inga*, which includes Three Gorges Corporation (22,500 MW dam for an estimated cost of $ 30 bn, generation of 98.8 TWh in 2014), Sinohydro, the State Grid International Corporation, the Chanjiang Survey Planning Design and Research Corporation and the Dongfang Electric Corporation; (2) a Spanish-led consortium called *Groupement pro-Inga*, which includes *Actividades de Construcción y Servicios* (ACS), Eurofinsa, AEE Power, Andritz Hydro of Germany, Andrade Gutierrez Engenharia SA of Brazil and… the China National Electric Engineering Corporation (CNEEC).

Social and environmental issues are in fact rather limited. The surface of the reservoir is fairly small, around 400 km², which is much less than the Aswan dam reservoir (built across the Nile in Egypt between 1960 and 1970, an area of 6,500 km²). Besides, evaporation levels are much lower. The number of people who should be displaced or affected is not so important for such a king-size project. A reinstallation plan of eight thousand people was considered by the World Bank two years ago. A final remark, however, is that the financial and technical parameters of the Grand Inga project might have to be amended according to climate change. Congolese hydrologists are expecting that Congo river flows will fall by 5 % between now and 2030 and even more afterwards.

Selected Pieces of P. Hendrick's Speech

Though the hydroelectric potential is huge in most African countries, it has been and is still poorly or non-adequately exploited.

One of the reasons is the incorrect use of a too heavily centralized hydraulic power generation and another one is that it's too expensive and too difficult to maintain small power generation units.

Two solutions bringing new technical and maintenance features are presented here. One of them is the old Archimedes' screw specifically designed for and used in turbine mode. This application is described for rivers in the Katanga province of DR Congo.

Advantages of the screw turbine: (1) design, construction and maintenance are simple; (2) significant reduction in the initial capital for civil engineering (which may represent up to 40 % of Small Hydropower (SHP) budget); (3) screw tolerates many impurities without affecting its functioning => coarse grids; (4) ecological technology is fish-friendly.

Example 1: Archimedes' screw: $P = 30$ kW; $\eta t = 86$ %; $De = 2{,}6$ m; $Nt = 26$ tr/min; three screws; inclination = 22° ("standard installation"). It was originally used to elevate water for irrigation as well as for drainage purposes. The Archimedes' screw turbine is an energy-related reversal of the Archimedean screw pump, invented in the mid-1990s with a generating capacity of around 4 kW. The generators' power outputs can now reach 140 kW. Specific investment costs range from 0.5 to 2 €/kwh and operating costs are comparatively low due to a wide screen spacing and the general robust structure.

Another solution is the very robust cross-flow or Banki-Michell turbine which is analysed for application in the Kayanza province in Burundi, *i.e.* electricity generation, by coupling to the national grid or autonomous production in isolated sites; hydromechanical application, by coupling to a mechanical device: pump, mill, heat pump, sawmill, etc.

Example 2: cross-flow turbine concept with fall height (low to medium) = 2.5 to 80 m; mass flow rate = from 30 to 600 l/s; mechanical power = from 2 to 120 kW; speed = from 200 to 1,100 rpm (these turbines advantageously replace the wheels of our ancestors).

Reference: BRESLIN, W. R. 1980. Small Michell (Banki) Turbine: A Construction Manual. Maryland (USA), Volunteers in Technical Assistance (out of a series of manuals primarily intended for use by people in international development projects) [https://pdf.usaid.gov/pdf_docs/PNAAP285.pdf].

Scientific Posters related to above Lectures on Topic 2

HYDRO

Variable-Speed Pumped Storage Bringing Flexibility to the South African Power System, Thomas MERCIER[1,2], Mathieu OLIVIER[2] & Emmanuel DE JAEGER[1]
[1] Mechatronic, Electrical Energy, and Dynamic Systems, UCLouvain (Belgium)
[2] Laboratoire de Mécanique des Fluides numérique, Université Laval, Quebec (Canada)

Archimedean Screw Turbine: Opportunity for Rural Electrification in DR Congo?, Prof. Jean-Paul KATOND MBAY, Université de Lubumbashi, DR Congo, & Prof. Patrick HENDRICK, Aero-Thermo-Mechanics (ATM), École Polytechnique, ULB (Belgium)

Small Hydropower Development in Burundi, Jean Bosco NIYONZIMA & Patrick HENDRICK, École Polytechnique, ULB (Belgium)

Invited Lecture

TOPIC 2 – ENERGY MIX (continuation)

NUCLEAR FISSION

15:00 **The Development of Small Modular Reactors for Emerging Nuclear Countries in Africa**, Peter BAETEN, Technical Manager MYRRHA Project, Belgian Nuclear Research Centre, Mol (Belgium) & Hamid Aït ABDERRAHIM, Deputy Director-General International Affairs, Belgian Nuclear Research Centre, Mol (Belgium)

Selected Pieces of P. Baeten's Speech

The renewed interest in nuclear power in Africa driven by a rapidly growing energy demand, persistent concerns over climate change and dependence on overseas supplies of fossil fuels has increased the prospects of considering this option in national energy strategies to ensure access to affordable energy for sustainable development.

NB: South Africa relies on some 1,800 MWe of nuclear capacity (built in the mid-1980s near Cape Town), which represents 5 % of their country's needs (or 2 % at continent level).

Many African countries have begun revisiting the nuclear option over recent years with a view to establishing long-term sustainable energy supplies. According to the World Nuclear Association (WNA), countries in the SSA region which are individually planning nuclear power are Ghana, Kenya, Namibia, Nigeria, Senegal, Tanzania, Uganda and Zambia. In North Africa, Egypt, Morocco, Tunisia and Algeria are also assessing the nuclear option.

A first prerequisite is the elaboration of national and regional planning for nuclear power development. Secondly, adequate legal and nuclear safety and security measures and infrastructures need to be installed. Thirdly, government leadership is necessary for the initial programme development, while continued government support is required throughout the life of the programme. Also, funding and financing during the initial programme development are necessary and critical. Moreover, in Africa the compatibility and integration in the electrical grid should be considered as an important infrastructure factor. Last but not least, one needs to address the human resource requirements of a nuclear power programme. Based on the previous considerations it is clear that large NPPs of 1,000 MWe and beyond are not so well suited to respond to the demand.

