TOWARD SMART AND INTEGRATED INFRASTRUCTURE FOR AFRICA

An agenda for digitalisation, decarbonisation and mobility

ICA The Infrastructure Consortium for Africa

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ACRONYM LIST

AfDB	African Development Bank
AFREC	African Energy Commission
AMU/UMA	The Arab Maghreb Union
AU	African Union
AUC	African Union Commission
CAPP	Central Africa Power Pool
CBA	Consumption-Based Approach
CEN-SAD	The Community of Sahel-Saharan States
CISA	Comprehensive ICT Strategy for Africa
COMELEC	Comité Maghrébin de L'Electricité
COMESA	The Common Market for Eastern and Southern Africa
EAC	The East African Community
EAPP	Eastern Africa Power Pool
EAS	East Asia and Pacific (all income levels)
ECCAS	The Economic Community of Central African States
ECOWAS	The Economic Community of West African States
ECS	Europe and Central Asia (all income levels)
GDP	Gross Domestic Product
GHG	Greenhouse gas
ICA	Infrastructure Consortium for Africa
ICT	Information and communication technology
IEA	International Energy Agency
IGAD	The Intergovernmental Authority on Development
INDCs	Intended Nationally Determined Commitments
IoT	Internet of Things
IRENA	The International Renewable Energy Agency
ITU	International Telecommunication Union
LBS	Location Based Services
LCN	Latin America and Caribbean (all income levels)
LPG	Liquefied petroleum gas
LTE	Long Term Evolution
MEA	Middle East and North Africa (all income levels)
MEC	Multi-access Edge Computing
NEPAD	New Partnership for Africa's Development
NPR	Next Production Revolution
OECD	Organisation for Economic Cooperation and Development
OSM	OpenStreetMap
PBA	Production-Based Approach
PIDA	Programme for Infrastructure Development in Africa
PPI	Private Participation in Infrastructure
PPP	Purchasing power parity
RECs	Regional Economic Communities of Africa
RES	Renewable Energy Sources
SADC	The Southern African Development Community
SAPP	Southern African Power Pool
SAS	South Asia
SDGs	Sustainable Development Goals
SSA	Sub-Saharan Africa (developing only)
SSF	Sub-Saharan Africa (all income levels)
TEES	Total Embodied Energy Supply
TPES	Total Primary Energy Supply
VGI	Volunteered Geographic Information
WAPP	West Africa Power Pool

Preface

The 13th Annual Meeting of the Infrastructure Consortium for Africa (ICA) takes place in Rome, Italy, on October 19th and 20th, 2017. The focus of the Annual Meeting is “Toward Smart and Integrated Infrastructure for Africa. An agenda for digitalisation, decarbonisation and mobility.”. It is hosted by Italy at the Italian Ministry of Foreign Affairs and International Cooperation headquarters in Rome, and jointly organized with AfDB/ICA. To prepare this background document for the Annual Meeting and to provide updated technical information for discussions, the Ministry of Foreign Affairs and International Cooperation- Direction General for Development Cooperation- signed a Memorandum Of Understanding with Politecnico di Milano and Politecnico di Torino, as qualified technical universities in the country, accepting to serve in this role.

The Departments of Energy of Politecnico di Milano and Politecnico di Torino were the focal points for the coordination of the document and technical competence on decarbonisation. The Department of Management Engineering and the Department of Mechanical Engineering for Politecnico di Milano and the Department of Electronics and Telecommunications and the Interuniversity Department of Regional and Urban Studies and Planning of Politecnico di Torino were also involved for the specific technical competence on digitalisation and mobility. Principal editors were Prof. Emanuela Colombo and Prof. Pierluigi Leone who coordinated the action with the other authors Prof. Marco Taisch, Prof. Federico Cheli, Prof. Carla Fabiana Chiaserini and Prof. Piero Boccardo. The coordination with the G7 priorities in Africa was assured by Dott. Andrea Gumina from the office of the Italian Sherpa. Strong contributions came from Dr. Marta Pinzone and Dr. Stefano Arrigoni from Politecnico di Milano. Input were also received by ENEL Green Power, ENEA and the Italian Ministry of Environmental See and Land.

Disclaimer

The views expressed herein are those of the authors and do not necessarily reflect the views of the Italian Government. This document has been produced without formal African Development Bank editing and do not imply the expression of any opinion whatsoever on the part of the AfDB.
Any map included are without prejudice to the status of sovereignty over any territory and to delimitations of any international frontiers and boundaries. Designations such as "emerging", or "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process.

Italian G7 Presidency 2017 and the Outreach Session on Africa at the Taormina Summit

The Italian G7 Presidency during the Summit in Taormina launched a fully dedicated Outreach Session on Africa continent a the presence of: the G7 Heads of State and Government, the Presidents of the European Council and of the European Commission, the Heads of State and Government of Ethiopia, Kenya, Niger, Nigeria and Tunisia, the Secretary General of the United Nations, the Director General of the IMF, the President of the World Bank, the Secretary General of the OECD, the President of the African Union, the President of the African Union Commission and the President of the African Development Bank. From the Chair's Summary of the Outreach Session [Italian G7 Presidency, 2017], the key elements of the message may be extracted.

Particular attention was given to the potential of innovation and the role of human capital in boosting sustainable and inclusive growth in the continent. In addition to a ***peaceful, secure and stable Africa,*** *three strategic points are highlighted as fundamental preconditions for sustainable development in Africa:*

- ***Unlocking Africa's potential through innovation and human capital development****: It was stated that innovation and human capital development can be powerful drivers of sustainable and inclusive development in Africa. The importance of extending the benefits of the New Production Revolution (NPR) to the African continent, drawing inspiration from the G7 People-Centered Action Plan on Innovation, Skills and Labor, was underlined.*

- ***A positive momentum****: It was pointed out that several elements are concurring to boost investment in the African continent, paving the way to an inclusive and innovation-driven development.*

- ***Promoting a new generation of innovation leaders:*** *The importance to support the emergence of innovation leaders in Africa - including by strengthening links between African and G7 scientific and academic systems - was emphasized. In this respect, Italy's announced its intention to launch a "G7 Exchange and Empowerment Program for Emerging African Innovation Leaders".*

Italian G7 Presidency 2017, "G7 Summit Chair's Summary Of the Outreach Session On Africa." 2017.
Available at http://www.g7italy.it/sites/default/files/documents/G7%20TAORMINA%20CHAIRS%20SUMMARY%20AFRICA_0.pdf

Background information: About the ICA

Launched at the G8 Gleneagles Summit in 2005, the **Infrastructure Consortium for Africa (ICA)** has the aim to help **improving the lives and economic well-being of Africa's people by fostering and supporting an increase in the infrastructural investment in the continent**, from both public and private sources. The ICA recognizes the strategic role that development of infrastructure has for the economy and for the social stability of the region. Using its convening power, the **ICA acts as a catalyst accelerating the development of Africa's infrastructure** with the aim at removing some of the technical and policy barriers to infrastructural investment.

The 13th ICA Annual Meeting is held in Rome, Italy, on October 20th 2017 under the co-chairmanship of the current Italian G7 Chair and the AfDB. The Plenary Meeting **"Towards the promotion of smart and integrated infrastructures in Africa: an agenda for digitalization, decarbonization and mobility",** is focused on the nexus between Infrastructure, the Next Production Revolution and the Sustainable Development Goals.

THE POTENTIAL OF THE NEXT PRODUCTION REVOLUTION IN AFRICA

- Africa is ready to **jump straight into the revolutionary frontiers that represent the enabling environment for the transformative change requested by the 2030 Agenda.**
- **The Next Production Revolution** (NPR) with **new digital technologies, materials** and **processes** will reshape design, engineering and production, enabling further leapfrogging in Africa.
- Among the **cluster of emerging technologies**, **Digital and Green Tech** appear as the most relevant for the achievement of the Sustainable Development Goals and are at the core of ICA 2017.
- **Physical** and **social infrastructures** are crucial for socio-economic growth and their application needs to meet the new **global institutional frame (**Paris Agreement, Addis Ababa Action Agenda).
- **Infrastructure development** needs to be designed in order to avoid the risk of **technological lock-in** to a set of configurations that may meet middle term targets but may fail beyond 2050.
- **Africa needs to bridge the large infrastructural gap** in the **energy, transport and ICT assets** to keep on fighting poverty, boosting local economy and entrepreneurship; additional resources are certainly needed to increase **capacity** but also **productivity of current asset**.
- Investments in infrastructure in developing countries are estimated to be at **1.8% of global GDP** while the investment gap should be between **2.5% and 4.3% of global GDP**.
- **In 2015, investments for Africa's infrastructures amounted to $83.4 billion** showing a 12% increase with respect to the previous year.
- **African national governments committed 34.1%** of total investments while the **private sector only 8.9%**. **Energy and transport** collected **more than 80%** of investments with 2/3 in the Sub-Saharan region.
- In Sub-Saharan Africa, private sector's investments experienced a shift from **ICT infrastructure,** with **few but big projects**, **to energy infrastructure** while interest in transport remains small.

Key Messages

Key Messages

SMART AND INTEGRATED INFRASTRUCTURE IN AFRICA

- **Middle- and low-income countries are coming** to be the major drivers of investment and growth and this **unique transformation** calls for rapid technical progresses: Progresses into digitalization, energy, transport and other spheres need to comply with the urgency of **controlling impact on climate**.
- The **'leapfrogging' transformation** needs to include a new set of attributes complementing sustainable and quality infrastructure and defining Smart and Integrated infrastructures (**SMART-I Infrastructure**) which are the essence of the taxonomy proposed for ICA 2017.
- **Sustainable infrastructures** are characterized by the **social, environmental and economic** dimension, to which **quality infrastructure** (ICA 2016) introduces **inclusiveness, safety** and **resilience.**
- **SMART-I Infrastructure** (ICA 2017) adds four new characterizing attributes:
  Integrated by data, function and governance: sustainable and quality infrastructures have to employ innovative ways of meeting governance and service needs, including the implementation of more responsive, productive and integrated information systems that complement hard infrastructure.
  Physical and Financially Decentralised: capillary and efficient technologies are more massively at the disposal of citizens and the capitals and infrastructure owners are shifting from large creditworthy entities to small ones.
  Life Cycle Perspective: the infrastructure for NPR needs to match the goal expressed by SDG11 dealing with new production patterns that need to be driven by rational use of resources in a long term and life cycle perspective.
  People-Centred: in line with the 2030 Agenda new consumption patterns are also needed. They may be obtained only by an appropriate and multi-dimensional involvement of citizens not only in their role as consumers but also as influencers, producers and agents of the change as indicated by the by the "G7 Summit, Chair's Summary of the Outreach Session on Africa".

THE ROLE AND STATUS OF SMART AND INTEGRATED INFRASTRUCTURE FOR PROSPERITY IN AFRICA

DIGITALISATION: THE NEW ERA OF INFRASTRUCTURE

- Within the **Next Production Revolution (NPR), Internet of Things, Big Data and Cloud Computing** will play a crucial role.
- **The Internet of Things (IoT)** is going to generate a massive amount of data, **Big Data** which require new, advanced analytic techniques and **cloud computing.**
- IoT effectiveness in applications like **transport, emergency management, remote monitoring** will depend on the quality of **bandwidth and rate connectivity** between "things" and infrastructure.
- The emerging **5G technology** can significantly mitigate the need for high capacity, costly backhauls; virtualization can allow services to be deployed everywhere, allowing a shift to distributed cloud.
- Despite the progress made in the last years, Africa still lags behind other regions in its access and use of digital infrastructures, digital technologies, and the Internet.
- The **broadband infrastructure gap, the related costs of services and devices, the lack of local content and low proficiency in digital skills** are among the critical barriers.
- Migration to mobile broadband is gaining momentum in Africa but still 600 million people do not have access to it. Fixed-broadband connection, can advance quickly to **high-speed fibre broadband** because it has not made massive investments in old copper-based technologies.
- Deploying **digital infrastructure** for Africa may bring a number of contributions to Prosperity and NPR like GDP increase, environmental benefit, efficient use of resources, qualified jobs.

DECARBONISATION: THE NEXUS ENERGY-CLIMATE-DEVELOPMENT

- Africa is expected to become more **energy demanding** due to its growing population and economy, both claiming access to reliable and affordable energy services.
- Africa wishes to confirm the continent commitment to maintain its **low contribution to global carbon emissions** in the long run.
- The **energy paradox** in Africa is recognised; energy supply is poor despite rich in resources. Home for the 16% of the global population, Africa accounts for only 6% of the primary energy supply and the 3% of the total electricity demand, with the 5% of the global CO_2 emission burden.
- **Underinvestment** in terms of power generation infrastructure is critical as proven by low installed capacity per capita and unit of GDP coupled with high values of energy and CO_2 intensity.

Key Messages

- Energy supply does not keep pace with population growth and **the capacity mix is mostly given by thermal power plants (**80%) in north and south, and hydro (20%) in central and eastern Africa.
- The roughly **150 GW of installed capacity** is unevenly distributed in the regions and the energy mix is not the mirror of the local natural endowment (except for COMELEC and SAPP).
- The current level of **annual investment** in the power sector (roughly $10-11 billion per year) is inadequate and huge **increase of four times** is at least needed.
- **Africa sub-regions differ consistently** in their availability and use of energy resources, this has led to an evident fragmentation of policies and action plans and a lack of harmonization.
- **Efforts of integration** appears in some strategies by AU and NEPAD with the launching of PIDA and AFREC, the AfDB and regional power pools.
- **SMART-I Energy Infrastructure** may contribute to Prosperity since renewable energies and efficiency can unleash access, a reliable power sector may boost business development, interconnections increase trade and savings and distributed systems inclusiveness and empowerment.

MOBILITY: THE GOAL OF CONNECTING PEOPLE AND GOODS

- Africa will experience an **increasing demand for transport services** as result of fast growing population and economy with a consequent strain on the transportation system.
- For each barrel of oil no longer used in Europe, almost one barrel more will be used in Africa in 2040 thus increasing **pressure on the environment and the socio-economic system**.
- Africa accounts for about one-fifth of total fatalities from road crashes worldwide although the share of global registered vehicles is only 2%. Road accidents cause significant economic losses.
- More than **50% of Africa's road network is unpaved**, air transport covers less than 2% of global passengers share and maritime transport accounts only for 5% of global traffic.
- It is imperative to **bridge the transport infrastructure gap** of Africa in terms of new capacity and modernization of existing assets, however following the current path for the implementation of new infrastructure may be unsustainable in terms of financial resource required and environmental impact.
- A step change in **future mobility patterns and multimodal transport** is envisaged: **information and communication technology (ICT) and the associated disruptive technologies** are reshaping the landscape with major trends in autonomous driving, shared mobility, connectivity, and electrification.
- Deploying **SMART-I Transport Infrastructure** may promote Prosperity mainly due to integration and digitalization that enable **multi-modal mobility** promoting efficiency and saving in connecting people and goods, while electrification may facilitate the **decarbonisation** of the sector.

SMART-I INFRASTRUCTURE IN AFRICA: RECOMMENDATIONS FOR AN ACTION AGENDA

Deploying **SMART-I Infrastructure** for Africa needs to be recommended to promote Prosperity. The **attributes** of SMART-I Infrastructure characterise the needed transformation of the African Socio-Economic **asset toward the NPR adoption** in the continent:

DIGITALISATION

- Broadband penetration needs to be widen in the continent to support sustainable development.
- Digital transformation is crucial to enable a new asset for African manufacturing and productivity.
- Digital technologies can boost people engagement and empowermen.

DECARBONISATION

- Renewable energy & efficiency need to be top priorities to unleash access to modern services.
- Increased power capacity and reliability need to boost local economy and business development.
- Interconnections and networking of energy systems cannot wait longer to increase trade and savings.
- Distributed energy systems may complement on grid option to increase inclusion and empowerment.

MOBILITY

- Smart transport infrastructure is prodromal of prosperity in Africa.
- Digitalization of transport and logistics spurs African manufacturing and productivity.
- Systemic integration and effective resource management need to be on top of the Africa Agenda to unveil the potential of Smart-I Infrastructure.

Smart-I Infrastructure requires a new paradigm:

- SMART-I Infrastructures need to be developed to reduce non-renewable resources consumption: a **new paradigm of consumption based accounting** is thus requested to define effective policies,
- the development of SMART-I Infrastructure needs to be accompanied by long-term capacity building programmes for a generation of African leaders, as remarked at the G7 Africa Outreach in 2017.

Executive summary

Africa is ready to **jump straight into the revolutionary frontiers which may represent the enabling environment for the transformative change requested by the 2030 Agenda**. Africa does not need to replicate misleading trends of development, production and consumption which are now calling for deep remedies. Indeed, strong efforts and **Partnership** at global level are requested to support the achievement of sustainable development while maintaining global **Peace**, reduce inequality among **People** and promote a more equitable **Prosperity** for all, including the **Planet** at large.

THE POTENTIAL OF THE NEXT PRODUCTION REVOLUTION IN AFRICA

In this perspective, **the Next Production Revolution** (NPR) represents a potential opportunity and a big challenge for Africa and its socio economic development, also due to the traditional leapfrogging attitude that has already characterized the straight and successful diffusion of a number of smart or clean innovations in the continent. Indeed, NPR entails a **confluence of technologies** ranging from a variety of **digital technologies** to **new materials** and **processes**. Moreover, in the 2030 Agenda of the United Nation, the 5 clusters of **emerging technologies** (**bio-tech, digital-tech, nano-tech, neuro-tech and green-tech)** are considered crucial for the achievement of the Sustainable Development Goals (SDGs). Among the five clusters it emerges that **Digital and Green Tech** appear as the most relevant for the achievement of the SDGs like Health, Water, Energy, Ecosystem, Land, Ocean Management, Climate Change, Sustainable Production and Consumption patterns. Recognizing this relevance, Digital and Green Tech, broken down into digital infrastructure, sustainable energy infrastructure and smart mobility have become the core of ICA 2017.

Physical (e.g., telecommunication, energy, transport, water supply) and **social infrastructure** (e.g., health, education, banking, commercial services) are crucial for socio-economic development at country level. However, **infrastructure development** needs to cope with the new global framework. Indeed, only a **confluence of technological innovation matching political, institutional and social innovations** may have the power to trigger a transforming process that is requested for our society. From a **technological standpoint** - the OECD has just formalized the concept of Next Production Revolution which will have a very strong impact on productivity, work, skills, markets, poverty and inequality, well-being and environment. From a **political and institutional point of view**, the Paris Agreement on climate change, the 2030 Agenda for Sustainable Development and the Addis Ababa Action Agenda represent paramount innovative reference assets. However, **infrastructure development**, within the current production schemes, may represents a big burden for additional green-house gases emissions. Thus, long lasting effects of infrastructure need to be considered in order to avoid the risk of **technological lock-in** to a set of configurations that are able to meet 2030 or 2050 targets but that inevitably are due to fail in achieving the target beyond 2030.