Small modular reactors (SMRs) with a typical power of maximum 300 MWe show the following benefits. First of all, in terms of electrical grid, SMRs are better suited to respond to: (1) electrical grids with limited capacity; (2) remote areas requiring smaller localized power centres to avoid long and expensive transmission lines; (3) geographically dispersed small- and mid-size urban centres; (4) incremental production capacity. Secondly, SMRs require a smaller capital investment cost and have the potential to reduce the cost uncertainties and construction timeframes associated with conventional NPPs. Because of their smaller size they could even be used in remote African locations.

Scientific Posters related to above Lectures on Topic 2

NUCLEAR FISSION

Nuclear Energy and Sustainable Development in Africa: Challenges and Ways Forward, Vincent Lukanda Mwamba, François Kazadi Kabuya, Commissariat général à l'Énergie atomique, Kinshasa (DR Congo) & Petrus Bompere Lemo, Comité national de Protection contre les Rayonnements ionisants, Kinshasa (DR Congo)

FUEL CELLS

Fuel Cells and Hydrogen for Emerging Countries: Flexible Devices for the Production of Sustainable Electricity in Africa, Dr. Jean-Luc Delplancke, Unité de recherche Materials Engineering, Characterization, Synthesis and Recycling (4MAT), École polytechnique, ULB (Belgium)

Invited Lectures

Topic 2 – Energy Mix (continuation)

SOLAR

15:50 **The Potential and Challenges related to Photovoltaic Electricity Generation and Local (DC) Microgrids**, Prof. Dr. Ir. Jozef Poortmans, Scientific Director PV@imec, Director R&D Strategy @EnergyVille and part-time Prof. KU Leuven and Univ. Hasselt (Belgium)

16:10 **The Value of Concentrated Solar Power for Developing Countries: Another Look on Energy Transitions**, Marcel Bial, Secretary-General European Solar Thermal Electricity Association

16:30 **Development of Solar Energy in Africa: A Challenge in terms of Resource Availability and Recycling**, Prof. Dr. Ir. Éric Pirard, Mineral Engineering, Materials and Environment, ULg (Belgium), member RAOS, & Dr. Ir. Sandra Belboom, Chemical Engineering, ULg (Belgium)

Selected Pieces of J. Poortmans' Speech

The presentation reviewed the technological and cost challenges related to the deployment of photovoltaic electricity generation. Thanks to the rapid price decline of PV generation the present levelized cost of electricity from PV source would be in the range of 4-7 €/kWh making PV economically perfectly conceivable. The presentation also highlighted the challenges related to the reliability of this electricity generation taking into account the specific climate over the African continent. From this it will become clear that reliability ensuring lifetimes longer than twenty years will require specific solutions for the tropical regions as compared to the subtropical regions.

However, even with all the solutions becoming affordable, large-scale deployment will also require the development of nano- and microgrids including local storage so as to deal with the intermittency of solar electricity generation. These nano- and microgrids could be based on DC solutions rather than pure AC as this could reduce the investment costs by 10-20 %. Such development is to be taken seriously as at least two thirds of the generation/load would be essentially DC-based (PV, batteries, LED illumination, ICT systems, ...).

Selected Pieces of M. Bial's Speech

Growth is at the beginning of the 21st century to a large extent achievable as 'green growth', based on an energy supply model designed as the most efficient combination of renewable sources. This will deliver reliability and affordability of a system, in which a centralized bulk energy supply to energy intensive industries will coexist with decentralized generation serving mostly local demand and 'circular' or 'participative' economy sectors.

The energy transition towards renewables that started in Europe is an irreversible process, even if the pace of this transition varies from country to country. It might of course just be accelerated or delayed by price swings on raw materials and fossil fuels or any major accident...

Countries in Europe claiming they can manage penetration levels of intermittent generation 'of nearly 100 %' either export system stability issues to their neighbours or manage such situations over short periods (sunny or windy weekends). This means that the reliability of a power system will soon no longer be managed at national level.

The good things ahead of us: (1) in this context, the supra-regional system responsibility (*i.e.*, the task of real-time balancing generation and demand) in today's power systems is to stay as the core task of Transmission System Operators (TSOs); (2) in order to manage intermittency of more generation sources, it will need to be increasingly coordinated with Distribution System Operators (DSOs) and new agents (independent power producers, 'prosumers', etc.).

The less good things ahead of us: (1) energy markets that are today largely financial markets cannot (by essence) and will not cover all value aspects; (2) current market mechanisms alone do not take into account externalized societal costs such as industrialization effects, business opportunities, health effects, dismantling costs, etc.

In conclusion, the best choice is to use Concentrated Solar Power (CSP) as soon as possible — as Morocco has impressively demonstrated (see Ouarzazate Solar Power Station, also called Noor Concentrated Solar Power Station). In doing so, people opt for a smooth energy transition based on a balanced technology mix made of non-intermittent generation technologies while incorporating commercially-proven bulk storage solutions.

Selected Pieces of E. Pirard's Speech

Photovoltaic (PV) panels take full advantage of the abundant sun in Africa and have several advantages such as the free cost of 'fuel' and no emissions during the production of electricity. These advantages are counterbalanced by the high amount of mineral resources needed, the lifetime of installations, the decreasing yield during operation years and the very limited recycling potential.

This study considers polycrystalline-silicon panels and highlights the advantages and drawbacks of PV as well as the limitations in the environmental evaluation of PV electricity production. Boundaries of the system will start with the production of the panel with the raw material extraction and will end with the end of its life. A special focus is put on the recycling of panels and the depletion of mineral resources. Silicon used in the photovoltaic panels is assumed to be produced from an inexhaustible source (silica sand), but only a very limited part of this resource is adapted to produce solar silicon.