Quality and reliable infrastructures are preconditions that may trigger access to different services pivotal for fighting poverty and boosting the local economy and entrepreneurship. **Africa needs to bridge a large infrastructural gap** in the **energy, transport and ICT assets** mainly due to **low population density**, **high concentration of landlocked countries** and **high share of rural settlements**. **In the energy sector, the infrastructure dearth** is largely manifest both from a quantitative and qualitative perspective. **Access to electricity and modern fuel** is still low in the Sub-Saharan region. Per capita electricity consumption, in the whole continent, is very low, less than **600 kWh/per capita per year** that represents less than 20% of the world average; **energy intensity**

and CO_2 intensity are very high, thus giving evidence of a very low efficient and not clean energy supply chain. **Transport infrastructure**, in terms of both roads, rail lines, air transport and port, is another crucial pillar to foster sustainable development in Africa enabling local, regional and international trade. **Road transport contributes to 90% of passengers' mobility** and more **than 80% of goods' exchanges**. More than **50% of Africa's road network is unpaved** hindering the access to basic social services and burdening local economic activities, especially for rural population. **Air transport is still modest** compared to other macro regional aggregations. **Maritime transport,** despite being fundamental for trade, is also weakly developed. **Information and communication technologies** had a rapid growth in Africa which is now the second largest mobile phone market in the world. But the Africa penetration rate of **mobile phones varying from 71% to 111%** is still among the lowest compared to other macro-regional aggregations. Moreover, individual Internet access still scores very low, having a range between **20 and 39%** of **individuals using Internet**. Despite the positive trends, African ICT sector is still relatively immature as shown by the **low number of fixed broadband subscriptions**, and with **low impact of Internet on African GDP** (1.1% compared to 3.7% of developed economies).

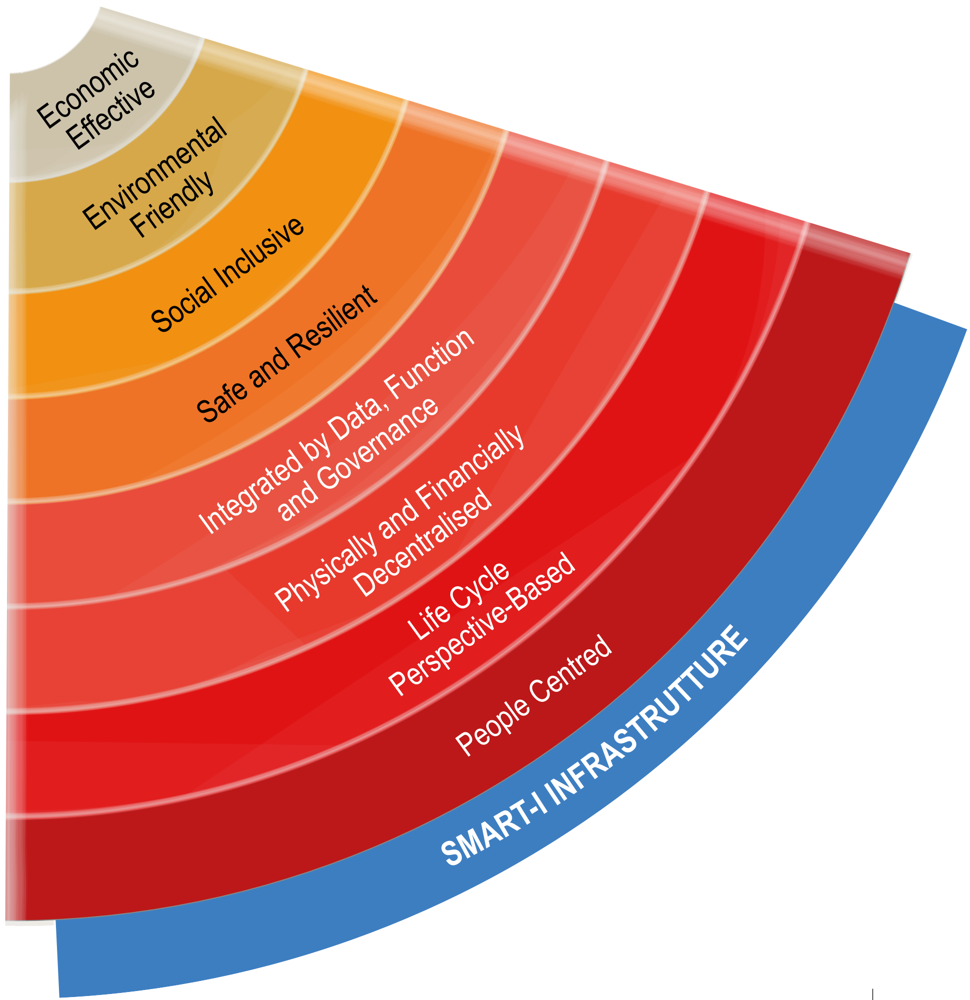
Filling the infrastructural gap of Africa is urgent and in this perspective, additional resources are needed, but further value could be brought by cooping wise investments on quantitative **capacity** with a set of other strategies to improve **productivity** of current infrastructural asset use. At global, level ensuring a value of **infrastructure stock at around 70% of GDP**, a rise of annual baseline infrastructure investment from **$2.6 trillion in 2013 up to $4.5 trillion in 2030** would be required. Such an investment would not be enough **to fill the existing gaps** between developing countries and developed regions, to **address universal access to roads, clean water, sanitation, and electricity** and to consider extra investments required to tackle environmental stresses from climate change mitigation and adaptation. The additional amount to meet the need of Sustainable Development for developing countries is between **$3.3 trillion and $45 trillion** per year to be mainly allocated in the sector of basic infrastructure (roads, rail and ports; power stations; water and sanitation), food security (agriculture and rural development), climate change mitigation and adaptation, health, and education. Within this total amount, **physical infrastructures** would require from around $1.6 trillion to $2.5 trillion per year. This brings to evidence an estimated gap close to $1-1.5 trillion per year when compared to current investments. As a global picture, investments in infrastructure in developing countries are estimated to be at **1.8% of global Gross Domestic Product (GDP)** while the investment gap should be between 2.4% and 4.2% of global GDP. **In 2015, investments for Africa's infrastructures amounted to $83.4 billion** showing a 12% increase with respect to the previous year. **African national governments committed 34.1%** of total investments while the **private sector shared only 8.9%**. **Energy and transport** sector collected **more than 80%** roughly equally distributed among the two for a total investments sharing of $69.4 billion. At regional scale, investments were mostly

allocated **in Eastern Africa** (23.1%). Investments from **private sector** were almost entirely focused in the **energy sector** and were mostly concentrated in South Africa (51.2%) followed by West Africa (17.2%) and North Africa (16.5%). In the whole Sub-Saharan Africa private sector investments were around **$6.3 billion with the power sector sharing more than 95%** of it and the remaining allocated in **road construction and water infrastructure**. In the period from **2010 to 2015** most of private investments in Sub-Saharan Africa were allocated in **ICT infrastructure** with **few but big projects**. However, in the last three years a shift of private investments from ICT **to energy infrastructure** has been observed. **Private investments in transport sector are still very small** mainly concentrated in ports.
The share of **middle- and low-income countries** in global GDP (on purchasing parity terms) has increased from less than 40% to more than 50% since year 2000 and is expected to increase to two-thirds by 2030; these countries are coming to be the major drivers of investment and growth. This **unique transformation** calls for rapid technical progresses in digitalization, energy, transport and other spheres. At the same time, this progress needs to be carried out in compliance with the urgency of controlling impact on resources, environmental quality and on climate. **The Next Production Revolution** offers to developing countries and therefore to Africa the opportunity to achieve sustainable development goals provided the setting of an enabling infrastructure and a new generation of leaders able to manage such innovation. The early path towards low-carbon and quality infrastructure has already led to a **'leapfrogging' change of infrastructure system**, which needs to be more focused on a comprehensive **smart and integrated** approach including *functional, data integration and governance;* a *decentralized paradigm*, a *life cycle perspective* and a *new and pro-active role of users*.

SMART AND INTEGRATED INFRASTRUCTURE IN AFRICA

Smart refers to a massive penetration of digital technologies in the infrastructure sector to control, manage and optimize uses. **Integration** refers to the coping of functionality, data integration and sharing across sectors between physical infrastructure like energy, transport, telecommunication and digital technology including the use of Internet of Things, Artificial Intelligence, Big Data. Integrated infrastructures can therefore promote a new **infrastructure governance** able to foster an overarching approach to planning, delivery and management of infrastructure assets. In addition, integration leads to the promotion of **new technological nexus,** overlapping different sectors, such as waste, energy, transport, ICT, banking, financing. This implies that the development of, e.g., transport, energy and ICT, infrastructures should be seen as intertwined and synergic.
Decentralization is a crucial element in the transformative path for infrastructure: from **the physical perspective,** we assist to a capillary distribution of technologies more massively available to citizens; digital technologies (e.g. smart-phone) have increased the chance for everyone to get access to digital

services, energy and also transportation services. Additionally, technological advances have allowed the deployment of “local” digital services, which may stand regardless the availability of connectivity with centralized infrastructures. From **the financial perspective,** we are assisting to a parallel shift of capitals and infrastructure owners, from large creditworthy entities (e.g., large corporations and central governments) to smaller one (e.g., households, smallholders, emerging economy cities without good credit ratings, new project developers). In the same perspective, investments in infrastructure need to be more directed to solutions that aim at **optimizing resource use in a life cycle and system perspective** enabling the transition that is requested from now to 2030 but also casting the right seeds for the more challenging shift needed to 2050. Lastly, a new **people-centered perspective is envisaged,** where households and communities are engaged in new or adapted forms of distributed control, with demand-response approach.
Smart and Integrated Infrastructures (SMART-I Infrastructure) need to become the driving element for the next investment generation in Africa and they are the essence of the taxonomy proposed for ICA 2017. They represent the natural evolution of the list of attributes for infrastructure development and complement the previous definition of **sustainable** and **quality** infrastructure.



THE ROLE AND STATUS OF SMART AND INTEGRATED INFRASTRUCTURE FOR PROSPERITY IN AFRICA

DIGITALISATION: THE NEW ERA OF INFRASTRUCTURE

To benefit fully from the digital economy, countries require a **smart and integrated digital infrastructure**. At its core, digital infrastructure includes telecommunications infrastructure, both fixed and mobile. Within the **Next Production Revolution (NPR),** technologies such as **Internet of Things, Big Data and Cloud Computing** will pay a crucial role. The IoT is going to generate a massive amount of data, so **Big Data** that require new, advanced analytic techniques. **Cloud Computing** enables ubiquitous, convenient, on-demand network access to a shared pool of memory and computing resources for data storage and processing. Among the large variety of applications that can benefit from the above technologies, some are of prominent importance to Africa:

- **Public transport.** Transport users can become fully informed about their travel options while at the same time providing information that enables transport authorities to plan and manage transport networks and services more efficiently.
- **Emergency management**. Massive amounts of data collected by public authorities as well as by people using specific digital applications (crowd-sourced data) can be effectively used to ensure swift response to and recovery from emergency situations such as natural disasters or energy grid failures.
- **Remote monitoring**. Users' smartphones can act as mobile sensors, gathering environmental and pollution data. Mobile apps further add the possibility for the users to report environmental data for the realization of smart city services, medical data, user habits (like smart meters).
- **E-learning**. Cloud computing, coupled with broadband wireless connectivity to the Internet, represents the ideal means to enable remote educational services and access to educational, training and learning material.

The future deployment and effectiveness of IoT, big data and cloud computing will depend on the availability, quality and security of the underlying infrastructure. Indeed, **high-data rate connectivity** (e.g., between the "things" or users and cloud computing servers), **ultra-low latency** (e.g., for robotics control applications in next-generation factories) and **data security and privacy** (e.g., user profiling or industrial data) are critical to the development of innovative services. In this context, mobile infrastructure represents an effective solution that can provide high capacity while avoiding the costs of fixed-broadband or satellite-broadband networks. In particular, the emerging **5G technology** can significantly help to mitigate the need for a high capacity, costly backhaul. Through virtualization, services can be deployed everywhere in the network, thus allowing the transition from a centralized, often costly cloud, to a distributed cloud.

In this regard, and despite the progress made in the last years, Africa still lags behind other regions in its access and use of digital infrastructures, digital technologies, and the Internet. The **broadband infrastructure gap, the related to**

costs of services and devices, the lack of local content and low proficiency in digital skills are among the critical barriers. Migration to mobile broadband is gaining momentum in Africa but still 600 million people do not have access to a mobile broadband service. On the side of fixed-broadband connection, Africa has the opportunity to advance quickly to **high-speed fibre broadband** as it has not made massive investments in old copper-based technologies.

The mentioned inter-dependent aspects must be addressed concurrently to **close the digital divide**, such as **infrastructure, affordability, local content, and skills development**. Digitalization has policy implications across different areas and, thus, maximizing its benefits requires more coordinated policies and regulation across sectors and authorities. To recognise the relevance of digitalisation, African leaders adopted the **"Agenda 2063" as the continent's new long-term vision for the next 50 years**.

Since ICT is intertwined with the energy, transport, water sectors, just to name a few, deploying a **digital infrastructure** for Africa will bring a number of contributions to prosperity, characterizing the digital revolution as a new era of infrastructure contributing to the transformation of the African Socio-Economic asset toward the NPR adoption in the continent.

Internet contributes **1.1% to the African Gross Domestic Product**, which is low compared to **global average of 3.7% for developed economies**. The overall benefits of digitalization in emerging economies derive from the **effectiveness, efficiency and innovation gains** in processes, products, services and business models that accompany the digital transformation. Thanks to the expansion of connectivity and accessibility across Africa, a new ecosystem of digital entrepreneurs and start-ups can emerge and flourish. Beyond the leapfrogging to mobile phones a similar leapfrogging could happen with distributed manufacturers, at least at the urban scale, allowing start-ups or small businesses with little capital to begin manufacturing on a small scale.

Digitalization can significantly contribute to mitigate environmental challenges to sustainable development, by enabling a more efficient use of energy and natural resources, and helping countries, cities and individuals to adapt to environmental threats with the improvement of monitoring and control. Digitalization may also contribute to social improvements through job creation and better access to basic services, such as health care and education.

In order to mitigate any future lock in, it is important to consider that digital technologies and infrastructures also contribute to the generation of Greenhouse Gas (GHG) emissions and e-waste, through the energy consumption involved in the lifecycle of digital infrastructure as well as the production, use and disposal of digital products and services. **Taking a lifecycle and circular economy perspective** and deploying systems to manage digital technologies is, therefore, crucial to minimize negative impacts. New business models are also characterised by an emphasis on high value-added services where people are at the centre of the stage and their role shift from being simple customers to become partners.

DECARBONISATION: THE NEXUS ENERGY-CLIMATE-DEVELOPMENT

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 and together with it, as remarked by PIDA, Africa wishes to confirm the **continent commitment to maintain its low contribution to global carbon emissions.** In this perspective, the challenge of NPR for Africa may allow some countries to leap-frog to more advanced stages of development in a number of sectors; energy being one of them. **Africa cannot lose momentum to investigate low carbon alternatives** for the long run in the path to decarbonisation and to the claimed decoupling among growth and greenhouse gases.

The energy paradox in Africa is nowadays fully recognised. Energy demand over the last decade has grown by more than 30% nevertheless, 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 of the **5% of the CO_2 emission burden**. Africa still lags behind other regions: per capita availability of energy is very low while **energy and CO_2 intensity are higher** than other regions. These numbers, together with the **low levels of installed generation capacity per capita**, and per unit of GDP represent the evidence of underinvestment in Africa in terms of power generation infrastructure. Indeed, installed capacity is roughly around **150 GW** unevenly distributed in the continent. The capacity mix is mostly given by **thermal power plants** (80%) due to the size of the North African and South African systems, and **hydro plants** (20%) mainly located in the central and eastern regions of Africa. The energy situation in Africa is very diverse in term of generation capacity and mix in the different regions. Except for COMELEC and SAPP, the generation mix in the other regions does not mirror the local natural endowment, but it is more the evidence of **short sighted planning and lack of regional integration**. The existing African **transmission system** (defined as lines with a voltage equal or above 100 kV), with a total length of less than 90.000 km, is the major bottleneck for further energy system integration and networking among the power pool as again suggested by PIDA.

The current level of **annual investment** in the power sector (roughly $10-11 billion per year) is inadequate and huge **increase of four times** is at least needed for supporting the boosting of the energy sector in term of installed capacity, transmission lines, quality of the service and universal and equitable access for all in the continent. The main challenge will be financing the large capital investment required by the transformation of the power sector, increasing private sector financing and sector cash flow by some 7-10 times their current levels. This big effort may be turned into a positive effect since no significant increase in average tariff may be required to finance the sector program, which would so remain around $8-10 cents /kWh due to the large amounts of low cost hydro power which would become available.

Africa sub-regions differ consistently in their availability and use of the energy resources. Such differences bring about different sets of challenges which have lead in Africa to an evident **pluralism of actors** involved in the energy sector through several policies and action plans. Governmental agencies and international organizations, development banks and funds, power utilities associations, NGOs and others, undertake actions addressing energy-related challenges. The **fragmentation of the policies and action plans** and the lack of harmonization represent one of the main key points. Indeed, actors involved in this frame have priorities and roles that often differ or overlap even if some efforts of integration have appeared over the last decade by **AU, NEPAD, AFREC and AfDB** and the increasing coordination within **the Power Pools.**

Modern energy services, though increasing, remains limited and diversified by regions in the continent. For instance, roughly 50% of Sub Saharan Africa population is without access to electricity, 80% of which leaving in rural area. On-grid solution stays the least-cost solution and provide access to the majority of those who gain it within 2030; renewable makes the 70% of the additional capacity to provide access. Reliable energy infrastructure with proper regulatory framework are crucial to transform the power sector and contribute to decarbonisation. **Bioenergy** in Africa, mainly fuelwood and charcoal, is still the dominant source of energy for Africa (a bit less than 80% of the population in SSA) affecting the health of hundred thousand people. 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 LPG. This is particularly crucial from an infrastructure perspective since a lack of proper distribution networks as well as adequate affordability of LPG may slow down progress in rural areas, where biomass alternative is often free of monetary costs. Beyond providing a short-term pathway to cleaner energy solutions, an LPG network and infrastructure can provide a platform for developing modern bioenergy solutions (e.g., biogas) towards a higher relevance of bioeconomy that is a pillar of the NPR.

The power sector is often weakly reliable in the African countries due to severe and frequent power shortages which happen in poorly maintained networks. On average, roughly 5% of **annual sales** are estimated to be lost due to electrical outages; electricity tariffs are, in many cases, among the highest in the world and the frequent recourse to emergency back-up oil-fuelled generators or captive power has induced consequences on the **electricity costs** for the final user (across businesses and households) and affect **product competitiveness.** Time and cost to get electricity connection affects **business development**.

As a general consideration, since GDP growth of more than 5% per year in Africa has been achieved despite poor electricity supply, it is not difficult to forecast the impact of a more reliable and affordable energy infrastructure on the economic and social development. A higher quality power network is expected to raise the productivity of African companies: every additional $1 invested in the power sector may generate more than $15 in incremental GDP. According to different scenarios and forecasts, the power demand will increase from the current value up to **three or four time** to 2040, and therefore, installed power generation capacity must rise from present levels to almost 400-600 GW by 2040. Forecasting different penetration of renewable energies will also imply a different level of investment. PIDA suggests that Africa will **save on electricity production costs** through power interconnectors among the Power Pools to enable large-scale hydropower projects while increasing access to power in the low generating area through inter-regional trade. In this configuration, the role of regional smart and integrated infrastructure will be crucial as suggested also by IRENA and IEA. Both of them include deeper regional co-operation and integration to facilitate new large-scale generation. **Integration will also call for stronger inter-sectorial synergies, high coordination and multi-sectorial governance as well as a life cycle perspective** in order to mitigate long term CO_2 lock in and allocate responsibility for energy consumptions among national economies and their productive sectors including trades.

The **debate between top-down or bottom-up approach** is going to be overcome in the perspective of providing universal access giving space to both approaches in order to mitigate the rural-urban divide. In the perspective of increasing further the quality and level of access for household, beyond the basic needs, and promote productive uses for community services, agriculture or rural industries, the contribution of distributed (off-grid) and decentralised generation (mini-grid) increases from covering the 17% for the new access of the New Policy Scenario to the 42% of the new access in the Universal Access Scenario. Reduction of costs and greater attention to energy efficiency, social entrepreneurial promotion, disruptive penetration of digital technology will be crucial for the future relevance that distributed generation may gain. Distributed Energy infrastructure may better respond to the needs, capacities, and aspirations of people and be absorbed within the local culture, adapted and later improved by the local people to sustain local ownership, promote economic growth and ensure long term impact.

MOBILITY: THE GOAL OF CONNECTING PEOPLE AND GOODS

Transport of goods and people is a prerequisite for a prospering economy **shaping mobility patterns, contributing to innovation and productivity while triggering economic, environmental and social benefits**. Transport infrastructure enables the connection of people to jobs, education and health services. It spurs the interactions among people that generate knowledge and visions for long-term development.

Future transport systems need to comply with many constraints in terms of quality and affordability, social and environmental impacts. Transport accounts for about 64% of global oil consumption, 27% of primary energy demand and 23% of total anthropogenic GHGs emissions. In 2040, for each barrel of oil no longer used in Europe, almost one barrel more will be used in the Africa. Africa has the primacy for the risk of a road traffic death resulting in about one-fifth of total fatalities from road crashes worldwide although the share of global registered vehicles is only 2%. Noteworthy, road accidents cause economic losses equal of up to 5% of GDP.

Future trends suggest that global transport volume for passengers and goods will double as result of fast-growing population and emerging economies with a consequent strain on the global transportation system. As a result, **significant investment will be required in the transportation infrastructure to increase capacity and improve productivity**. Similarly, there will be the need of more **efficient and reliable vehicles** relying on more sustainable fuel sources.

The infrastructure dearth of Africa in the field of transport is evident from the very low total intra-African trade in 2011 that was only 11% of African trade with the rest of the world, stating the poor internal connection among the countries and the region. More in detail, Africa's terrain variety has an impact on critical transport and in general, there is a **huge range of maturity in terms of infrastructure**. For example, Angola has just 4 km of roads per 100 square kilometers of land; Ghana's road density is more than 10 times as high, while South Africa has 62 km of roads per 100 square kilometers.

Roads represent the main mode of goods transport in Africa; however, most of continent's roads are unpaved or in poor condition and quality tends to reduce in case of non-international truck roads. Formally speaking a network of **trans-African highways** exists, to potentially permit people and goods travelling across African countries, but their impact is limited by the poor quality of some of them. Indeed, where road infrastructure is adequate, road maintenance is a worrying problem reducing dramatically the percentage of road in good or fair condition.

Africa's **rail** networks have severe infrastructural problems and deficiencies: generally, rail lines date back to colonial period and are poorly maintained. These network densities are lower than Europe's range of 200 to 1,000 km per million people. It is also notable that African exports are largely bulky primary commodities, which could be transported more efficiently and at lower cost by rail than by road, therefore, **rail development holds huge opportunities for investors**.

Maritime transport, despite fundamental for trade is also weakly developed. **Ports** are the most important transportation mode to access African continent especially for goods. Nevertheless, ports are not enough to handle existing traffic. Africa operates 64 ports but they **share only around 5% of global traffic**. South Africa, Morocco, Egypt and Cameroon contribute to around 68% of the regional maritime traffic.

There exist several **international airports** for passenger traffic while air transportation of goods is not enough developed. Generally, there is a **lack of physical connections and coordination between the different transport infrastructure and terminals**.

Several policies related to transportation and logistics are already in place sustained by the Programme for Infrastructure Development in Africa (PIDA). Overall, PIDA aims at developing a functional African Regional Transport Infrastructure Network (ARTIN) at the least economic cost, with priority for landlocked countries, while minimizing the environmental impact and including gateway ports and air transport services, increasing efficiency, cost, reliability and safety. It is urgent to increase the **infrastructure capacity** of Africa to sustain economic growth since a positive correlation between real income per capita and road and rail density exists originated by the increased opportunity of connecting people to jobs and goods to markets. Introducing digital technologies into existing transport infrastructure can also **increase productivity, expanding the connections of**

existing assets while predicting and avoiding disruption, thus changing old paradigms basing solely on capacity. Finally, intermodal transport solutions can be promoted thus increasing the productivity of the whole transport and logistic value chain.

Beyond productivity of infrastructure, integrated and intelligent transport network is able to sense demand, measure performance and monitor the health of physical assets thus enabling **radical new ways of monitoring and maintaining the roads, track and runways**. Cognitive technology can improve automation and safety of vehicles. Finally, connected and automated vehicles are likely to lead to modifications in terms of security, safety, emissions reduction and time management while travelling on roads. All these measures promise to reduce the actual burden of poor transport infrastructure in Africa's economies.

Smart transport and logistics infrastructure enable the Next Production Revolution by the digitisation and **integration of vertical and horizontal value chains, the development of new digital business models and customer access platforms**. Overall, digitalization has a high potential to improve internal operations of companies in a wide variety of areas including **asset management and the delivery of new investments**.

The implementation of smart transport and logistics solutions can stimulate more **decentralized and small business offering a greater flexibility that could overcome financial barriers**.

Transport infrastructure needs to shift for speeding up the disrupting change coming from the new mobility landscape with a major trend in shared mobility. Cities have been indicated as the most relevant segmentation dimension that will determine mobility behaviour and, thus, the pace of transport changes. Shared mobility solutions will provide **user-centered mobility services** empowering people and changing the approach to operations and planning based on users' choice and priorities.

A people-centered approach is also required to develop capacity and skills that drive transformation as the lack of **digital culture** has been recognized as a major barrier for the implementation of smart transport infrastructure. Finally, crowdsourcing give empowerment to people in a global perspective by changing the **granularity of measures, monitoring and planning**.

Remarkably, smart and integrated infrastructure can promote sustainable mobility ensuring more inclusive and healthy transport services. Furthermore, electrification of transport could promote the **integration of transport and energy infrastructure** and can give momentum to more efficient and reliable vehicles relying on more sustainable fuel sources and carriers thus helping the penetration of renewable energy in a final sector with a strong lock-in with carbon-based fuels. On the other hand, using electric vehicles as power grid infrastructure for energy storage options provide a higher flexibility of the energy system as a whole helping a higher penetration of renewable power sources.

SMART AND INTEGRATED INFRASTRUCTURE IN AFRICA: RACOMANDATIONS FOR AN ACTION AGENDA

Deploying SMART-I Infrastructure for Africa needs to be recommended to promote Prosperity. Some of ten key recommendations emerges from the data and policy analysis in the different sector of digitalisation, decarbonisation and smart mobility are:

1. *Broadband penetration needs to be widen in the continent to support sustainable development.*
2. *Digital transformation is crucial to enable a new asset for African manufacturing and productivity.*
3. *Digital Technologies can boost people engagement and empowerment.*
4. *Renewable Energy & Efficiency need to be top priorities to unleash access to modern services.*
5. *Increased power capacity and reliability need to boost local economy and business development.*
6. *Interconnections and Networking of energy system cannot wait longer to increase trade and savings.*
7. *Distributed energy system may complement on grid option to increase inclusion and empowerment.*
8. *Smart transport infrastructure is prodromal of prosperity in Africa.*
9. *DigitalWization of transport and logistics spurs African manufacturing and productivity.*
10. *Systemic integration and effective resource management need to be on top of the Africa Agenda to unveil the potential of Smart-I Infrastructure.*

The attributes of SMART-I Infrastructure also complement and characterise the needed transformation of the African Socio-Economic asset toward the NPR adoption in the continent:

Economic Effective. The positive impact of broadband penetration opens a new era for the infrastructure development and an innovative asset for the national economy contributing to business development, annual sales saving, operational costs reduction, productivity and competitiveness, affecting national GDP by taking profit from the positive correlation with income boosted by the opportunity of connecting people, jobs, goods and markets.

Environmental Friendly. Africa cannot lose momentum to investigate low carbon and efficient alternatives in order to prepare the long term future beyond 2030. Digitalised energy infrastructure and shared mobility with proper regulatory framework allow cleaner energy services and avoid lock in in the transportation sector, and enable a more efficient use of energy and natural resources.

Social Inclusive. SMART-I Infrastructure needs to act on the social divide allowing different services to be available for all in order to meet basic needs, community expectations like health and education, productive uses in the industrial or agricultural sector. In addition, the reliability of services supports fair conditions for business development by reducing the upfront cost of investment that otherwise could be met only by higher income categories.

Safe and Resilient. SMART-I Infrastructure for distribution networks (electricity, roads…) are crucial for reducing the divide among rural and urban area and to fasten the adoption of modern, healthy and safe services. Data collected from sensors, machines and vehicles enable rapid decision-making and improve productivity, operational safety and maintenance and a new engagement by people is expected by the introduction of new digital products and services that allows customer-specific solutions.

Integrated by data, function & governance. Introducing digital technologies and proper governance into existing infrastructure increases productivity thus changing old paradigms based only on capacity and giving more relevance to efficiency. Inter-sectorial synergies are crucial: energy, water, ICT, transport, so that governance needs to be the backbone of SMART-I Infrastructure. New ways of interaction and cooperation with suppliers and customers enable open innovation and crowdsourcing.

Physically and Financially Decentralised. A new ecosystem of digital entrepreneurs needs to flourish associated to new business models like distributed manufacturers, starting with little capital and using the earnings to finance expansion. Distributed solutions, boosted by cost reduction, energy efficiency, social entrepreneurship, disruptive digital technology, bring the double advantages of increasing renewable energies and reducing investment. The implementation of smart transport and logistics solutions can stimulate more decentralized and small business offering a greater flexibility that could overcome financial barriers.

Life Cycle Perspective-Based. Life cycle and circular economy perspective need to be a new paradigm on which SMART-I Infrastructure development is promoted for assessing a fair allocation of resource's consumption and synergies and trades among different economic sectors and economies. A new paradigm of consumption-based accounting is thus requested to define effective policies.

People Centred. New products and services as well as new business models are characterised by an emphasis on high value-added digital technology where people are the centre of the stage. Decentralised solutions need to be driven by local needs, respond to capacities, and aspirations of people and be absorbed within the local culture, adapted and improved by local people. So, empowerment driven by capacity development (technical, managerial, institutional) can increase ownership and avoid lock-in solution for the long run while facilitating the NPR promotion as stated at the G7 Africa Outreach in Taormina 2017.

1 The potential of the Next Production Revolution in Africa

1.1 NPR AS A STEP ALIGNED WITH THE SUSTAINABLE DEVELOPMENT AGENDA

Africa is ready to **jump straight into the revolutionary frontiers** that represent the enabling environment for the transformative change that is so strongly requested by the 2030 Agenda. Africa does not need to replicate misleading trends of development, production and consumption that are now calling for strong efforts and **Partnership** at global level in order to set appropriate remedies, support the achievement of sustainable development while maintaining global **Peace**, reduce inequality among **People** and promote a more equitable **Prosperity** for all, including the **Planet** at large.

The confluence of technologies for the Next Production Revolution

In this perspective, **the Next Production Revolution** (NPR) represents a potential opportunity and a big challenge for Africa and its socio economic development, also considering the traditional leapfrogging attitude that has already characterized the straight and successful diffusion of a number of smarter or cleaner innovations in the continent as clearly stated within the "G7 Summit, Chair's Summary of the Outreach Session on Africa" [1]. Indeed, NPR entails a **confluence of technologies** (see box 1) ranging from a variety of digital technologies (e.g. 3D printing, Internet of Things, advanced robotics) to **new materials** (e.g. bio- or nano-based) and **processes** (e.g. data driven production, artificial intelligence, synthetic biology) [2]. Although conventional materials and industrial processes will be still used in the twenty-first century [3,4], the merging of the real

BOX 1

Digital transformation

Digital transformation of industrial production is strongly enabled by information and communication technologies including big data, cloud computing and internet of things. Integration and networking of physical, digital, data and people may result in innovative solutions like additive manufacturing and autonomous machines/systems that are able to transfer digital instructions to the physical world, human-machine integration like touch interfaces and augmented reality systems [Baur et al., 2015]. The introduction of these solutions in industry has been referred as Industry 4.0 that is the use of intelligent technical systems for mass production [Stahel, 2016].

New Materials

New materials are crucial in the NPR and involve a higher deployment of bio-based products and nano-structured solutions. Biochemicals, bioplastics and biofuels represent the largest market share for biomass-derived products. Recent studies [OECD/IEA, 2014], [E4Tech et al., 2015] indicated that almost 100 bio-products from sugar platform are currently under pilot or lab-scale investigation and will reach the market between 2020 and 2050. Nanotechnology promises to develop several organic and inorganic materials for applications in many fields including water and wastewater treatment, desalination and materials for energy. Advanced carbon-based materials like graphene and carbon nanotubes promise a technological revolution based on their sensational properties [Peplow, 2013]. In addition, nano-catalysts will increase properties of technologies for energy generation and storage. The development of nano-based materials is depending in the advances of production processes but also in materials modelling, scientific instrumentations and infrastructure.

New Processes

New processes are emerging from the convergence of bio, digital and nanotechnologies that will reshape design and production in terms of materials deployment and production schemes. Genomics, synthetic biology, additive manufacturing and computational design enable the design of biologically-based parts and devices as well the redesign of existing, natural biological systems [Oxman, 2015]. As these technologies have an impact on the production and the distribution of goods and services, they will have far-reaching consequences for productivity, skills, income distribution, well-being and the environment as stated by the OECD.

C. Baur and D. Wee, "Manufacturing's next act | McKinsey & Company.", 2015. [Online]. Available:http://www.mckinsey.com/business-functions/operations/our-insights/manufacturings-next-act. [Accessed: 02-Apr-2017].
E4tech, Record, and WUR, "From the sugar platform to biofuels and biochemicals - Final Report for the European Commission.", 2015.
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N. Oxman, "Design at the intersection of technology and biology.", TED Talk, 2015. [Online]. Available: https://www.ted.com/speakers/neri_oxman. [Accessed: 02-Apr-2017].
M. Peplow, "Graphene: The quest for supercarbon.", Nature, vol. 503, no. 7476, pp. 327–329, Nov. 2013.
W. R. Stahel, "The circular economy.", Nature, vol. 531, no. 7595, pp. 435–438, Mar. 2016.

and virtual worlds, the use of new materials and processes will deeply reshape design, engineering and production. To transform the potential of this confluence into an effective power for Africa, an enabling infrastructure as hard component is strongly needed and a new generation of leaders able to manage such innovation being as soft component cannot be neglected.

Technology and Innovation for the SDGs

In addition to the specific relevance for the NPR, also in the 2030 Agenda [5] the role of the **emerging technologies** is considered crucial for the achievement of the Sustainable Development Goals in 2030. Emerging technologies may be grouped into 5 clusters: **the bio-tech, digital-tech, nano-tech, neuro-tech and green-tech** (see Box 2).

Box 2

Bio-Tech
They include genomics, industrial biotechnology, synthetic biology, etc…

Digital-Tech
They include big data, cloud computing, internet of things, 3D printing, etc…

Nano-Tech
They include nanomaterials, nano process, nano systems, etc…

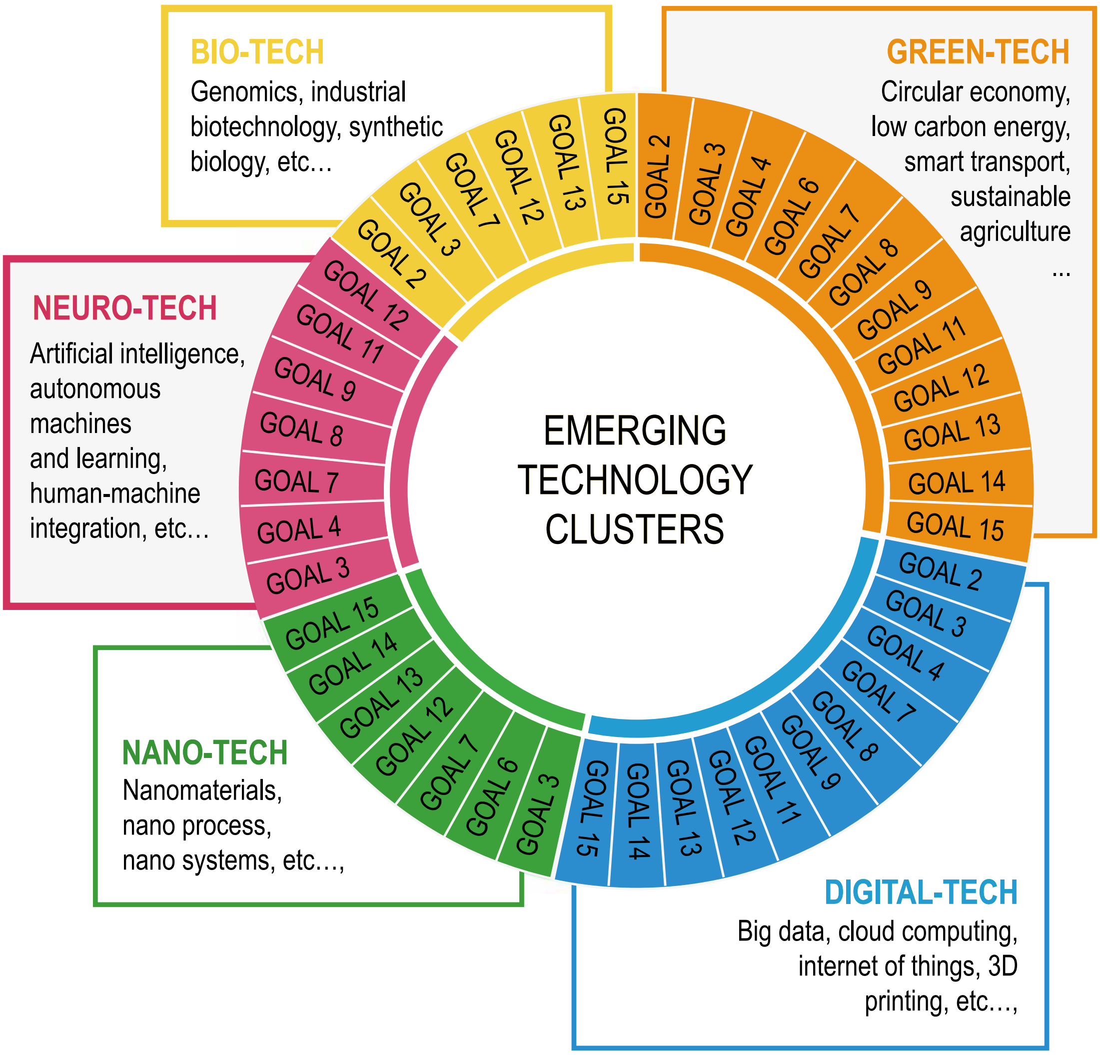
Neuro-Tech
They include artificial intelligence, autonomous machines and learning, human-machine integration, etc…

Green-Tech
They include circular economy, low carbon energy, smart transport, sustainable agriculture...