As the amount of PV panels increases through the years, and their lifetime is about thirty years, some recycling routes should be implemented and should influence the design of panels to avoid a landfill at the end of their life.

NB: polycrystalline silicon is a highly pure, polycrystalline form of silicon, used as a raw material by the solar photovoltaic and electronics industry. It is produced from large rods, which are sliced into thin silicon wafers and used for the production of solar cells, integrated circuits and other semiconductor devices.

Scientific Posters related to above Lectures on Topic 2

SOLAR

Concentrated Solar Power, Battery Storage for Solar Photovoltaic (PV) Flexibility, Solar PV for Water Pumping, and Biomass: Solution for Sustainable and Flexible Power, Jean-Michel WAUTELET, CMI Solar, Seraing, Sébastien BORGUET, Mechanical Engineering Group Leader Hydrogenics, ULg, & Fabrice DELFOSSE, CMI Balteau (Cockerill Maintenance & Ingénierie SA), Sprimont

PV Generation Optimized for Remote Households in Central Africa, Maarten VERGOTE, Department of Physics, Royal Military Academy, Brussels, & Nathan WINDELS, Mathnasium of Saskatoon, Saskatoon (Canada)

Development of Energy Efficiency and Passive Technologies in Buildings for Improving Users' Comfort: Experience of the Belgian Development Agency in Uganda, Senegal and Palestine, Benoît LEGRAND (as unit coordinator), Paul VERLÉ (as head of department), both in Infrastructure and Environment Unit, Belgian Development Agency (BTC), & Jan VAN LINT, BTC (Uganda)

Affordable Mobile Solar Water Pumps for Small Farmers, Ahmed ABBAS, SunCity Energy, American University in Cairo (Egypt)

Invited Lectures

TOPIC 2 – ENERGY MIX (continuation)

Wednesday morning 25 October

BIOENERGY

09:20 **Wood: An Ever Present Domestic Energy Priority for People in Emerging Africa**, Jean-Noël MARIEN[1], Régis PELTIER[2], Émilien DUBIEZ[2], & Théodore TREFON[3]

[1] Retired Centre de Coopération internationale en Recherche agronomique pour le Développemen (CIRAD)
[2] CIRAD UR Forêts et Sociétés, Montpellier (France)
[3] Royal Museum for Central Africa, Tervuren (Belgium)

09:40 **A Locally Manufactured Gasification Technology for the Valorization of Agricultural Wastes in West African Countries**, Prof. Hervé JEANMART[1], Séverin TANOH[2], Wilfried OUEDRAOGO[3], Yohan RICHARDSON[2], Sayon SIDIBE[2], Frédéric BOURGOIS[1] & François PINTA[4]

[1] UCLouvain, Louvain-la-Neuve (Belgium)
[2] Institut international d'Ingénierie de l'Eau et de l'Environnement, Ouagadougou (Burkina Faso)
[3] Institut de Recherche en Sciences appliquées et Technologies, Ouagadougou (Burkina Faso)
[4] CIRAD, Montpellier (France)

Selected Pieces of R. Peltier's Speech

The sustainable management of wood-energy resources is possible and is one of the keys for the future. Here are presented some of the results of the Makala project, a EU-funded programme in DRC and Congo-Brazzaville from 2008 to 2014 (Makala project: www.makala.cirad.fr – EU EuropeAid DCI-ENV/2008/151-384). The project has developed on a large scale various operational tools for a sustainable wood resource management. These range from simplified, but efficient, management planning for rural communities, to various methods to create or regenerate a large area producing wood resources through the natural regeneration of degraded forests, agroforestry systems, or the plantation of fast-growing species. Achieving a more efficient carbonization process is another important issue. The feasibility of improved stoves also was discussed.

Our vision: given that urban population growth will in many cases lead to an increase in household energy requirements which will surpass what can be provided by tree formations, the authors argue that planners should consider the development of energy mixes that combine the sustainable production of wood energy with a partial transition to other energy sources (fossil, hydro-electricity, solar or biomass). The importance of carbon economy was also discussed by examining some international processes as the REDD (Reducing Emissions from Deforestation and forest Degradation) initiative or Green Fund for the Climate (UN).

To put it very simply, REDD involves some kind of incentive for changing the way forest resources are used. As such, it offers a new way of curbing CO_2 emissions through paying for actions that prevent forest loss or degradation. These transfer mechanisms can include carbon trading, or paying for forest management.

There is as yet no formal mechanism for REDD with international recognition under the Kyoto Protocol, but voluntary REDD projects are starting round the world.

Selected Pieces of H. Jeanmart's Speech

Rural populations in Africa depend almost exclusively on woody biomass to meet their energy needs, which are usually limited to cooking and some food processing.

Nevertheless, this limited use together with the biomass exported to the cities lead to an unsustainable pressure on resources. At the same time, agricultural activities lead to the production of large quantities of residues (cotton stalk, rice husks, etc.).

These wastes have an energetic potential that could be exploited locally. But, contrary to woody biomass, the combustion of these residues is complex. Gasification could help convert efficiently these residues into more useful forms of energy: not only heat but also electricity. Downdraft fixed-bed gasifiers are the most suitable technology for the range of power (50 => 200 kWth) and feedstocks considered. While gasification could significantly improve the access to energy in rural areas, the imported technologies (*e.g.* from Europe and India) are too complex and thus not resilient.

Existing local technologies do not sufficiently take into account the peculiarities of the gasification process and of the available feedstocks. A technology designed to be efficiently manufactured, operated, and maintained locally could overcome the barriers that prevent the development of gasification in rural areas of West African countries.

Such a concept entails many challenges. The characteristics of feedstocks, especially the moisture and ash content, may vary a lot. The quality of the available steel makes it unsuitable for high temperature processes and prone to corrosion. The local manufacturing techniques must be adapted to produce airtight vessels from available parts. The cooling and cleaning requirements for the syngas must be matched without producing hazardous liquid effluents. However, the numerous challenges can be overcome with suitable designs for the different parts of the gasification facility.