These emerging technologies are **combinatorial** which means that they are not conceived as stand-alone monolith, but interact in many ways and interest a variety of disciplines like physics, biology, computer science and others affecting thus research, industrial business and the world's economy at large.
Analyzing these clusters in the light of the 17 SDGs, it emerges that **Digital and Green Tech are the most populated clusters** as shown in Figure 1. This means that they appear as supportive tools for the achievement of many SDGs like Health, Water, Energy, Ecosystem, Land, Ocean Management, Climate Change, Sustainable Production and Consumption patterns. Moreover, Digital and Green Techs are the emerging technological clusters **mostly related to infrastructure** and therefore those from which, on the perspective of ICA, any transformative path in Africa to cope with NPR challenges should start. Finally,

enabling Digital and Green Techs may be considered **as an essential precondition** to the future development of Bio-Nano and Neuro-tech in Africa.
For the above three reasons Digital and Green Tech are at the core of ICA 2017. More in details, Digital Tech is directly linked to Digital Infrastructure while Green Tech includes two main components that are Sustainable Energy Infrastructure and Smart Mobility.

FIGURE 1. LINKS BETWEEN EMERGING TECHNOLOGY CLUSTERS AND SUSTAINABLE DEVELOPMENT GOALS



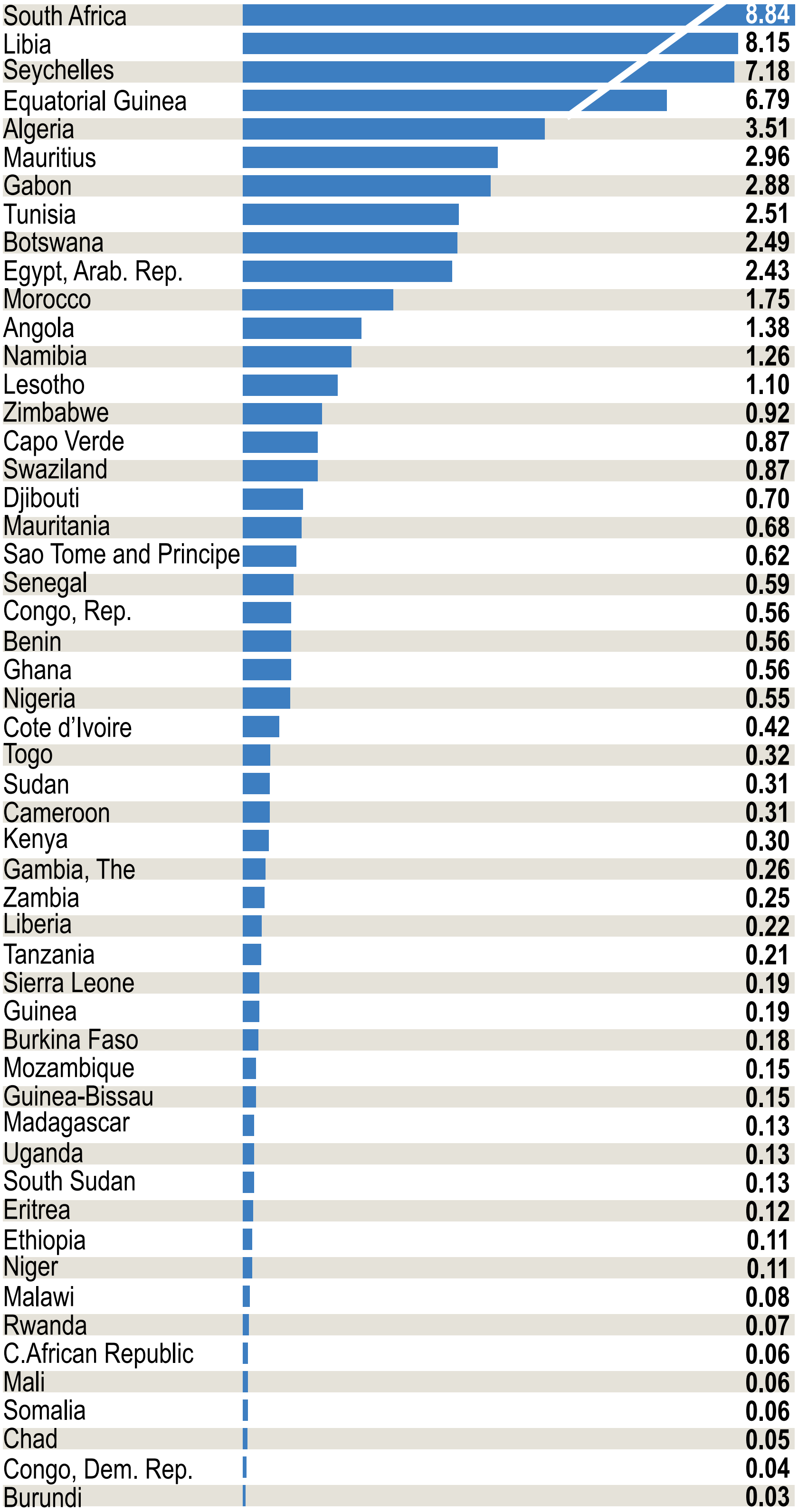
Source: Own elaboration from OECD, "Enabling the next production revolution: the: the future of manufacturing and services- Interim Report.", Meeting of the OECD Council at Ministerial Level, 2016, [2] and United Nations, "Global Sustainable Development Report.", New York, 2016, [5].

1.2 INFRASTRUCTURE FOR SOCIO-ECONOMIC DEVELOPMENT AND WITHIN THE POST-PARIS AGREEMENT

Infrastructures are a crucial asset in the socio-economic development of the countries. The relevance of both **physical** (e.g., telecommunication, energy, transport, water supply) and **social infrastructure** (e.g., health, education, banking, commercial services) for socio-economic development has been extensively investigated over the last years [5-9] including the impact in developing countries [10,11]. **Infrastructure** is critical to ensure basic human needs for food, water, energy, transportation, communication. However, **infrastructures development** needs to cope with the new global frameworks. A **confluence of technological innovation matching with political, institutional and social innovations** coupled with other megatrends may have the power to trigger a transforming process that is requested for our society. From a **technological standpoint** - the OECD has formalized the concept of the Next Production Revolution that will have a disruptive impact on productivity, work, skills, markets, poverty and inequality, well-being and environment. From a **political and institutional point of view**, the Paris Agreement on climate change, the 2030 Agenda for Sustainable Development and the Addis Ababa Action Agenda represent paramount innovative reference assets. They set a **universal, integrated and transformative vision** for a better world including a new financing framework to achieve sustainable development goals and the mitigation of global threats that erode the current conditions of well-being and stability. Infrastructures are a **crucial pillar in this global ecosystem for systemic innovation. Infrastructures** may be drivers of economic growth and development, enablers of technological progress to find the right balance to both economic and environmental challenges (e.g., providing new jobs while promoting efficiency of services and /or products).

However, **infrastructure development**, within the current production schemes, may represents a big burden for additional greenhouse gases emissions even if the specific value for Africa are much lower (Figure 2) than the average of other continents. Indeed, **Paris Agreement** indicates a 'net-zero' emissions energy system by 2100 to limit average global temperature rise well below 2 °C. Therefore, long lasting effects of infrastructure need to be considered in order to avoid the risk of **technological lock-in** to a set of configurations that are able to meet 2030 or 2050 targets but that inevitably are due to fail in achieving the target for 2100 [12]. Approximately 90% of African countries have submitted their **Intended Nationally Determined Commitments** (INDCs) meaning a high commitment towards international policies as shown in Figure 3.

FIGURE 2. YEARLY PER-CAPITA EMISSIONS OF SOME AFRICAN COUNTRIES. (METRIC TONS PER CAPITA)



Source: Own elaboration from The World Bank, "Data | The World Bank." [Online]. Available: http://data.worldbank.org/. [Accessed: 29-Apr-2017], [13]

FIGURE 3. INDCS MAXIMUM MITIGATION TARGETS OF SOME AFRICAN COUNTRIES

Among others, Tunisia indicated a reduction of its carbon intensity of 41% in 2030 with reference to 2010. In the case of South Africa, the time-frames within the peak, plateau and decline trajectory range are 2025 and 2030, in which emissions will be in a range between 398 and 614 Mt CO_2–eq.

> 75%

Sierra Leone, Namibia, Eritrea

> 50%

Chad, Nigeria, Ethiopia, Djibouti, Congo, Rep. Equatorial Guinea, Gabon, Angola

> 25%

Madagascar, Gambia, Ghana, Lesotho, Niger, Zimbabwe, Morocco, Cameroon, Mali, Togo, Mauritius, Kenya, Cote d'Ivoire, Senegal, Central African Republic

> 0%

Zambia, Mauritania, Algeria, Uganda, Benin, Burundi, Burkina Faso, Dem. Rep. Congo, Botswana, Liberia

Source: Own elaboration from UNFCCC, "Synthesis report on the aggregate effect of intended nationally determined contributions." [Online].
Available: http://unfccc.int/focus/indc_portal/items/9240.php. [Accessed: July-2017], [14]

Quality and reliable infrastructures are a precondition that may trigger access to different pivotal services for fighting poverty. Quality and reliable infrastructures help increasing the quality of life and boost local economy and entrepreneurship. Nevertheless, infrastructure development is still poor in the African continent. **Africa, indeed, needs to bridge a large infrastructural gap** compared to other macro regions. This is particularly true when dealing with **energy, transport and ICT assets**. The **low population density**, the **high concentration of landlocked countries** and **the high share of rural settlements** hinder a large-scale infrastructure development resulting in expensive services compared to other macro-regional aggregations.

Energy Services

In the energy sector, the infrastructure dearth is largely manifest both from a quantitative and qualitative perspective. The African average per capita of **electricity production and consumption**, as well as the share in **access to electricity and to modern fuels** are incomparably lower than the world average and definitely the lowest among the others aggregated regions (Figure 4).

FIGURE 4. ENERGY INFRASTRUCTURE – MACRO REGIONAL ENDOWMENT

	Electricity production (Billions of kWh)	Per capita electricity consumption (kWh per capita)	Access to electricity (% of population)
Sub-Saharan Africa	467.4	496.8	37.5
South Asia	1,478.4	707.3	80.0
East Asia & Pacific	8,735.9	3,682.5	96.5
Middle East & North Africa	1,379.6	2,906.4	97.0
Latin America & Caribbean	1,588.2	2,121.9	97.0
Europe & Central Asia	5,254.8	5,369.0	100.0
North America	4,977.4	13,230.3	100.0
WORLD	**23,863.9**	**3,144.4**	**85.3**

Source: Own elaboration from The World Bank, "Data | The World Bank." [Online]. Available: http://data.worldbank.org/. [Accessed: 29-Apr-2017], [13]

Moreover, energy uses underline the substantial dependency on traditional use of solid biomass especially at household level and a very low efficiency in the sector as synthetized by the **energy intensity** which is more than 1.5 times that of Europe and Central Asia.

More in details, **access to electricity** is limited to **less than 40%** of total population in the Sub-Saharan region with a huge gap relative to 80% share in South Asia (Figure 4). Some countries still provide electricity to less than **10% of the total population** and rural areas, of around 20 Sub-Saharan countries, are almost lacking electrical energy services. **Access to clean fuels** and technologies for cooking is even smaller accounting for less than **15% of Sub-Saharan population** (Figure 4). Electricity production is very low, just a fraction of production rates in other macro regions. Despite averaged with Middle East, it is also evident that the features for North Africa are different especially in term of access. At any rate, and as continental average, electricity consumption per capita is less than **600 kWh/per capita per year** representing less than 20% of the world average. Energy intensity is almost twice the world average and more than three times the OECD level. The indicators given in Figure 4, gives evidence of an economic structure that still relies on very low efficient and not clean supply chains for manufacturing. This is the essence of the energy paradox in Africa: despite rich in resources, Africa is indeed poor in energy supply and lack of reliable and valuable energy services.

	Access to clean fuels and technologies for cooking (% population)	CO2 emissions (kg per 2010 US$ of GDP)	Energy intensity level of primary energy (MJ/$2011 PPP GDP)
	14.6	0.51	7.1
	32.5	0.95	4.7
	59.2	0.73	6.1
	97.1	0.81	5.3
	86.5	0.32	4.0
	97.2	0.30	4.6
	100.0	0.32	5.8
	57.6	**0.50**	**5.4**

Transport Services

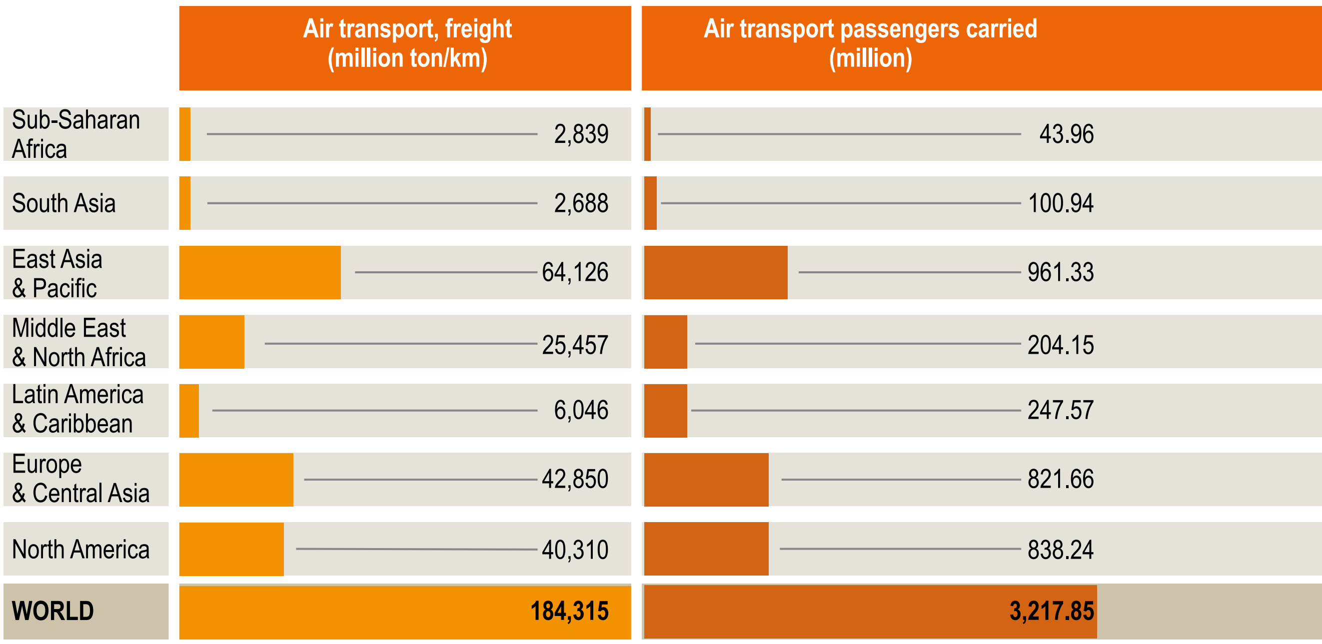
Transport infrastructure, in terms of both roads, rail lines, air transport and port, is another crucial pillar to foster sustainable development in Africa enabling local, regional and international trade. **Road transport contributes to 90% of passengers' mobility** and more **than 80 % of goods' exchanges**. More than **50% of Africa's road network is unpaved** hindering the access to basic social services and burdening local economic activities, especially for rural population [15].

Rail networks are weakly developed in Africa: including North Africa they account for less than 8% of rail lines (Figure 5) mostly concentrated in South Africa (around 20,000 km), Sudan (around 4,500 km) and Congo Dem. Rep. (around 3,500 km). Thirteen Sub-Saharan African countries have **no operational rail networks. Spatial density of operational rails are as low as 30 to 50 km per million people**, with only few countries (Gabon, Botswana, and South Africa) having network densities of more than 400 km per million people.

Air transport enables **the trade of time-sensitive, perishable exports** such as food products that are becoming increasingly important foreign-exchange earners for African countries. In the last ten years air transport freight has almost doubled reaching more than **2800 million ton/km in Sub-Saharan Africa** (Figure 5). However, even including North Arica, **air transport is still modest** in the continent when compared with other macro regional aggregations (Figure 5).

From an integrated perspective, it is worth mentioning the lack of transport connectivity between roads, rail lines and ports that may instead contribute to facilitate the empowerment of the sector [15].

FIGURE 5. TRANSPORTATION INFRASTRUCTURE – MACRO REGIONAL ENDOWMENT



Source: Own elaboration from The World Bank, "Data | The World Bank." [Online]. Available: http://data.worldbank.org/. [Accessed: 29-Apr-2017], [13]

Digital Services

Information and communication technologies had a rapid growth in Africa that is now the second largest mobile phone market in the world. In 2014 Africa had **around 760 million mobile subscribers** with a projection to achieve 1 billion target by 2016. Nevertheless, penetration rate of mobile phones ranges from 71% in SSA to 111% in the aggregated region including North Africa is still among the lowest when compared with other macro-regional aggregations. Moreover, individual Internet access is still very low with slightly less than **20% of individuals using internet in SSA and less than 40% in the aggregated region including North Africa** but progression are going fast (data at 2017 is slightly above 28% of total population [16]). Indeed, this percentage was only **5% in 2009** giving evidence of the fast growth of the sector. Despite the positive trends, African ICT sector is still relatively immature as shown by **low fixed broadband subscriptions** for both Sub Saharan African and North Africa (Figure 6), thus giving a cause to the **low impact of Internet on African GDP** (1.1% compared to 3.7% of developed economies and 1.9% of emerging economies [17]).
Zooming the continental perspective, at regional level, lack of infrastructure is concentrated on Central and Eastern Africa in terms of access to electricity, road infrastructure and internet access, as shown in Figure 7.

	Air transport, registered carrier departures worldwide (million)	Rail lines (total route-km)
	679	59,634
	927	77,897
	7,907	127,034
	1,505	32,046
	2,784	102,460
	7,447	375,844
	10,847	280,349
	32,095	**1,055.26**

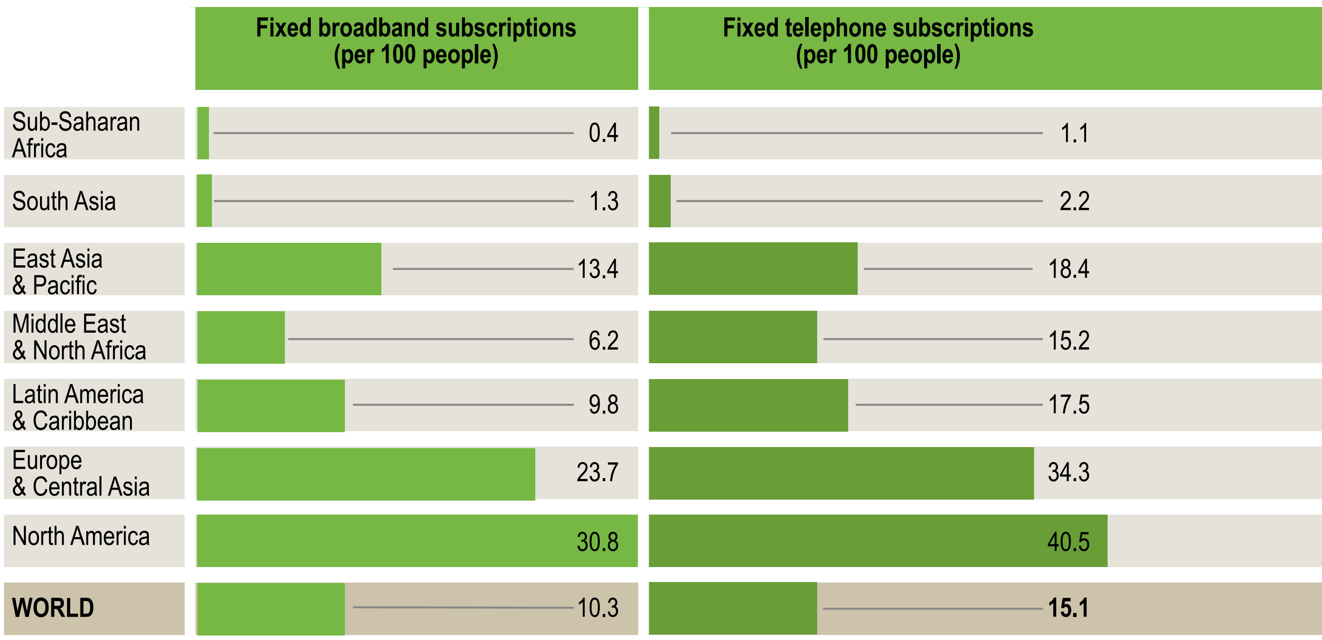
Investment Gap for increasing capacity and beyond

Filling the infrastructural gap of Africa is urgent and in this perspective, additional resources to increase **capacity** are certainly needed. Nevertheless, a stronger added value could be brought to the sector by promoting a set of other strategies to improve quality of use for the current infrastructural asset, thus improving specific **productivity**.

From a global perspective, a **cumulative investment of $57 trillion by 2030** was recently suggested [18] to maintain an adequate infrastructure capacity and service relative to GDP, which means ensuring a value of **infrastructure stock at around 70 % of GDP**. A rise of annual baseline infrastructure investment from **$2.6 trillion in 2013 up to $4.5 trillion in 2030** would be therefore required in this scenario. Though a good base, such an investment would not be enough **to fill neither the existing gaps** among developing countries and developed regions, **nor addressing universal access to roads, clean water, sanitation, and electricity** in the continent. Furthermore, it does not consider extra investments required to tackle environmental stresses from climate change mitigation and adaptation [18].

Indeed, widening the approach beyond baseline, **global investment needed to achieve SDGs are estimated in the order of $5 trillion to $7 trillion per year** [19]. The range to be allocated to developing countries is between **$3.3 trillion and $4.5 trillion** per year with investments mainly in the sector of basic infrastructure (roads, rail and ports; power stations; water and sanitation), food security (agriculture and rural development), climate change mitigation and

FIGURE 6. ICT INFRASTRUCTURE – MACRO REGIONAL ENDOWMENT



Source: Own elaboration from The World Bank, "Data | The World Bank." [Online]. Available: http://data.worldbank.org/. [Accessed: 29-Apr-2017], [13]

adaptation, health and education.

Within this total amount, **physical infrastructures** in developing countries would require from around $1.6 trillion to $2.5 trillion per year. This brings to evidence an estimated gap close to $1-1.5 trillion per year when compared with the current investments [19,20]. Figure 8 shows global data broken down by sector where investments in infrastructure in developing countries are estimated to be at **1.8% of global Gross Domestic Product (GDP)** while the investment gap should be between 2.5% and 4.3% of global GDP. In line with the scope of the ICA background paper, Figure 8 also shows that a stronger commitment in infrastructure investments would be needed in the **energy, transport and ICT** sectors as well as in their integration.

In 2015, investments for Africa's infrastructures amounted to $83.4 billion showing a 12% increase with respect to the previous year [21].

African national governments committed 34.1% of total investments while the **private sector shared only 8.9%**.

Energy and transport sectors collected more than 80% of total investments sharing each roughly half of the total expenditure of $69.4 billion. At regional scale, investments were mostly allocated **in Eastern Africa** (23.1%).

The whole **Sub-Saharan Africa**, excluding South Africa, was recipient of $55.4 billion or **2/3 of total investments**. Investments from **private sector** were almost entirely focused in the **energy sector** and where mostly concentrated in South Africa (51.2%) followed by North Africa (16.5%) and West Africa (17.2%). In the whole Sub-Saharan Africa private sector investments were around **$6.3 billion with the power sector sharing more than 95%** of it and the remainder

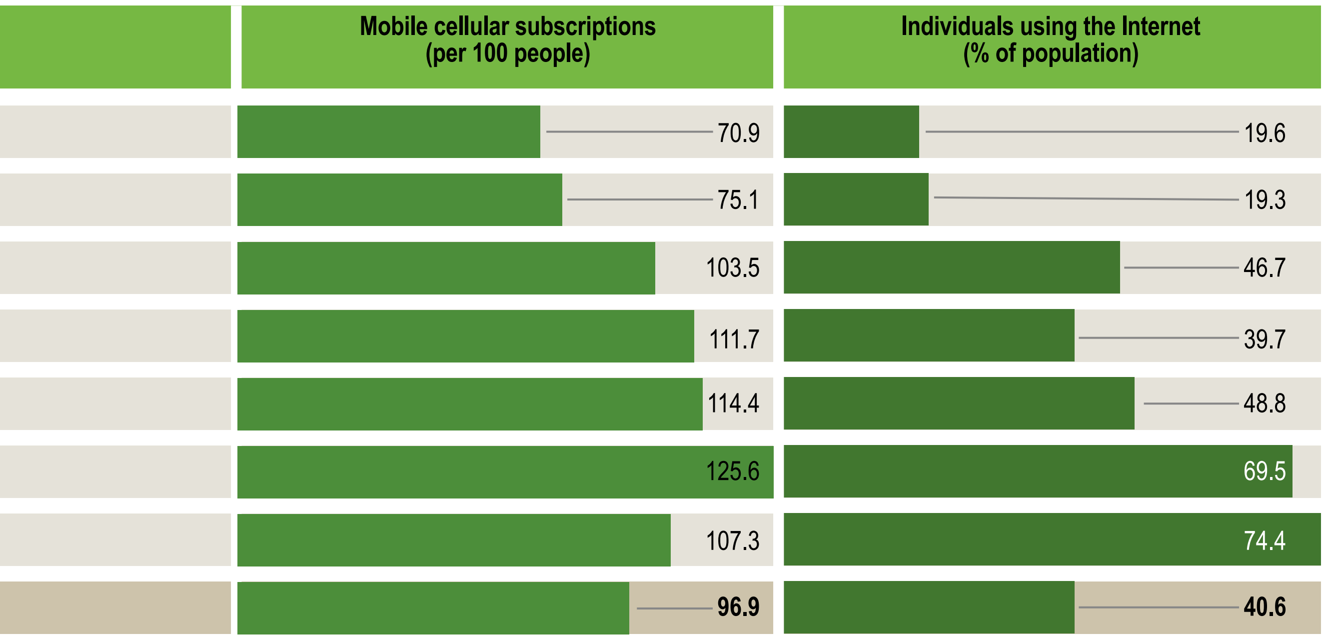
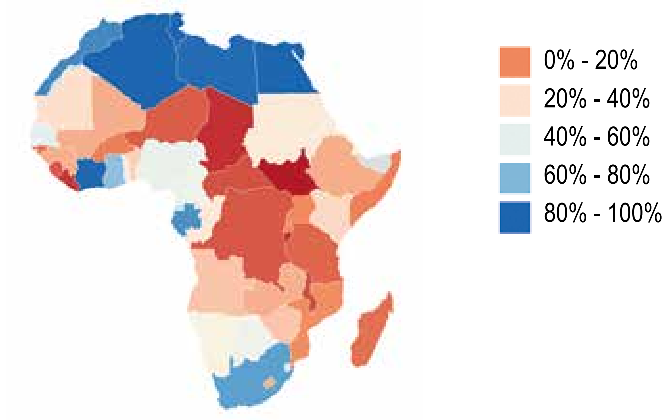
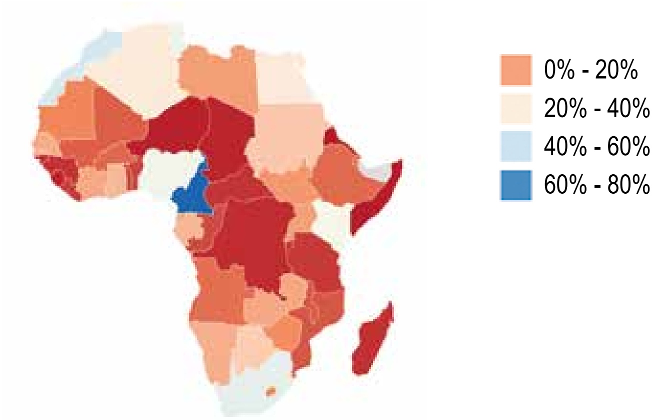


FIGURE 7. ENERGY INFRASTRUCTURE - REGIONAL ENDOWMENT

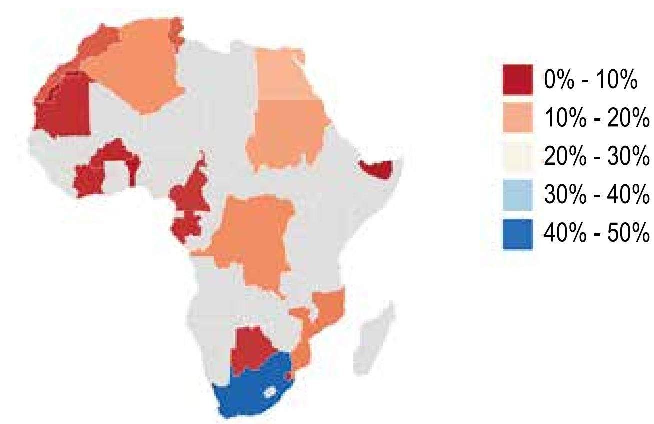
ACCES TO ELECTRICITY
% of population



INDIVIDUALS USING INTERNET
% of population



RAIL LINE TOTAL ROUTE - KM
%



Source: Own elaboration from The World Bank, "Data | The World Bank." [Online]. Available: http://data.worldbank.org/. [Accessed: 29-Apr-2017], [13]

allocated in **road construction and water infrastructure**.
Figure 9 shows the trend of private investment; indeed, in the period from **2010 to 2015** most of private investments in Sub-Saharan Africa were allocated in **ICT infrastructure** with **few but big projects**. However, in the last three years a shift of private investments from ICT **to energy infrastructure** has been observed. **Private investments in transport sector are very small** mainly concentrated in ports and less in airport and roads.
Figure 10 shows the evolution of private investments in the period from 2000 to 2015 in different macro-regional aggregations and from a different perspective. It appears clear how the effort from private sector was mostly concentrated in **ICT infrastructure especially for the Sub-Saharan Africa case**. Moreover, investments were of large-scale type as shown by the relative low number of projects in Sub-Saharan Africa in comparison with other macro-regional aggregation.

FIGURE 8. CURRENT INVESTMENT AND GAPS IN DEVELOPING REGIONS BY SECTORS

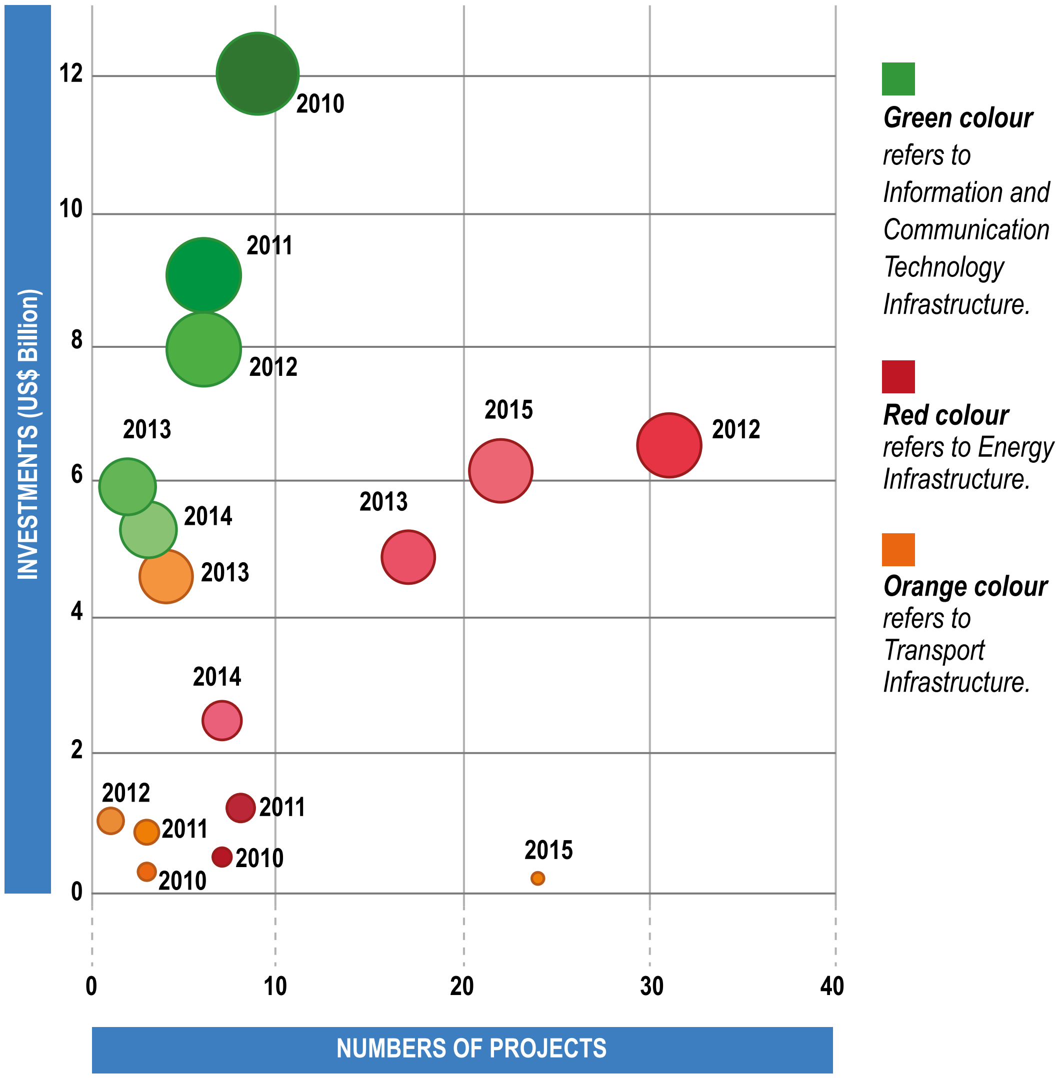
Only upper estimates of investments gaps are shown.

	Actual Investment (% Global GDP)	Investment Gap (% Global GDP) upper estimate
Power	0.3	0.9
Transport	0.4	0.6
Telecommunications	0.2	0.3
Water and sanitation	0.2	0.3
Food security and agriculture	0.3	0.3
Climate change	0.2	1.0
Health	0.1	0.2
Education	0,1	0.3
Physical Infrastructure	**1.3**	**3.1**
Total infrastructure	**1.8**	**4.2**

Source: Own elaboration from United Nations, "World Investment Report 2014: Investing in the SDGs: An Action Plan.", 2014, [19].

FIGURE 9. PRIVATE INVESTMENTS IN SUB-SAHARAN AFRICA FROM 2010 TO 2015

Dark to light colours' variation refers to time shift from 2010 to 2015



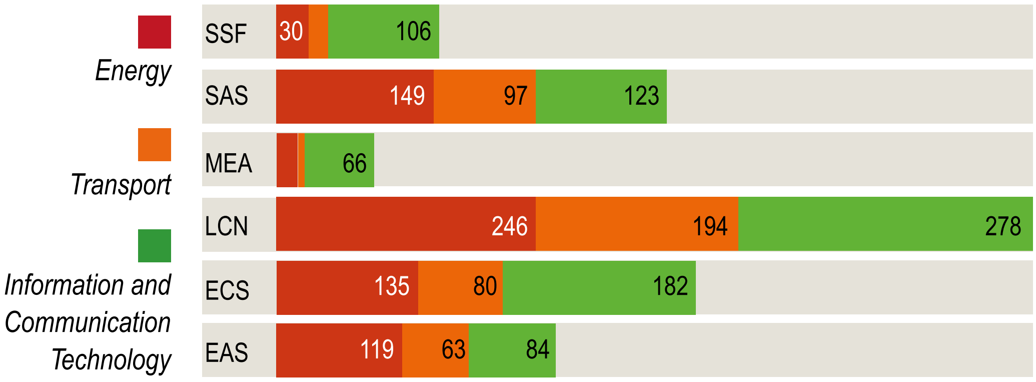
Source: Own elaboration from The World Bank, "Private Participation in Infrastructure (PPI) Project Database - World Bank Group." [Online]. Available: https://ppi.worldbank.org/. [Accessed: 28-Jun-2017], [22]

FIGURE 10. PRIVATE PROJECTS IN DIFFERENT MACRO-REGIONAL AGGREGATIONS FROM 2010 TO 2015

SSF: Sub-Saharan Africa.
SAS: South Asia.
MEA: Middle East and North Africa.
LCN: Latin America and Caribbean.
ECS: Europe and Central Asia.
EAS: East Asia and Pacific.

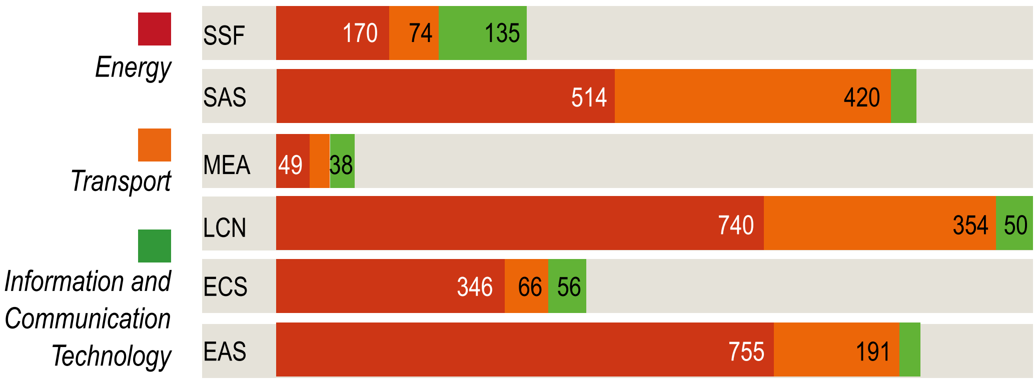
PRIVATE INVESTMENTS IN VARIOUS MACRO-REGIONAL AGGREGATIONS

(2000-2015) US$ billion



NUMBER OF PRIVATE PROJECTS IN VARIOUS MACRO-REGIONAL AGGREGATIONS

(2000-2015)



Source: Own elaboration from The World Bank, "Private Participation in Infrastructure (PPI) Project Database - World Bank Group." [Online]. Available: https://ppi.worldbank.org/. [Accessed: 28-Jun-2017], [22]

BOX 3

Are investments on the right track?
A comparison among current investment and needed investment

In the **energy sector alone**, in order to meet the New Policies Scenarios proposed by the International Energy Agency in 2014 [OECD/IEA, 2014] **investments of more than $110 billion per year to 2040 in the whole Sub-Saharan Africa are needed, $46 billion** of which related to power generation, transmission and distribution. In this scenario, the sub-Saharan power system would expand it generation capacity of more than 4 times from roughly 90 GW to 385 GW and diversify its mix: coal (South Africa) and hydropower (all regions) will come to be supplemented by natural gas and by an increased share of renewables (including solar, wind, geothermal and biomass) which will double the share of today in 2040. This investment, will allow to reduce the share of fossil fuel installed capacity from 77% in 2012 to 54% in the same period supporting the path toward a more decarbonised scenario but still not providing universal access for all. Indeed, according to the IEA's Africa Century Case, additional $17 billion should be added on average per year over the period 2013-2040 in order to provide **full electricity access in urban areas and achieve two-thirds in rural areas of all countries of sub-Saharan Africa**. The African Century Case is also accompanied by "improvement of the reliability of electricity supply, reducing the incidence of power outages by half". **A higher quality power network is expected to raise the productivity of African companies**: every additional $1 invested in the power sector in the African Century Case generates more than $15 in incremental GDP.
Compared to the mentioned **$83.4 billion of investments for Africa's infrastructures in 2015**, the investments' needs are definitely much higher as it is evident by this comparison based only on (some of the needs) of the energy sector.