After a description of the potential contribution of agricultural wastes to the energy needs in rural Africa, these challenges were detailed and illustrated with results, including experimental data taken from the development steps of a gasification technology manufactured in Burkina Faso for the production of heat and electricity.

Scientific Posters related to above Lectures on Topic 2

BIOENERGY

The Cogeneration in Sugar Mill: An Energetic Deposit Opportunity for Sustainable Development in Sub-Saharan Africa, Pierre KANA-DONFACK, César KAPSEU & Denis TCHEUKAM-TOKO, University of Ngaoundere (Cameroon)

ECOmakala: Meeting Energy Needs, Fighting Poverty and Protecting the Forests of the Virunga National Park, Eastern Democratic Republic of Congo, Mone VAN GEIT, International Programs Manager, World Wide Fund for Nature, WWF-Belgium (Brussels)

Scientific Posters not directly related to any above Lecture

MISCELLANEOUS

Science and Diplomacy in Central and Western Africa: Remarkable Achievements and Challenges, César KAPSEU, Department of Process engineering, University of Ngaoundere (Cameroon) & Liliane D. T. ATOUKAM, Faculty of Arts, Humanities and Social Sciences, University of Ngaoundere (Cameroon)

Zero Emissions Energy in an African Context, Tim BERCKMOES, CEO, Managing Director Anglo Belgian Corporation, Ghent (Belgium)

Use of Distributed Generation to improve Operation of Overloaded Grids in Africa, Marien OKANA NSIAWI OTIIN[1], Laurent Kitoko[2], Pascal KAMABU TSONGO[1] & Ali ATUNDEZI GAHUMA[3]

[1] Laboratoire de Génie électrique, Département d'Électricité, Faculté polytechnique, Université de Kinshasa (RD Congo)

[2] Director SNEL (Société nationale d'Électricité), Kinshasa Gombe (RD Congo)

[3] NTIC-Acteurs RDC, Kinshasa (RD Congo)

Linking Sustainable Energy with Soil Health and Carbon Sequestration through Frugal Innovation, Venkata RAMAYYA ANCHA, Institute of Technology, Jimma University, Addis Ababa (Ethiopia)

Sustainability of Solar Mini-Grids in Nigeria, Adedoyin ADELEKE[1], Chuks DIJI[1] & Debora LEY[2]

[1] Centre for Petroleum, Energy Economics and Law, University of Ibadan (Nigeria)

[2] Central America Regional Clean Energy Initiative, Guatemala City (Guatemala)

Sustainable Path for Renewable Energy Promotion in African Rural Areas, Dr. Marthe Djuikom Vandenbergh, FERDEDSI/IPEED (Institut populaire de l'Eau et l'Energie pour le Développement)

EU-Africa Research & Innovation Partnership on Climate Change and Sustainable Energy – A RINEA Technical Paper for Priorities, Arthur Guischet[1], Mokhtar Sellami[2] & Jean Albergel[1]

[1] IRD (Institut de Recherche pour le Développement), South African Department of Science and Technology (DST)

[2] MESRS (Ministère de l'Enseignement supérieur et de la Recherche scientifique), Alger (Algeria)

Topic 3 – Research, Innovation and Education in Support of Sustainable Energy Policies

In order to support any energy policy it's very important to continuously improve research, innovation and higher education programmes, thereby training a new generation of energy experts, able to identify the energy challenges in their country and to come up with robust solutions adapted to local conditions.

Invited Lectures

Topic 3 – Research, Innovation and Education in Support of Sustainable Energy Policies

Wednesday afternoon 25 October

13:30 **MOOCs for Africa: Lessons Learned**, Dr Dimitrios Noukakis, Center for Digital Education (including *MOOC Afrique*), École polytechnique fédérale de Lausanne (EPFL), & Prof. Pierre Dillenbourg, EPFL, Academic Director Center for Digital Education (MOOC Factory)

13:50 **Massive Open Online Courses: An Answer to the Issues Facing Higher Education in Sub-Saharan Africa?**, Nicolas Roland ('ULB Podcast'), Éric Uyttebrouck, Cellule PRAC-TICE (Pédagogie, Recherche-Action & TICE), ULB, & Prof. Philippe Emplit, DSAA (Département de support aux activités académiques), ULB

14:10 **Sharing Knowledge Online and Improving Education Using MOOCs**, Prof. Sandra Soares-Frazão & Emer. Prof. Yves Zech, Institute of Mechanics, Materials and Civil Engineering (IMMC), UCLouvain

Selected Pieces of D. Noukakis' Speech

The African (un)employment paradox!

- — 2.5 million engineering jobs to be filled in sub-Saharan Africa;
- — 60 % of unemployed are university graduates!

Le Réseau d'Excellence des Sciences de l'Ingénieur de la Francophonie (RESCIF) a été créé en 2010. Il met en œuvre une coopération novatrice, ciblée et durable entre quinze universités technologiques francophones visant à répondre à certains défis majeurs des pays émergents et en développement. Il s'agit de travailler sur cinq thèmes essentiels pour l'avenir: l'eau, l'énergie, la nutrition, la sécurité alimentaire et l'urbain. Des secteurs cruciaux, plus spécialement pour certains pays du Sud, soumis à des conditions climatiques et à des problèmes de sécurité alimentaire extrêmement difficiles.

Le RESCIF travaille en partenariat avec l'Agence universitaire de la Francophonie (AUF) et développe avec elle un guide des bonnes pratiques en matière de partenariats technologiques destiné à l'ensemble des universités émergentes de la francophonie.

Des centres de compétence ont été mis en place dans chacune des institutions membres. Leur but est de développer des MOOCs (*Massive Open Online Courses)* localement et d'assurer ainsi leur pérennité. Trois institutions ont été sélectionnées pour développer les trois premiers centres (*MOOC factories*): l'École supérieure polytechnique (ESP) de Dakar, Sénégal, l'École nationale supérieure polytechnique de Yaoundé (ENSPY), Cameroun, et l'Institut national polytechnique Félix Houphouët Boigny (INP-HB), Yamoussoukro, Côte-d'Ivoire (http://www.rescif.net/fr/content/moocs).