OECD/IEA, "World Energy Outlook 2014.", OECD Publishing, 2014.

2

Smart and Integrated Infrastructure in Africa

The share of **middle- and low-income countries** in global GDP (on purchasing parity terms) has increased from less than 40% to more than 50% since year 2000 and is expected to increase to two-thirds by 2030. The world is indeed experiencing an historic structural transformation, where **developing countries are coming** to be the major drivers of investment and growth. In addition, they are driving the largest wave of urbanization than ever, as more than 1.5 billion people will move to cities within 2040. This **unique transformation** calls for rapid technical progresses in digitalization, energy, transport and other spheres like biotechnology and materials. Nevertheless, at the same time this progress needs to be carried out in compliance with the urgency of **controlling carbon footprint** and impact on climate. In this scenario, a major expansion of investment in modern, clean, and efficient infrastructure will be essential at global level, but vital for Africa also for meeting the long-term compliance with the Paris Agreement. **The Next Productive Revolution** offers, to developing countries and therefore to Africa, the opportunity to achieve sustainable development goals provided the setting of an enabling infrastructure and a new generation of leaders able to manage such innovation. Embracing the pathway toward Smart and Integrated Infrastructure, designed to enable the convergence among digital, energy and transport/logistics platforms is an opportunity to boost the Next Productive Revolution.

INTEGRATION OF PHYSICAL AND DIGITAL INFRASTRUCTURE

2.1

The early path towards low-carbon and quality infrastructure has already lead to a **'leapfrogging' change of infrastructure system**, which needs to be more focused on a comprehensive **smart and integrated** approach including *functional and data integration*, a *decentralized paradigm*, a *life cycle perspective* and a *new and pro-active role of users*.

First, smart refers to a massive penetration of digital technology in the infrastructure sector to control, manage and optimize uses. Secondly, **integration** indeed, refers to the coping of functionality of different physical infrastructures, data integration and sharing across sectors between energy, transport, telecommunication and digital infrastructure [23]. Infrastructures shape already today a complex network of multiple and mutual effects (e.g., failure in the power grid can hinder transport sector, etc.); however, infrastructure management is sectorial, disjointed and scattered, geographically and jurisdictional. Integrated infrastructures can therefore promote a new **infrastructure governance** able to foster an overarching approach to planning, delivery and management of infrastructure assets.

In addition, integration leads to the promotion of **new technological nexus** overlapping different sectors (waste, energy, transport, ICT, banking, financing) not necessary and exclusively relying on the import of 'plug-and-play' high tech solutions. In turn, this entails opportunities for new business models adding a win-win outcome of infrastructure investment. Overall, functionality and data integration promises to foster infrastructure productivity while addressing specific needs of people – this may be an effective way to mitigate the poverty trap and giving people access to service needs.

Decentralization is a crucial element in the transformative path for infrastructure, having two main meanings. From **the physical perspective,** we assist to a capillary distribution of technologies that are more massively at the disposal of citizen; digital technologies (i.e smart-phone) have increased the chance for everyone to get access to digital services, energy and transportation services. From **the financial perspective,** we are assisting to a parallel shift of capitals and infrastructure owners, from large creditworthy entities (e.g., large corporations and central governments) to smaller ones (i.e., households, smallholders, emerging economy cities without good credit ratings, new project developers), with new intermediation patterns which may open channels for participation of diverse actors.

Decentralization can offer a viable solution to those landlocked African countries that cannot access traditional centralized infrastructures. Furthermore, decentralization can mitigate constraints of low population density and high share of rural settlements.

In the same perspective, investments in infrastructure need to be more directed to solutions that aim at systemic/sustainable design, design-to-cost, lean execution, and service delivery.

The aim is to **optimize resource use in a life cycle and system perspective** enabling the transition that is requested from now to 2030 but also casting the right seeds for the more challenging shift needed to 2050.

Lastly, a new **people-centered perspective is envisaged where** households and communities are engaged in new or adapted forms of distributed control, with demand-response becoming a key resource. The development of the digital era has allowed information to become an asset for all with direct implication into ICT, energy and transport:

- **In ICT** since the lack of fixed line telecommunications presents a significant opportunity for mobile communication that has allowed people to be connected even in rural areas.
- **In low-carbon infrastructures**, cost reduction trends and the raising of a new category like the prosumer are disruptive paradigms promoting new win-win solutions for the penetration of renewable energies and distributed systems.
- **In the transport system,** the shift is revolutioning the sector orienting it toward efficient interface with existing informal and private transport providers, with soft and shared mobility solutions.

Smart and Integrated Infrastructure have therefore the potential to boost the Next Production Revolution by creating a **network of things, services, data and people**.

2.2 TAXONOMY OF SMART AND INTEGRATED INFRASTRUCTURE

Smart and Integrated infrastructures (**SMART-I Infrastructure**) need to become the driving element for the next investment generation in Africa. They represent the natural evolution of the list of attributes for infrastructure development and complement the previous definition of **sustainable** and **quality** infrastructure.

Indeed, as reported in the literature **Sustainable infrastructure** [24] are characterized by three attributes:

- **Socially sustainable:** inclusive to enhanced livelihoods assets by increasing access to basic services, by reducing poverty and by addressing vulnerability to climate change, cyber-attacks and terrorism.
- **Economically sustainable:** infrastructures should not burden governments with unpayable debt but rather create jobs, boost GDP and support local suppliers and developers.
- **Environmentally sustainable:** infrastructure should limit all types of pollution during construction and operation and support the conservation and sustainable use of natural resources.

As reported and analyzed at the ICA 2016 conference, **Quality infrastructure** introduces some additional attributes:

- **Economic effectiveness:** economic efficiency relates to both how well the initial investment is carried out and how well the subsequent physical asset is operated and maintained.
- **Inclusiveness:** inclusiveness relates to the degree to which the infrastructure service leads to the benefits of economic growth reaching the broadest possible segment of the population.
- **Safety and Resilience:** safety in use and operation and resilience against natural disaster relate to how well the infrastructure asset is able to perform under a wide range of climatic and other outcomes.
- **Sustainability**: it encompasses the degree to which environmental and social impacts are minimized and the degree to which their financing, operation and maintenance are ensured in the long run.

In the previous paragraph the introduction of Smart and Integrated infrastructure has added four new crucial attributes that should characterize **SMART-I Infrastructure (**Figure 11):

- **Integrated by data, function and governance**: sustainable and quality infrastructures have to employ innovative ways of meeting governance and service needs, including the implementation of more responsive, productive and integrated information systems that complement hard infrastructure (e.g., demand-side management systems, super-responsive grids, cross-sectorial/regional digital management and connection). For this reason, Governance keeps a key role at this level.
- **Physical and Financially Decentralised:** to take profit of the capillary and efficient distribution of technologies which are more massively at the disposal of citizens and the parallel shift of capitals and infrastructure owners, from large creditworthy entities to small ones.
- **Life Cycle Perspective**: the infrastructure for NPR needs to match the goal expressed by SDG11 dealing with new production patterns that need to be driven by rational use of resources in a long term and life cycle perspective.
- **People-Centred**: in line with the 2030 Agenda new consumption patterns are needed. They may be obtained only by an appropriate and multi-dimensional involvement of citizens not only in their role as consumers but also as influencers, producers and agents of the change. In this perspective, the issue of **crowdsourcing may become relevant**: technological changes over the past 10 years, in combination with increased bandwidth and the ability to provide better tools for collaboration, have led to "crowdsourcing". A People-driven approach is also envisaged within the "G7 Summit, Chair's Summary of the Outreach Session on Africa".

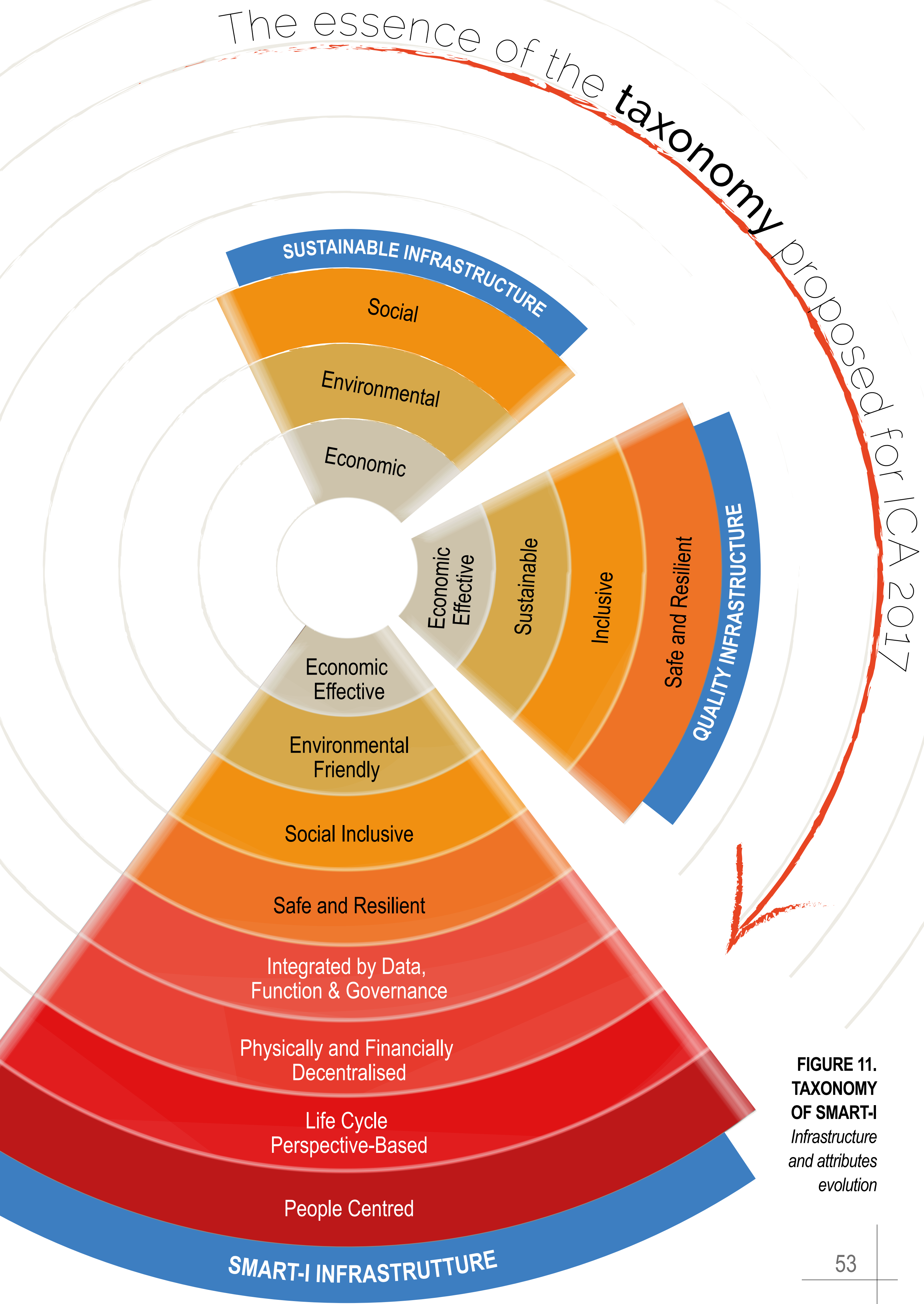


FIGURE 11. TAXONOMY OF SMART-I
Infrastructure and attributes evolution

3 The role and status of Smart and Integrated Infrastructure for Prosperity in Africa

The agendas of accelerating sustainable development, eradicating poverty and mitigating climate change are deeply intertwined. Growth strategies that fail to tackle poverty and/or climate change will prove to be unsustainable, and vice versa. A common denominator to the success of both agendas is infrastructure development. Infrastructure is an essential component of growth, development, poverty reduction, and environmental sustainability [19].
At the same time, the next 15 years will be crucial for arresting the growing carbon footprint of the global economy and its impact on the climate system.

3.1 DIGITALISATION: THE NEW ERA OF INFRASTRUCTURE

The combination of Internet of Things, 5G technology, Big Data and Cloud Computing is enabling new services, applications and business models across the economy. They are building blocks of the digital innovations that are transforming production and productivity in manufacturing, agriculture and services.
"Intelligent transport systems" contribute to improvements in traffic planning and management; smart metering and smart distribution systems can support the sustainable production and distribution of electric power and the efficient usage of water. Sensors and crowdsourced data gathered through users' smartphones can effectively monitor weather and environmental parameters for climate change monitoring. Likewise, they can be used to prevent or effectively manage natural disasters and emergencies. The combination of sensors with satellite or wireless connectivity technologies is at the basis of high-precision agriculture, which enables the matching of farming practices to the temporal and spatial variations of crop needs. Similar technologies permit reliable control of industrial automation

and robotics, while broadband wireless communications enable smart healthcare services in geographically remote areas.

To fully benefit from the digital economy, countries require a **smart and integrated digital infrastructure**. At its core, digital infrastructure includes telecommunications infrastructure, both fixed and mobile. This enables the creation of a "cyber" infrastructure devoted to the collection and analysis of data, which represents a form of capital usable for a theoretically unlimited range of purposes.

Within the Next Production Revolution (NPR), **Internet of Things, Big Data and Cloud Computing** will pay a crucial role.

The Internet of Things (IoT) consists of any physical and virtual (i.e., a representation of real object in a computer system) object that can be connected to other objects and to the Internet, creating a fabric between things as well as between humans and things. With IoT, products, services and platforms are able to connect, virtualise and integrate each other not only within close environments but also across different networks creating a much more connected world.

Cloud computing is defined as "a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction" [25].

Finally, Big Data represent information assets characterized by high volume, velocity and variety. Big Data collection and analysis through advanced analytic techniques is another pillar of the NPR since technological advances are unleashing enormous amounts of data. Data is becoming part of our infrastructure, alongside more traditional physical assets like transport networks, power generation and water supply [26]. Its potential is endless, especially in the case of **open data** that anyone can access, use or share. Among the large variety of applications that can benefit from open data, some are of prominent importance to Africa:

- **Public transport.** Transport users become fully informed about their travel options while at the same time enable transport authorities to plan and manage transport networks and services more efficiently. Crowdsourced public transport maps are a successful example of this approach: city residents can map the routes using smartphone applications when no official ones exist. The World Bank itself has initiated several initiatives to develop such applications, which can also provide reporting, planning and multimodal connections.
- **Emergency management.** Massive amounts of data collected by public authorities as well as by people using specific applications (crowdsourced data) can be effectively used to ensure swift response to and recovery from emergency situations such as natural disasters or energy grid failures.
- **Remote monitoring.** Users' smartphones can function as mobile sensors, gathering environmental and pollution data. Mobile apps further add the possibility for the users to report environmental data for the realization of smart city services, as well as medical data to monitor spreading of diseases. Smart meters as well as mobile apps can enable the analysis of user habits to understand water and energy consumption and improve the management of such resources.

Digital infrastructure enabling the Next Production Revolution

The future deployment and effectiveness of IoT, Big Data and Cloud Computing, that are key technologies of NPR, will depend on the availability, quality and safety of the underlying infrastructure. Although many of the IoT applications can be used over low-bandwidth networks since they require very low data rates (e.g., kilobits/s or less), some monitoring efforts require **significant amount of bandwidth**. Indeed, even IoT applications requiring low bandwidth may demand a high-capacity infrastructure if a massive number of "things" deployed over a geographical area need to transfer data to a server in the infrastructure, or if other IoT/ICT applications are running concurrently. Finally, some IoT applications require **ultra-low latency**, especially when robotics control applications have to be supported as in next-generation factories; in this case, high-data rate connectivity must be provided between the "things" and the infrastructure.

In addition, cloud-based services can benefit from high speed, as higher broadband speeds allow data stored remotely to be accessed as quickly as on a local hard drive, and synchronised across multiple devices [27].

There is, therefore, a risk that countries and communities that do **not have access to a high-capacity and high-speed infrastructure are left behind** [28]. Furthermore, concerns around **data protection, security and privacy** remain another major hurdle to the adoption of these systems in place [29]. In this context, the development of an enabling digital infrastructure is of paramount importance, in order to promote the new paradigms that are the base of NPR.

Mobile infrastructure represents an effective solution that can provide high capacity while avoiding the costs of fixed-broadband or satellite-broadband networks. In particular, the emerging **5G technology** can significantly help to mitigate the need for a high capacity, costly backhaul. 5G is a game changer, enabling (a) industrial transformations through wireless broadband services provided at Gigabits/s speeds; (b) the support of new types of applications connecting devices and objects (the Internet of Things), and (c) versatility by way of service and network virtualisation allowing innovative business models across multiple sectors (e.g., transport, health, manufacturing, logistics, energy, media and entertainment). Through virtualization, services can be deployed everywhere in the network, thus allowing the transition from a centralized, often costly cloud, to a distributed cloud. Likewise, **network virtualization** enables the realization of the so-called **LTE-in-a-Box (LTE-IB)** concept, i.e., the deployment of a "local" mini LTE (Long Term Evolution) network. LTE-IB enables the development of mobile connectivity and data services in geographically remote locations, or for enterprise and industrial customers in a dedicated manner. As an example, it can provide a high-capacity private network for an oil platform that needs to use safe mobile devices in a high-risk environment, or for a factory, that requires reliable wireless connections for automation systems.

Of particular relevance in the context of network virtualization and IoT, is the new **Multi-access Edge Computing (MEC) paradigm**, which enables the implementation of storage and computing services at the edge of the mobile network (e.g., at the cellular base stations or at the Wi-Fi access points), hence close to

the end users. MEC does not require high-capacity connectivity with a far-away centralized cloud; rather, it implements a distributed cloud at the edge of the network. For example, through MEC, massive data from the IoT can be collected and processed "locally", i.e., "at the edge", without the need of transferring the data to a server in the centralized cloud. The advantage of such innovative technology scenario is multi-fold. First, processing at the edge data collected through an IoT system, implies that a much smaller amount of data (or, even none) will have to be transferred over long distances thus greatly reducing the need for high bandwidth as well as energy consumption in the mobile network backhaul. Second, ultra-low latency services can be successfully supported, thanks to the "local" service implementation allowed by MEC. Third, MEC technology can boost local IT companies for competition with other international players in the cloud computing market, by allowing the development of a distributed cloud, with limited financial investments. Finally, data protection, privacy and security provisioning, which still represent a major hurdle to the adoption of cloud systems, can be greatly facilitated by keeping data local.
However, in order to exploit the MEC paradigm, high capacity wireless connectivity should be guaranteed between the edge of the infrastructure and, e.g., the "things" of an IoT system, by adopting the emerging 5G radio access. Furthermore, the innovative MEC technology should be made ubiquitous by deploying enough computational and storage resources at the edge of the current network infrastructure.
Collection and analysis of open, big data, however, requires the development of an innovative infrastructure, which ensures ubiquitous mobile connectivity, the availability of computational and storage resources, and data privacy and protection. In particular, the latter could be addressed through the realization of advanced secure platforms that allow data portability, i.e., the possibility for individuals to be in control of the data they generate and to decide with which organizations, or other individuals, data can be shared.

Status and numbers

IoT, big data and cloud computing in Africa are in their early growth stages. According to [29], in most of the African countries the diffusion of cloud computing is driven by governments as a mean for delivering e-government initiatives. South Africa represents an exception where the corporate sector demand is driving the growth of cloud-computing.
Despite the progress made in the last years, Africa still lags behind other regions in its access and use of digital infrastructures, digital technologies, and the Internet [30].
According to the *Networked Readiness Index 2016,* even though several African countries are among the countries that have improved their performance at most (e.g., South Africa (65th, up 10), Ethiopia (120th, up 10), and Côte d'Ivoire (106th, up 9)), the region is still the lowest-scoring one [31].
Similarly, Africa shows the lowest *ICT Development Index* performance level [28]. Altogether, 29 out of 37 African countries rank *as Least Connected Countries* in

the bottom quartile of the overall Index distribution, including the 11 countries with the lowest overall Index rankings [28].

Key barriers remain in the nexus among infrastructure, affordability and usage [31]. The **broadband infrastructure gap is still huge**. Other main non-infrastructure barriers that limit the adoption of Internet are related to costs of services and devices, lack of local content and low proficiency in digital skills [32].

Migration to mobile broadband is gaining momentum in Africa. However, limited network coverage remains one of the key barrier to mobile Internet adoption. In 2016 there were 72 live Long Term Evolution (LTE) networks in 32 countries across Africa, 3G and 4G networks covered 50% and 16% of the African population respectively [33]. A percentage that is around 30% lower than the global average for both technologies, meaning that 600 million people in Africa still do not have access to a mobile broadband service. Furthermore, it has been highlighted a correlation between 3G coverage and the proportion of the population living in urban areas. Moving further into rural and remote areas, mobile broadband is still a greater challenge, often because of a lower business profitability [33].

In many countries, mobile-broadband has become the dominant, and often the only available, broadband access technology, as only 1.4% of Africans have fixed-broadband connection [34]. Fixed-broadband remains very important whenever high-speed, no-mobile access is required, or connectivity with the centralized cloud has to be ensured [28]. However, in the NPR, especially in factories, wireless (i.e. mobile) connectivity is equally relevant.

Africa has the opportunity to advance quickly to high-speed fibre broadband because it has not made massive investments in old copper-based technologies. A massive deployment of optical fibres for broadband connectivity to centralized cloud services is therefore essential to applications that require remote computing, data storage and analysis.

Progress have been made in **national backbones, regional and international high-speed networks** (submarine optical fibres or satellite). In 2016, submarine cable capacity reached 33 countries and in the past 5 years, submarine cables have brought a twenty-fold increase in international bandwidth [35].

In the same period, the terrestrial fibre infrastructure doubled and fibre networks are increasingly used for the backhaul of mobile networks. Notwithstanding, national backbones and cross-border infrastructures remain one of the least developed element of the network in Africa [36,37].

Finally, an important element is the availability of local **Internet Exchange Points** to reduce dependence on international connectivity for local internet services and, thus, to achieve lower costs. In this respect, the African Internet Exchange System, an African Union project implemented by the Internet Society, aims at having 80% of African users' internet traffic exchanged within Africa by 2020 [38].

Policy in place

The fast development and wider use of digital technologies and infrastructures require the parallel **modernisation of the policy and regulatory frameworks** at different levels. In this respect, an ecosystem has emerged in Africa involving

a broad range of actors for securing the right interface and alignment – both in the short and long term - among continental, regional and national development plans.
It is worth noting that many inter-dependent aspects must be addressed concurrently to **close the digital divide**, such as **infrastructure, affordability, local content, and skill development**. Next generation policies must not only focus on **supply-side** issues but also on **demand-side** issues of digital literacy, as well as privacy, cybersecurity, and internet governance [30].
Moreover, digitalization has policy implications across different areas and, thus, maximizing its benefits requires more coordinated policies and regulation across sectors, with telecom/ICT working with data protection and competition authorities, but also with actors in other domains, such as health, education, energy, transport, finance and industry.

Continental level

African leaders adopted the "Agenda 2063" as the continent's new long-term vision for the next 50 years [39].
In the Agenda 2063, **digitalization is recognized as one of the major lever that can help achieve African long-term aspirations**. The agenda is coordinated by the African Union Commission's Information Society Division and the "Agenda 2063: First Ten-Year Implementation Plan 2014-2023" was launched to domesticate the first 10-years plan into national and regional plans to ensure its effective implementation at different levels.
Furthermore, the African Union's High-Level Conference on the Data Revolution endorsed the concept of **making official data open** by default and, in June 2014, the Convention on Cybersecurity and the Personal Data Protection was signed with the aim of harmonizing e-transactions, personal data protection and cybercrime legislations [35].
The e-Africa Programme of the New Partnership for Africa's Development (NEPAD) Agency - the technical body of the African Union – is aimed at **boosting broadband access** in Africa. This is achieved through [40]: (a) increasing bandwidth and investment in ICT; (b) reducing costs of access to ICTs; (c) improving online content and services; (d) enhancing ICT skills on the continent; and (e) enabling the policy environment for ICT in Africa.
The AUC Information Society Division and NEPAD Agency e-Africa Programme in consultation with Regional Economic Communities (RECs) and Specialised Agencies of the African Union prepared a "Strategic Framework for Communication and Information Technology Development in Africa- the Comprehensive ICT Strategy for Africa (CISA) 2015 – 2025". The framework is composed of 7 Strategic Pillars and associated objectives and outputs [41]: (a) Post and ICT Infrastructure; (b) Capacity Development; (c) e-Applications and Services; (d) Enabling Environment and Governance; (e) Resources and Partnerships; (f) Industrialization; (g) Research and Development.
In 2014, the SMART Africa Manifesto was also endorsed by all Heads of State and Government of the African Union at the 22nd Ordinary Session of the Assembly of the African Union in Addis Ababa [42]. In order to achieve

the SMART Africa vision of "Transforming Africa into a single digital market", 5 pillars, which reflect the 5 principles of the Smart Africa Manifesto, were identified: (a) Policy, (b) Access, (c) e-Government, (d) Private Sector/Entrepreneurship and (e) Sustainable Development. The pillars base on four, cross-cutting enablers such as innovation, communications and advocacy, capacity building and resource mobilization.
The SMART Africa Alliance is the framework for implementation, monitoring and evaluation of the SMART Africa Manifesto. Currently, the Alliance is a partnership bringing together all African countries adherent to the Manifesto represented by the Africa Union, ITU, World Bank, Africa Development Bank, Economic Commission for Africa, the GSMA, Internet Corporation for Assigned Names and Numbers and the Private Sector.

Regional level

Africa's Regional Economic Communities (RECs) include 8 regional bodies, the building blocks of the African Economic Community established in the 1991 Abuja Treaty. RECs not only constitute key elements for economic integration in Africa, but also are key actors in promoting cooperation and harmonization in the telecommunications and digital sectors.
A first step in this direction was done through the "Harmonization of ICT Policies in Sub-Saharan Africa" (HIPSSA) project, which realized a comparative study of the various initiatives in place and provided recommendations and guidelines for improvement. Moreover, in-country technical assistance was made available for transposing the regional guidelines into national legislative and regulatory frameworks according to national specificities [43].
The main ICT policies and regulations that have been adopted at the RECs level [44], can be grouped into: (a) National Policy Priority for ICTs; (b) Market Liberalization; (c) Policy and Regulatory Harmonization; (d) Spectrum Policy Development; (e) Cyber Security; (f) Statistics/ Data Collection; (g) Infrastructure Development- Regional Backbone, Missing Links, Alternative Infrastructure; (h) e-Applications development support; (i) Universal Service Projects; (j) Education, research and health connectivity; (k) Duties & taxes on ICTs; (l) Training/ HRD.
Today, according to the *Africa Regional Integration Index* 2016, IGAD community is the top performer in the Regional Infrastructure Composite Sub-Index [45] (Figure 12), made of four indicators: (a) Infrastructure Development Index: transport; electricity; ICT; water and sanitation; (b) Proportion of intra-regional flights; (c) Total regional electricity trade (net) per capita; (d) Average cost of roaming. However, REC programmes and progress are ongoing across the regions. As an example, in 2015, EAC, COMESA and SADC approved a set of projects with the aim of supporting the operationalisation of the Grand Free Trade Area of the Tripartite. The joint programme on digitalization focuses on the implementation of an inter-regional ICT broadband infrastructure network and a harmonised policy and regulatory framework for ICT and infrastructure development in the three RECs.

Countries Level

Awareness of the role of digitalization for national development has increased over the past decade, generating a number of national policies and regulations across African countries.

One of the most dominant policy and regulatory issue has been around **extending affordable broadband access to the majority of the population**. This involves the creation of a level playing field for operators and redefining universal access and service strategies to reach areas and population groups that are beyond the market and require special interventions.

By the end of 2011, more than 40 African countries established separate regulators. The mobile segment has been very competitive and, nowadays, the majority of countries have more than three operators in the mobile market [46], while only two countries have full monopoly [47].

On the other hand, limited activity in opening up the fixed-line segment has been registered over the past years.

Universal Access and Service policies complement the national broadband policies. One of the alternatives, followed by many countries worldwide, is the use of a Universal Service Fund. In Africa, often the legal or regulatory framework needed to drive the funds has not been put in place and currently very few of the African funds permit the funding of broadband deployment [48].

Spectrum remains a critical resource and **spectrum management** is another important aspect in the policy arena. In this respect, Africa agreed to transition to digital broadcasting with the aim of making better use of transmission spectrum, which would free up spectrum for other purposes. However, most African countries failed to meet the International Telecommunication Union's deadline for the switchover. This delay and fragmented assignment can have a direct negative impact on network coverage and penetration.

Another transition that Africa is not implementing fast is that to the Internet addressing protocol, IPv6. IPv6 is necessary for long-term Internet expansion, especially in the IoT scenario. To date, South Africa and Egypt registered 97% of the African IPv6 addresses [35], which means that the adoption in the other countries is lagging behind.

Added value for Prosperity in Africa

Deploying **digital infrastructure** for Africa may bring a number of contributions to Prosperity in Africa. Internet contributed USD 18 billion or **1.1% to the African Gross Domestic Product in 2012**, which is low compared to **the average of 3.7% in developed economies** [35]. Numerous studies have verified the positive impact of greater broadband penetration on GDP growth. The World Bank highlights that every 10% improvement in broadband penetration increases GDP by 1.3% [32]. In addition, the study finds that a 10% increase in broadband penetration is correlated with a 1.35% increase in GDP for developing countries. Research from the GSMA finds strong correlations between mobile broadband penetration and GDP per capita and other

FIGURE 12. OVERVIEW OF REGIONAL INDICATORS INCLUDING INFRASTRUCTURE

	Trade integration	Regional infrastructure	Productive integration	Free movement of people	Financial and macroeconomic integration
CEN-SAD	0.353	0.251	0.247	0.479	0.524
COMESA	0.572	0.439	0.452	0.268	0.343
EAC	0.780	0.496	0.553	0.715	0.156
ECCAS	0.526	0.451	0.293	0.400	0.599
ECOWAS	0.442	0.426	0.265	0.800	0.611
IGAD	0.505	0.630	0.434	0.454	0.221
SADC	0.508	0.502	0.350	0.530	0.397
UMA	0.631	0.491	0.481	0.493	0.199
Average of eight RECs	**0.540**	**0.461**	**0.384**	**0.517**	**0.381**

CEN-SAD
The Community of Sahel-Saharan States

COMESA
The Common Market for Eastern and Southern Africa

EAC
The East African Community

ECCAS
The Economic Community of Central African States

ECOWAS
The Economic Community of West African States

IGAD
The Intergovernmental Authority on Development

SADC
The Southern African Development Community

AMU/UMA
The Arab Maghreb Union

Source: Data from African Union, African Development Bank Group, Economic Commission for Africa, "Africa Regional Integration Index. Report 2016.", 2016, [45]

researchers suggest that doubling mobile broadband data use leads to a 0.5% increase in GDP per capita growth rate [35].

Digitalization can also significantly contribute to mitigate environmental challenges, by enabling a more efficient use of energy and natural resources, and helping countries, cities and individuals to adapt to environmental threats with the improvement of monitoring and control.

Furthermore, although it is difficult to give broad generalisations of the global environmental impact of additive manufacturing, some possible green 3D printing realities lie more in aligning economic incentives with environmental impacts, enabling lean production, expanding material alternatives, and increasing energy efficiency in the use-phase of some products [49].

Beyond the economic and environmental dimension, digitalization may also contribute to social improvements through job creation and better access to basic services, such as health care and education. Digitalization can also create value for consumers by decreasing search and information costs while enhancing trust and transparency.

Regarding job creation, there are two main dimensions to take into account: (a) digital infrastructures as a direct source of jobs (i.e., building and maintaining infrastructure creates jobs), and (b) digital infrastructures as an input into a growth process that creates jobs across other sectors. In this respect, 10-point increase in the digitalization level would lead to an average 0.84% reduction in the unemployment rate [50]. On the other hand, digitalization of manufacturing could see a "reshoring" of production in developed countries while developing countries may see an uptick in entrepreneurialism with new business models.

Digitalization can also increase equality of access to basic services that a society requires, such as health, education and financial services, which are crucial for achieving the sustainable development goals.

In the health care domain, wearable devices and health apps can be used to empower citizen to monitor their health, access to health-related information and advice, and manage their status in a better way. Through telemedicine services, patients can connect to general practitioners and specialists without travelling considerable distances. Doctors can access the patient's information in real time and be alerted by connected devices that capture major health indicators and update the medical report. Furthermore, sensors can use it to monitor the "cold chain" delivery of vaccines, particularly to remote and rural areas. Big data derived from devices, social media and other digital sources can contribute to provide timely and detailed information for monitoring.

In education, students can access school materials - with contents in multiple local languages - loaded on a smart device. Learning results can be sent to the teacher and reports updated in real time, adjusting the proficiency level and future learning contents based on the progress made. From the smart device, the student can connect to classmates and teachers to share knowledge and work collaboratively. Similarly, adults can address their skill gaps and engage in lifelong learning in a more convenient way. Overall, it is estimated that digitalization has a positive impact on health, education, and living standards measures in emerging economies: a 10-point increase in the digitalization score can lead to an increase of 0.13 points in the Human Development Index [50].

The overall benefits of digitalization in emerging economies derive from the effectiveness, efficiency and innovation gains in processes, products, services and business models that accompany the digital transformation. Studies on Industry 4.0 in Africa (e.g.,[50,51,52]) show that manufacturing companies can benefit from (a) the effective analysis, assessment and application of data collected from sensors and machines that enable rapid decision-making and improve productivity, operational safety and maintenance; (b) the introduction of new digital products and related services towards customer-specific solutions; (c) new ways of interaction and cooperation with suppliers and business partners in local and global value chains, and also with customers through open innovation and crowdsourcing.

New paradigms such as the "datafication" of business-relevant processes, the interconnection of physical objects via the IoT and data mashups can promote

functional integration of different sectors including infrastructure and new opportunities of governance at corporate and institutional level.
Thanks to the expansion of connectivity and accessibility across Africa, a new ecosystem of digital entrepreneurs and start-ups can emerge and flourish associated to new business models. There are currently more than 117 Tech hubs in Africa [30], where developers and entrepreneurs are supported to create products and services, which could represent a big step towards addressing local problems.
Beyond the leapfrogging to mobile phones that has entailed enormous economic and social benefits to millions of people; a similar leapfrogging could happen with distributed manufacturers, at least at the urban scale, allowing start-ups or small businesses with little capital to begin manufacturing on a small scale, then using the earnings to finance expansion into mass manufacturing.
In order to mitigate any future lock in, it is important to consider that digital technologies and infrastructures can also add to global environmental challenges, in particular to the generation of Greenhouse Gas (GHG) emissions and e-waste [47]. Digitalization can contribute to GHG emissions, through the energy consumption involved in the lifecycle of digital infrastructure as well as the production, use and disposal of digital products and services. The rate of growth of e-waste can be particularly high because of the rapid pace of change in digital technologies. Furthermore, a high proportion of e-waste is often traded and treated informally or illegally in African countries.
The reshoring of manufacturing related to advanced digital technologies in developed countries could entail a new geographical shift in emission and production of wastes thus making necessary a life cycle perspective and a systemic approach for the estimation of direct and embodied emissions and the production and consumption-based paradigms.
Taking a lifecycle and circular economy perspective and deploying systems to manage digital technologies and infrastructure sustainably is, therefore, crucial to minimize negative impacts and turn them into a resource for Prosperity in Africa.
Finally, new business models are characterised by an emphasis on high value-added services where people are the centre of the stage and see a shift from simple customers to partners.

Energy is considered the lifeblood of the modern society since almost all the economic activities have always been sustained by the discovery of new energy sources, coped with the right capacity of using and managing them properly [53]. The relevance of energy is well consolidated within the 2030 Agenda where, among the 17 Sustainable Development Goals, Goal 7 is fully dedicated to energy. According to this new impetus, the Sustainable Energy for All initiative together with the World Bank and the IEA are also redesigning the framework of access to energy for better highlighting the link between energy – services – development [54][55]. Moreover, the conclusion of COP21 and COP22 confirmed energy to be at the centre of the discussion for any mitigation actions aiming at reducing the overall emission of greenhouse gasses. In this perspective, it is so clear that for achieving more effective and faster gains at global level, the international community has to promote approaches that go beyond attributing individual responsibility, and try to promote convergence, partnership and advanced cooperation even starting from voluntary basis as with the National Determined Commitment.

Energy infrastructure for decarbonisation as a step towards the Next Production Revolution

The energy-climate-development nexus presents two faces. From one side the increasing attention to the environment stresses the global concern about overexploitation of limited natural resources used for human activities [56]. From the other side, the historical evidence states, that no country has substantially reduced poverty without an increased use of energy, in the form of different carriers and without a progressive shift to more efficient sources and high quality energy services [57]. In this perspective, the correlation between energy, economic growth, and poverty reduction, in the scientifically sound literature, confirms two main evidences whose relevance may vary from country to country: a direct component achieved by improving the lives of direct beneficiaries and an indirect one pursued by supporting local economic growth [58].