Liste des quinze universités francophones issues de douze pays différents d'Afrique, d'Amérique, d'Asie, d'Europe et du Moyen-Orient:

- — École nationale supérieure Polytechnique de Yaoundé, Cameroun;
- — École Mohammadia d'Ingénieurs, Université Mohammed V, Rabat, Maroc;
- — École normale supérieure de Lyon, France;
- — École polytechnique fédérale de Lausanne, Suisse;
- — École polytechnique Montréal, Canada;
- — École polytechnique Paris-Saclay, France;
- — École supérieure polytechnique, Université Cheikh Anta Diop de Dakar, Sénégal;
- — INP Grenoble, France;
- — Institut international d'Ingénierie de l'Eau et de l'Environnement (2IE), Ouagadougou, Burkina Faso;
- — Institut national polytechnique Félix Houphouët-Boigny, Yamoussoukro, Côte-d'Ivoire;
- — Université polytechnique de Hô-Chi-Minh-Ville, Vietnam;
- — Université catholique de Louvain, Louvain-la-Neuve, Belgique;
- — Université d'État d'Haïti, Port-au-Prince, Haïti;
- — Université Quisqueya, Port-au-Prince, Haïti;
- — Université Saint-Joseph de Beyrouth, Liban.

Selected Pieces of N. Roland's Speech

Massive open online courses (MOOCs) are representing nowadays a global phenomenon in the education and distance-learning fields. Following the success of these courses on the African continent, the study *MOOC Afrique: analyse des besoins, étude de faisabilité et recommandations* by N. Roland, M. Stavroulakis, N. Francois & P. Emplit, 2016 (http://podcast.ulb.ac.be/site/recherche-MoocAfrique.html) provides a state of the production and usage practices of these MOOCs in sub-Saharan Africa — supported by study visits in Senegal and Cameroon — and looks at how they can provide a relevant answer to the issues facing higher education. Moreover, this research initiates reflections on the quality of education and its control so as to deploy such schemes in the African context.

The authors also describe the main recommendations provided by their research in order to offer solutions (in technical, educational and development terms) that are adapted, perennial and promoting the empowerment of local populations in the development of distance learning and MOOCs, namely:

— Recommendation 1: adopt, within universities, a technological equipment approach based on user's needs;
— Recommendation 2: develop technological solutions for teaching and learning adapted to the sub-Saharan African context;
— Recommendation 3: develop teachers' training programmes for digital university education;
— Recommendation 4: develop educational support units in universities;
— Recommendation 5: develop facilities to support students at university;
— Recommendation 6: develop, in online courses, support and support spaces for students;
— Recommendation 7: create a network of universities for the development of educational innovation in sub-Saharan Africa;
— Recommendation 8: encourage the production and dissemination of Creative Commons licensed resources;
— Recommendation 9: promote and support the development of innovations in digital university education;
— Recommendation 10: implement a policy of skill recognition through massive open online courses;
— Recommendation 11: develop a research-action component on effectiveness and satisfaction with the different types of educational innovation devices.

Selected Pieces of S. Soares-Frazão's Speech

The development of Internet offers a wide range of new opportunities for the world of education. Massive Open Online Courses (MOOCs) are developed by several international renowned institutions in different fields related to their course programmes. A MOOC is typically conceived as a series of short videos where the professors explain the key topics of the course, complemented in some cases with additional documents to be read by the learners. Associated to the videos, exercises are provided, mostly under the form of quiz, to check the understanding and progress of the learner.

Such open courses, which can generally be followed free of charge, are really an opportunity for southern countries: with this new, up-to-date and interactive material, students and learners from these countries can access knowledge that was before restricted to a limited number of institutions.

Of course, this new world of knowledge also opens new questions, especially about evaluation and certification. What is the real value of a certificate delivered after completion of a MOOC? How to be sure that the person registered to the MOOC is the right real person who completed the graded activities? Then, in southern countries, a frequent concern of the professors is the possible loss of responsibility and power of decision in the evaluation process. Can the professors still decide whether a student passes or not? Will all professors be replaced by computers? Technical issues also arise: following a MOOC usually requires a good quality Internet connection to watch the videos, download additional course material, participate in forum activities and discussions and perform the graded assignments. Can such an Internet connection be guaranteed all over the world? Certainly not.

To propose adapted answers and solutions to all these questions, a new and innovative way of thinking teaching activities is required. Based on the recent experience of a MOOC in fluvial hydraulics developed at the *Université catholique de Louvain* in collaboration with the State University of Haiti, which was followed by a large number of learners issued from southern countries, these questions are discussed with the aim of proposing possible solutions for making these new technologies affordable and useful to anyone in the world.

Concluding Session: Two Keynote Speeches

14:50 **Measuring Sustainable Energy Projects to Orient Strategies for Meeting People Needs, and a New Role of Science**, Prof. Emanuela Colombo & Dr Lorenzo Mattarolo, UNESCO Chair in Energy for Sustainable Development, Department of Energy, Politecnico di Milano, Milan (Italy)

15:10 Panel with session chairpersons, including brief presentations from the floor (representatives of EIB, 3E, 2IE, etc.)

EIB Financing of Sustainable Energy in Africa, Monica Peña Sastre, European Investment Bank (EU Bank)

Accelerating the Energy Transition in Africa: Feasibility and Development. Resource Assessments, Lender's Technical Advisory, Owner's Engineering, Geert Palmers, CEO of 3E (technical consulting, software and strategy for sustainable energy development worldwide)

Perspectives and Suggestions for the Solution of Energy Problems in Africa through a Rapid Development of Renewable Energies, Prof. Yezouma Coulibaly, International Institute for Water and Environmental Engineering (2iE), Ouagadougou (Burkina Faso)

16:00 **Closing Remarks**, Jozef Smets, Ambassador, Director Sub-Saharan Africa, Belgian Ministry of Foreign Affairs, representing Didier Reynders, Deputy Prime Minister and Minister of Foreign Affairs and European Affairs

16:20 **Conclusion**, Scientific Conference Committee (Georges Van Goethem)

16:30 Closure of Conference

Selected Pieces of E. Colombo's Keynote Speech

Science as unusual! = > *e.g.* multidisciplinary approach, ethics, science diplomacy (beyond traditional mission, while preserving science independence!).

Concerns about overexploitation of resources: human and economic activity goes along with the capacity of using natural resources.

The concern about overexploitation of natural resources has come to be global: they are limited; their misuse affects the environment; the non-equitable distribution affects international security.

Why is it so difficult to scale up successful strategies that can keep pace with population growth? Reasons are different and worth a deep analysis which may also vary from country to country. However, there is a common and general perspective that is shared by the majority of researchers in energy access: we need to know more in detail the effects of any energy strategy in order to better distil the best practice and drivers of success and, equally important, be able to dig bad practices and the reasons for failure.

Given this framework, a proper evaluation metric able to assess the effects of energy projects on the changes of community livelihoods and the positive effects on social, economic and environmental levels is strongly needed to assess future strategies and policies.

Relying on some recognized evaluation frameworks, such as the OECD-DAC criteria (relevance, efficiency, effectiveness, sustainability and impact) and the process perspective of the World Bank Institute's Results Chain (input, activities, output, outcome, impact), our research provides a framework for 'performance and impact assessment' of energy projects.

This approach is structured in two phases:

— A project-based step, which assesses projects in terms of process performance. In the first phase, four OECD-DAC criteria may be calculated with common metric (adopting exergy-based technique or recent Life Cycle Analysis extensions). In this way, a 'proxy' of the total (non-renewable) primary resources undertaken during the project may be captured. So, different projects may be compared in terms of efficiency or effectiveness (and other DAC criteria). This step gives a measure of the performance of the project in terms of resources consumed to obtain a given set of results, creating a database of benchmarks and standards.

— A people-based step, which assesses the project impact on the beneficiaries. The second phase aims at measuring the effects of the project on local livelihoods, assessing in terms of target community's capitals, like natural, physical, human, social and financial aspects. Taking the original idea from the 'Sustainable Livelihoods Framework', the methodology proposed for impact assessment requires an application procedure where the definition of the evaluation hierarchy, often done via knowledge-based approaches, represents a crucial step.

Application has been conducted on real case studies by private players, public institutions and NGOs in Malawi, Ethiopia and Chile. Currently POLIMI is working with the 'Energy Sector Management Assistance Program' (ESMA, World Bank) and Enel Foundation to evaluate synergies between Project Influence Area (PIA) and the Multi-tier Framework (MTF).

Impact on development cannot be reduced to a single quantitative number or compressed within an engineering procedure, but rational methodologies may help policy makers or donors to better assess their decision and evaluate long-term strategies in order to fasten the process toward universal energy access to all.

Selected Pieces of J. Smets's Concluding Keynote Speech

Joint action to strengthen sustainable management of natural resources is one of the prominent flagships as listed out in the 'Joint Communication for a Renewed Impetus of the Africa-EU Partnership', adopted in May 2017 by the EU. This Joint Communication is in fact a strategy document.

Out of this list, one of the prominent flagships is the following: "to launch a new EU-Africa Research and Innovation Partnership on climate change and sustainable energy".

Throughout my different mandates in Africa, I could observe from nearby the huge challenges and problems but also the high potential in the sector of sustainable energy and what we call here "a sustainable energy mix".

We have to look at the African continent in a different and innovative way, and this must be reflected at all levels, including the level of EU-African relations, a fast-evolving framework where my country is a prominent actor. It is within this context that we are also looking these days at the future of the Cotonou agreements while the debate on "Post-Cotonou" is going on and the stakes are high.

Belgium is one of the EU member states in favour of the continuation of an ambitious relationship between Europe and the ACP countries, whereby we would like to see the three regional pillars (Africa, Caribbean and Pacific) to become more prominent. For us, the African pillar would be a priority. So, we want to move towards a legally-binding, ambitious and at the same time more efficient and adapted partnership. This has to happen at the UN level. But it should also happen as part of the EU-Africa relations.

I would like to plead in favour of the drafting of a short policy document that would reflect the main conclusions of this conference and that would give guidelines to our governments and policy makers. For our part, we would commit to raising awareness on such a document and its conclusions and to sharing it with our European partners. We could even organize together a follow-up round table.

ACKNOWLEDGEMENTS

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— Prof. Dr. Nathalie Verbruggen, member RAOS, Laboratoire de Physiologie et de Génétique moléculaire des Plantes, Université libre de Bruxelles;

— Prof. Dr. Ir. Éric Pirard, member RAOS, Mineral Engineering, Materials and Environment, Université de Liège;

— Prof. Dr. Pierre Petit, member RAOS, Laboratoire d'Anthropologie des Mondes contemporains, Université libre de Bruxelles;

— Ir. Christian De Meyer, member RAOS, École polytechnique fédérale de Lausanne (EPFL) and Columbia University, USA;
— Prof. Dr. Ir. Jean-Pierre Tshibangu Katshidikaya, member RAOS, Head Department of Mining Engineering, Faculty of Engineering, Université de Mons.

— Dr. Ir. Pépin Tchouate Héteu, DEECC Consulting (Energy, Environment, Climate Change mitigation);
— Prof. Dr. Wail Benjelloun, President Mediterranean Universities Union (UNIMED);
— Prof. Idris Eisa El Tayeb, PhD University of Reading (UK), National Energy Research Center, Khartoum (Sudan);
— Prof. Dr. Izael Pereira Da Silva, Deputy Vice-Chancellor, Strathmore University (Kenya);
— Dr. Emmanuel Kofi Ackom, UNEP, DTU Partnership, Technical University (Denmark);
— Jean Albergel, Senior Scientist, Coordinator of European Affairs, CNRS-IRD Joint Office in Pretoria (South Africa);
— Prof. Ed Brown, UK Low Carbon Energy for Development Network.

Especially helpful to me during the preparation of this conference were:

— Prof. Emanuela Colombo, member RAOS, UNESCO Chair in Energy for Sustainable Development, Politecnico Milano (Italy);
— Ir. Bernard Mairy, Executive Director European Society for Engineers and Industrialists (SEII).

Policy Note

International Conference
Sustainable Energy for Africa
Royal Academy for Overseas Sciences
Brussels, 23-25 October 2017
pp. 295-300

Science Diplomacy: Added Value for our International Policy? ("Science as unusual – Diplomacy as unusual")

(Policy note requested by Belgian Federal Public Service
"Foreign Affairs" as follow-up of subject conference)

by

Georges Van Goethem[*] & Philippe Goyens[**]

In 2017, the Belgian Royal Academy for Overseas Sciences (ARSOM-KAOW, or RAOS in English) organized a conference, "Sustainable Energy for Africa", jointly with private and public European and African bodies involved in energy issues.

It hosted approximately one hundred and fifty participants from twenty-five countries.

The conference provided an opportunity for several universities and research centres (as well as some NGOs) from Belgium and elsewhere to present their scientific expertise and specific strategies regarding the development of sustainable energy in Africa.

The conference came up with a number of avenues to be explored about the role of diplomacy via science in the field of international relations, a key subject for Belgian policy which can be summed up in a three-point 'policy note', as discussed below:

- Scientific research, a response to the specific needs of developing countries?
- Science diplomacy, added value for our international policy?
- Role of the Royal Academy for Overseas Sciences in Belgian policy.

These three points are illustrated in the text below with reference to ten speakers' presentations.

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[*] Member of the Academy; co-organizer of the conference "Sustainable Energy for Africa" (23-25 October 2017).

[**] Member of the Academy, former Permanent Secretary.

Scientific Research, a Response to the Specific Needs of Developing Countries?

On the one hand, all over the world, every day, scientists, engineers, technicians and healthcare professionals demonstrate what we feel instinctively — that the pace and impact of research and technological innovation are dizzying.

On the other hand, population growth, the escalation of climate change and increasing inequality across the world are leading to upheavals in human needs, such as energy, water, food, healthcare, housing and education. This can put a serious strain on international relations. Meeting these needs gives rise to social and environmental problems, with implications for political governance. These problems can take quite different forms from one country to another, and can be particularly tragic in developing countries.

Ref. 1: "Development of sustainable power systems in Africa: external and internal constraints", Aymen Chaouachi, Elia Grid International, Brussels

It is also clear that in various scientific fields, leading-edge ideas and projects can come from anywhere — not only from the best laboratories and think tanks, but also from local communities, *i.e.* a bottom-up approach. Projects together with research centres in developing countries have proved successful, for example those of the *Coopération technique belge* (CTB/BTC), the Belgian Development Agency, and various NGOs which contribute their scientific and technical expertise to development schemes and international cooperation. It is worth remembering that Belgian cooperation has a long tradition of support for applied research in the fields of medicine and agriculture, both directly within bilateral projects and indirectly via international research organizations such as the CGIAR (Consultative Group on International Agricultural Research).

It is noteworthy that the Belgian Development Agency was renamed Enabel on 1 January 2018, the new name evoking the English verb 'to enable' and reflecting the priorities of Belgian aid — making people more resilient, favouring development and bringing partners together. As Deputy Prime Minister Alexander De Croo explained in his policy address:

> Those who want to move forward but who lack the means, knowledge or capacity will get a helping hand from our country [https://www.enabel.be/fr/content/enabel-rebaptisee-enabel-au-1er-janvier-2018].

Ref. 2: "Success stories of renewable energy installations in Africa" Mustafa El Tayeb, The Future University (Sudan), corresponding member RAOS & Idris El Tayeb, National Energy Research center, Khartoum (Sudan)

Working together with field workers, the world of research and, in particular, science academies can play an important part in identifying promising technological innovations and implementing them on behalf of the companies involved.

This requires bridge building between, on the one hand, politicians and diplomats who know developing countries well and, on the other, researchers who are well informed about scientific progress in the technical and other fields referred to above.

Ref. 3: "Africa is rich in energy resource, yet poor in energy access – The 66 % issue", Emmanuel Kofi Ackom, UNEP, UDP Partnership, Technical University Denmark

International scientific cooperation can contribute to the development of academic and technological careers in the fields of engineering and public health, which will make it possible for new generations in developing countries to excel at a global level. In this way, these new generations of experts will acquire the skills necessary for dealing with various problems at local and global level, while at the same time being involved in the development of their national economies. Threats to look out for, however, are the 'brain drain' and the export of unprocessed primary products from developing countries.

Ref. 4: "Role of mining activities in the development of renewable technologies (e.g. cobalt for batteries)", Jean-Pierre Tshibangu Katshidikaya, Mining Eng., UMons (Belgium), member RAOS

Science Diplomacy, Added Value for our International Policy?

Science diplomacy, as the name suggests, lies at the interface between two fields, that of diplomacy (the implementation of a country's foreign policy by means of dialogue, negotiation and, where relevant, development aid) and that of science (in the broadest sense of the word, referring to the activities of training, research and innovation in different fields), involving an exchange of knowledge and skills.

Ref. 5: "African universities and science diplomacy in favour of alternative sources of energy", Wail Benjelloun, President UNIMED (Mediterranean Universities Union)

In ancient history, sciences were virtually always used as a vehicle for winning wars or gaining economic advantages, and only rarely for the good of society as a whole (with the exception of medicine of course). However, science can be used in quite another way, as was shown at the end of World War II. Science diplomacy was a central objective when Unesco, the UN body responsible for education, science and culture, was founded in 1945. More recently, during the Cold War (1947-1991), elementary particle physics laboratories on either side of the 'iron curtain' freely exchanged the results of their research (with the agreement of their respective governments). At the time, this certainly helped to make international scientific cooperation a tool for peace between the two opposing blocs (Western and Soviet). We should remember that, alongside science, diplomacy also uses the 'services' of culture (in parallel with state 'hard power', a more cultural 'soft power' has emerged) and sport (the Greek Olympic Games tradition was revived in 1896 by P. de Coubertin).

These days, in a number of countries, cooperation between scientific communities and the world of politics is increasingly and generally shifting in the direction of 'soft power'. No longer is it just about cooperation — albeit rather tentative — on highly specific matters (*e.g.* elementary particle physics). What is needed is a three-pronged approach in which open-minded researchers and diplomats work proactively, keeping in mind the objectives of serving national or European interests:

- Developing knowledge and promoting the scientific community on the international scene by facilitating cooperation with other countries (by means of university exchanges of the Erasmus Mundus type and major international research infrastructures such as CERN and ITER).
- Seeking the input of researchers to provide insight into, or address issues of, international importance, such as climate change, human health, education and access to energy, water and food (in line with the United Nations' 17 Sustainable Development Goals Agenda 2030).
- Taking the initiative in diplomacy between countries with sharply conflicting ideologies and political systems. Examples are certain European Union international research projects, one of which is SESAME ("Synchrotron light for Experimental Science and Applications in the Middle East", Jordan, 2017).

In this new context of 'soft power', scientific communities and the political world are seeking more effective ways of bringing together all parties concerned. These may be in the public sector (*e.g.*, universities and research centres) or in the private sector (*e.g.*, a business partnership contributing to a balanced, *i.e.* mutually profitable, economic cooperation programme). They may also be joint public-private (for example, the public-private partnership BIO, Belgian Investment Company for Developing Countries). It is also necessary to involve economics and business experts to address, for instance, the external debt problem of certain Highly Indebted Poor Countries (HIPCs). Innovative solutions are welcome, an example being 'debt-for-development swaps', in other words the conversion of external debt into an international investment fund for reconstruction and development (typically in the social and business sectors), with a view to optimizing the use of a country's resources and infrastructure. The aim of science diplomacy in developing countries is to contribute to the development of robust, fair and socially acceptable systems that meet economic, public health, energy policy and environmental requirements. As far as energy policy is concerned, special attention should be devoted to integrated energy planning.

Ref. 6: "Why will (green) mini-grids play an important role in electricity access in Africa?", Pépin Tchouate Héteu, Senior Consultant DEEC Consulting (Energy, Environment, Climate Change mitigation)

Ref. 7: "Energy highways envisaged ... but is it the right approach?", Paul Frix, Senior Economist, Hon. DG Belgian Development Cooperation, Counsellor CBL-ACP

Role of the Royal Academy for Overseas Sciences in Belgian Policy

We live in a world without borders. There is a clear link between, on the one hand, population growth, the escalation of climate change and growing inequality in the world and, on the other hand, the influx of migrants and refugees seeking asylum in Europe — even if this influx is mainly due to civil wars and failed states in some regions. These problems may appear to be unconnected but they are actually interconnected (nexus): nations, economics, energy, water, food, soil sciences, health, climate, biodiversity, etc. Science naturally provides a common language whereby practical solutions are sought and bridges are built between cultures.

We must take rapid action to develop science that will lead us to an understanding of our planet as a complex system, and implement sustainable policies for future generations. We must invest in research that helps us improve how we manage water, grow food and combat disease. In particular, we must develop effective, affordable and non-polluting means of producing the electricity essential for the development of modern civilization.

Ref. 8: "Technological and political challenges regarding resource availability and recycling", Éric Pirard, Mineral Engineering, Materials and Environment, ULg (Belgium), member RAOS

The overall approach and long-term view presented above challenge us to think about our international relations, especially regarding developing countries. Aid from industrialized countries — generous as it may be, but often one-way and short term — must in the future be provided within fair partnerships in order to build a shared future (which implies a long-term shared vision between industrial and developing countries).

We need to question how development aid contracts are awarded and rethink the current more than sixty-year-old concept of public aid. A specific question is how to better understand the needs of beneficiaries in the field and how to approach civil society in countries receiving aid. The history of development aid has demonstrated the importance of a sense of personal and collective responsibility in recipient countries. For example, a bond linking the population with the authorities is essential in developing respect for the state. This is where international solidarity associations and organizations not recognized by ministries of development could play a role as important as that of classical NGOs.

Aid budgets should also be adapted, based on a better evaluation of ongoing projects and a more rigorous analysis of the end results (*N.B.*: Belgian aid in 2017 was 0.5 % of GDP, well below the target of 0.7 % — see Report 2017 CNCD-11.11.11). This will require developing and implementing qualitative and quantitative efficiency criteria based specifically on positive long-term impact and the multiplier effect, which will help avoid financing white elephants.

Ref. 9: "Measuring sustainable energy projects to orient strategies for access to energy", Emanuela Colombo, UNESCO Chair in Energy for Sustainable Development, Milan (Italy), member RAOS

Belgium's Royal Academy for Overseas Sciences aims to contribute its expertise ("what is best available science?*"*) to deal with the needs discussed above. Via its three sections — human sciences, natural and medical sciences, and technical sciences — RAOS intends to increase its scientific authority and improve the application of science in development cooperation. In Belgium, other scientific institutions and national or regional political authorities are jointly involved. University professors and public or private sector researchers should routinely follow in the wake of economic missions and state visits by our country to developing countries, with a view to setting up new joint scientific projects and creating educational links with local partners.

Ref. 10: "Access to the best available scientific and technical information for policymakers", John F. May, Population Reference Bureau, Washington DC

RAOS continues to work in the same basic direction, supporting Belgian international policy towards developing countries (involving in particular the Ministries of Foreign Affairs and Development Cooperation) by promoting science diplomacy, as described in this 'policy note'. This takes place within the broader framework of European Union policy (DG International Cooperation and Development) and that of the UN ('17 Sustainable Development Goals Agenda 2030').