A turning point is knocking at the door of the global economies, since the two faces of the coin means that growth cannot happen at any costs. This is even more true for Africa, which is rich in resources but still poor in energy supply [59] and where, as stated by the presidency of the AfDB, “more cost-effective power is critical for driving faster economic growth and equitable social development” [60]. 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 but, together with it, as remarked by PIDA [61].

Africa wishes to confirm the continent commitment to maintain its low contribution to global carbon emissions by (a) developing large hydro resources; (b) shifting from oil to gas for power generation and (c) transforming its huge potential of geothermal, solar and wind into power.

The above consideration leads to understand the crucial role of the continent in the path toward decarbonization at global level. Indeed, the energy strategies, the technological leapfrogging, the native innovations that the continent (each country alone or in connection through the power pools) will select, could have a great impact on domestic growth as well as global development and environmental preservation.

Africa cannot lose momentum to investigate low carbon alternatives in the long run, since for instance, the huge hydro potential might be sufficient until 2035. Therefore, the joint role of modern renewable energies in Africa and energy efficiency also promoted by digital technology might contribute to the long term path of decarbonisation and to the claimed decoupling among growth and greenhouse gases.

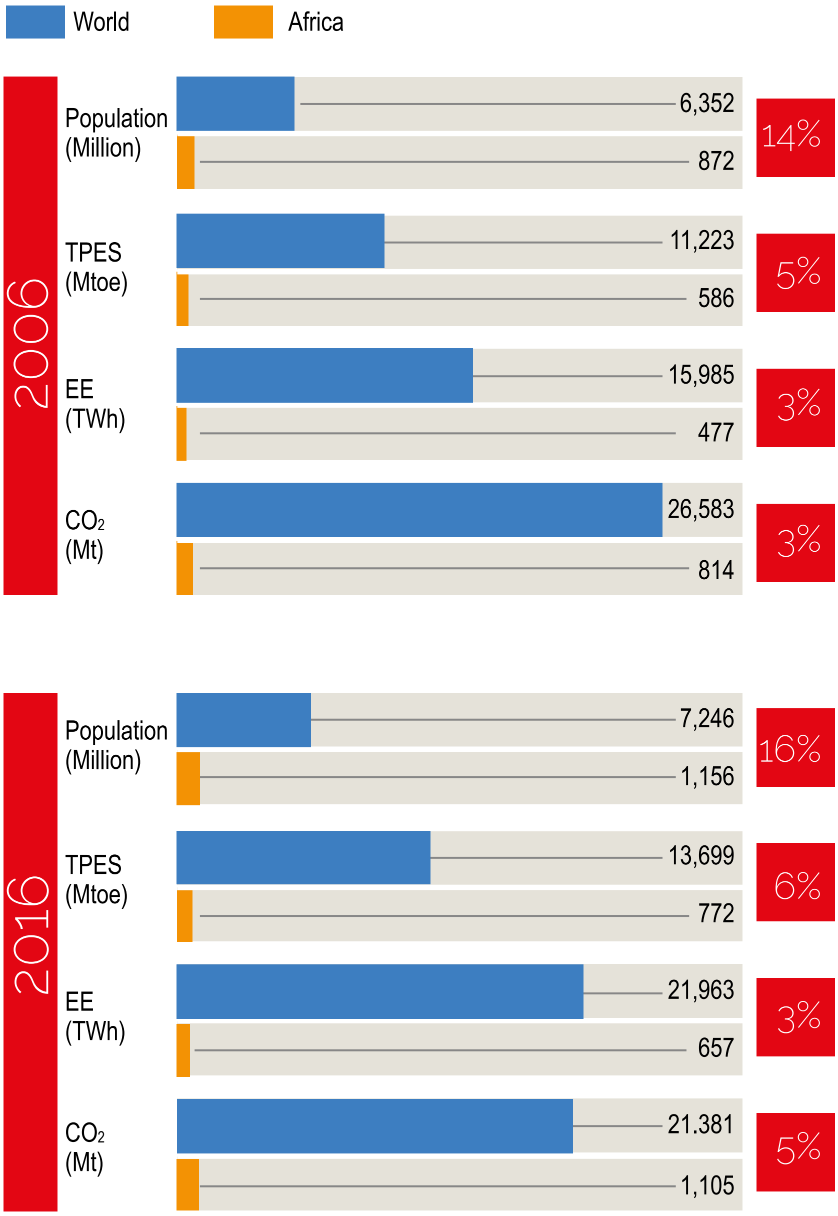
Overall CO_2 emissions may increase slower than GDP and electricity demand, as the share of hydro increases and some countries like South Africa shift to low GHG technologies and sources. In the long run, support "to low GHG technologies will be important to curb the increase in GHG emissions per capita without limiting availability or raising prices" thus leading to a new era of prosperity matching the need of people and planet, as envisage by the 2030 Agenda and a new era of production remarked by the confluence of technologies at the base of the NPR [49]. The success of this path will be effective if a proper regulatory system will be in place at regional and country level and adequate environmental policies will be tailored to the local context, not necessary duplicating the industrialized scheme (for instance, environmental taxation may better meet with weaker institutional framework and a more distributed energy sector compared "to cap and trade" approach). Finally also the role of energy efficiency need to be emphasized in the continent as a crucial key driver to reducing both local pollutants and greenhouse gases, while ensuring energy security and saving cost and time of adding additional capacity.

In this perspective, indeed, the challenge of NPR for Africa, though critical for the potential risky shift in the global value chain, may allow some countries to leap-frog to more advanced stages of development in a number of sectors. The energy sector represents a peculiar case, characterised by a rapidly declining costs of distributed renewable-based technologies for generation, penetration of digital technologies in the distribution and transmission sector, lunching of an ensemble of business models enabled by innovative metering system, rising of new producer-consumer categories, as well as improved channels for knowledge sharing.

Status and number

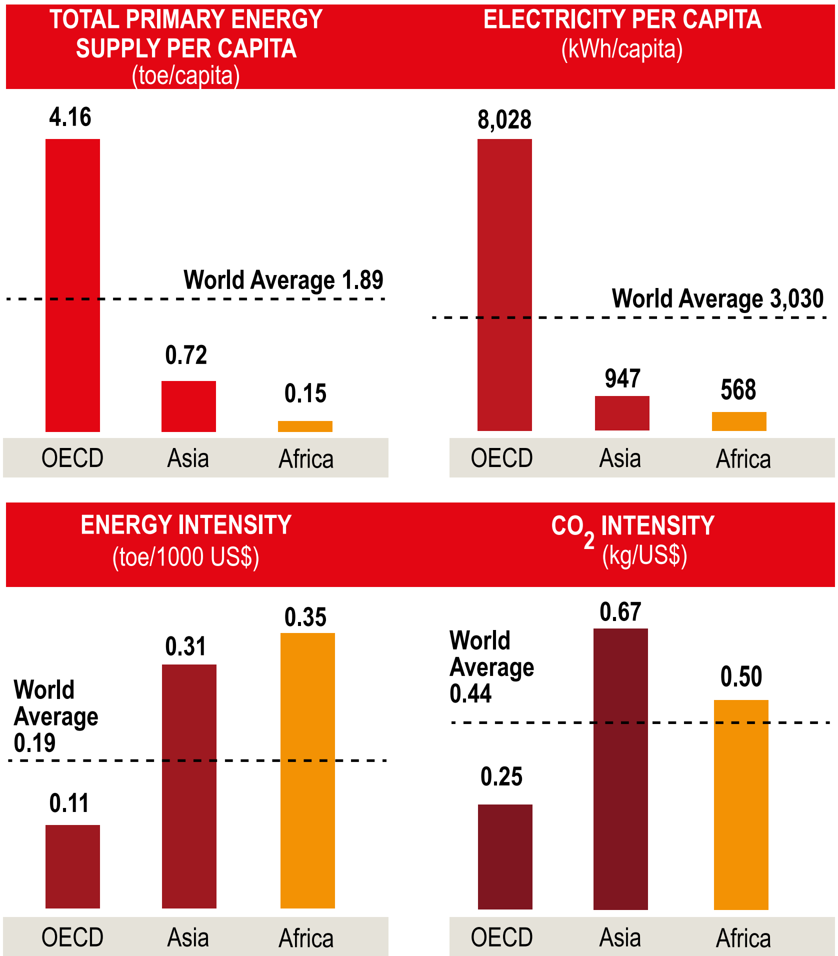
The energy paradox in Africa is nowadays fully recognised. Energy demand over the last decade has grown by more than 30 % (roughly 40 % for the electricity supply) nevertheless even if home to the 16% of the global population,

FIGURE 13. EXTENSIVE ENERGY INDICATORS: AFRICA AND WORLD AVERAGE



Source: OECD/IEA, "Key world Energy Statistics.", 2006, [62] and OECD/IEA, "Key world energy statistics.", 2016, [63].

FIGURE 14: INTENSIVE ENERGY INDICATORS: OECD, ASIA, AFRICA AND WORLD AVERAGE



Source: OECD/IEA, "Key world energy statistics.", 2016, [63]

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 of the 5% of the CO_2 emission burden. By comparing some **quantitative extensive data** at a decade distance (Figure 13) some considerations about energy demand emerge: (a) the growth for both primary energy and electricity is hardly keeping pace with population growth and (b) it still relies mostly on fossil fuels as it is evident by the increase in the share of CO_2.

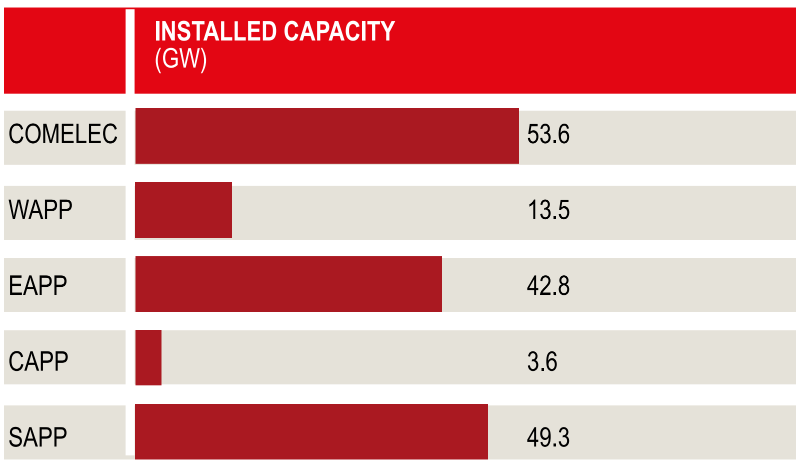
Deepening the analysis with a bench of **qualifying intensive indicators**, Africa still lags behind other regions (Figure 14): per capita availability of energy both primary and electricity are very low while energy and CO_2 intensity are higher. These numbers, together with the low levels of installed generation capacity per capita, and per unit of GDP represent the evidence of under investment in Africa in terms of power generation infrastructure. Indeed, installed capacity is

roughly around 150 GW (from the 125 GW of the PIDA [60][61] to the 147 of IRENA [64] and 158 of IEA [59]) (comparable to that of Italy or other European countries) unevenly distributed in the continent; roughly 30% in the COMELEC, 35% in South Africa alone and the remaining 35% in the rest of the whole Sub-Saharan region.
According to PIDA, the capacity mix is mostly given by thermal power plants (around 80%) due to the size of the North African and South African systems, and hydro plants (around 20%) mainly located in the central and eastern regions of Africa. Wind, solar, biomass and geothermal energies are going to increase their relevance with large developments of wind in Morocco and Egypt and the potential of geothermal source in Kenya and Ethiopia.
Aside, this general consideration, the energy situation in Africa is very diverse in term of generation capacity and mix in the different region, as highlighted by analysing the specific Power Pools: WAPP, SAPP, CAPP, EAPP, COMELEC (Figure 15).
Except for COMELEC and SAPP the generation mix in the other regions does not mirror the local natural endowment, but it is more the evidence of short sighted planning, which favours the development of thermal capacity, presenting shorter construction period and low upfront investment compared to hydro or other renewables.
The existing African transmission system (defined as lines with a voltage equal or above 100 kV) has a total length of less than 90.000 km [60] . Three critical features make the transmission system to be the major bottleneck for further energy system integration and networking among the power pool as again suggested by PIDA:

- Low density compared to Africa extension (drawn mainly to serve the major urban areas).

FIGURE 15: INSTALLED CAPACITY, INSTALLED CAPACITY PER CAPITA AND CAPACITY MIX IN THE POWER POOLS (1)(2)

(1) The membership of the Power Pools are defined according to the PIDA reference [60]:
WAPP: Senegal, Mali, Liberia, Guinea, Sierra Leone, Guinea Bissau, Côte d'Ivoire, Togo, Gambia, Niger, Benin, Burkina Faso, Nigeria and Ghana.
SAPP: Namibia, Botswana, Swaziland, South Africa, Lesotho, Mozambique, Zimbabwe, Angola, DRC, Tanzania, Zambia, Malawi.
CAPP: Rwanda, Cameroon, Equatorial Guinea, DRC, Angola, CAR, Gabon, Chad, Burundi, Congo.
EAPP: Egypt, Sudan, Djibouti, DRC, Ethiopia, Tanzania, Kenya, Uganda, Rwanda, Burundi, Somalia, Eritrea.
COMELEC/North Africa: Morocco, Algeria, Tunisia, Libya, Egypt.
(2) Note that there are overlapping in the membership of countries so that the sum over all the pool cannot be compared with the total installed power in Africa.



Source: Sofreco led consortium, "Study on Programme for Infrastructure Development in Africa (PIDA) - Africa Energy Outlook 2040.", 2011, [60].

- Lack of unified standards (15 levels of transmission line voltages exist: from 110 kV to 700 kV).
- Lack of integration (drawn as independent systems from the coast to the interior - except for SAPP).

Rewiring the power grid is therefore another major infrastructural point to consider beyond the repowering with new renewable generation plants. Indeed, a higher penetration of renewable sources needs to cope with an adequate transmission and distribution infrastructure enabling a dispatch the generated power. This is crucial also to prepare the paths to mitigate the expected Africa's power sector emissions increase in share of world emissions after 2030 due to hydro potential becoming gradually exhausted and to avoid potential lock-in (see Box 4).

According to the Africa Energy Outlook [60][61], $42 billion are annually requested in the Africa power sector, with substantial, upfront investment required for empowering transmission system, to meet future demand in a standard scenario. In the IRENA [64] perspective investment needs for new generation capacity between 2015 and 2030 are in the range of $26-50 per year (not discounted) while investment needs for -transmission and distribution range from $20-30 per year.

In order to meet the requirement coming from the New Policies Scenarios proposed by the International Energy Agency in 2014 investments are higher. In just a part of Africa (Sub-Saharan Africa- SSA), roughly $45 billion per year are required for power generation, transmission and distribution. In this scenario, the SSA power system (excluding the North Africa Region) would at least expand its generation capacity of more than 4 times from less than 100 GW to roughly 400 GW and diversify its mix: coal (South Africa) and hydro-power (all regions) will come to be supplemented by natural gas and by an increased share of renewables (including solar, wind, geothermal and biomass)

	INSTALLED CAPACITY PER CAPITA (MW/million people)	CAPACITY MIX		
		THERMAL	HYDRO	OTHERS
	339	89.7%	9.0%	1.3%
	48	60.6%	39.4%	-
	213	82.7%	16.9%	0.4%
	27	69.3%	30.7%	-
	110	81.3%	18.7%	-

BOX 4

Are investments in infrastructure on the right track to meet the energy needs for all?

Carbon footprint and potential lock-in

The carbon footprint of existing global infrastructure at 2008 was 122 Gt CO_2. The average per capita carbon footprint of infrastructure in industrialized countries was 53 t CO_2, 5 times larger than that of developing countries (10 t CO_2) [Muller et al., 2013].
Implementing new infrastructures in developing countries to meet Western standard and with current technologies would lead to 350 Gt CO_2 of emissions related with the production of construction materials. This value corresponds to 35-60 % of the remaining carbon budget at 2050 in 2°C policy scenarios.
In the work by Davis et al. [Davis et al., 2010], "committed emissions" of existing infrastructure represents high infrastructural inertia which may be the primary contributor to total future warming commitment. Cumulatively, 496 gigatonnes of CO_2 will be emitted from the combustion of fossil fuels by existing infrastructure between 2010 and 2060. Scenarios that assume continued expansion of fossil fuel–based infrastructure predict cumulative emissions of 2986 to 7402 Gt CO_2 during the remainder of this century, leading to warming of 2.4° to 4.6°C by 2100 and atmospheric concentrations of CO_2 greater than 600 ppm. It is therefore necessary to account for the carbon footprint of new infrastructures aiming at breaking a carbon lock-in.

S. J. Davis, K. Caldeira, and H. D. Matthews, "Future CO_2 emissions and climate change from existing energy infrastructure.", Science, vol. 329, no. 5997, pp. 1330–3, Sep. 2010.
D. B. Müller et al., "Carbon Emissions of Infrastructure Development," Environ. Sci. Technol., vol. 47, no. 20, pp. 11739–11746, Oct. 2013.

which are likely to double in 2040 their current share. In the same period, for SSA, the share of installed fossil fuel capacity will decrease from around 77% to 54% supporting the path toward a more decarbonized system as CO_2 emission from the power sector will shift their responsibility from the 2 to 3% of the global share while electricity production will increase more than 3.5 times. Nevertheless this improved system will not be able to provide universal access for all, having at least more than 0.5 billion people still affected [59].

A little less than $20 billion should be added on average per year over the period 2013-2040 in order to provide full electricity access in urban areas and achieve at least 67% in rural areas of all countries of sub-Saharan Africa. This investment will also contribute to improve the reliability of electricity supply, reducing the incidence of power outages by half.

Even though some differences are highlighted according to the different scenarios, it is clear that the huge amounts, make the current level of investment (around $10-11 billion per year) fully inadequate for the energy sector in Africa, remarking the current level of under-investment. As remarked also within the "G7 Summit, Chair's Summary of the Outreach session on Africa", one of the main challenge will be financing the large capital investment required by the transformation of the power sector, increasing private sector financing and sector cash flow by some 7-10 times their current levels. To attract investment a stable and reliable regulatory framework must be put in place in order to de-risk them and involve qualified operator, and, in the same time, a gradual transition of supporting schemes towards competitive mechanisms, mainly based on tenders need to be carried out, together with the promotion of long-term price signals. This big effort may be turned into a positive effect since no significant increase in average tariff may be required to finance the sector program, which would so remain around $8-10 cents /kWh due to the large amounts of low cost hydro which would become available.

Policy in place

Africa sub-regions differ consistently in their availability and use of the energy resources. Such differences bring about different sets of challenges which have led in Africa to an evident pluralism of actors involved in the energy sector through several policies and action plans [65]. Governmental agencies and international organizations, development banks and funds, power utilities associations, NGOs and others, undertake actions addressing energy-related challenges. The fragmentation of the policies and action plans and the lack of harmonization represent one of the main key points. In fact the actors involved in this frame have priorities and roles that often differ or overlap even if some efforts of integration have appears over the last decade and involves continental institutions, governmental actors, development fund entities [66].

Continental Level

The commitment of **African Union (AU)** in the energy sector has been present for many years, and NEPAD (New Partnership for Africa's Development) represents the implementing agency deputed to this involvement. Established in 2001, NEPAD works in strict cooperation with continental partners and actors of the energy sector: from the institutional side (e.g. the Forum of Energy Minister of Africa), to the union of private power companies (e.g. UPDEA) [67]. Within its activity, NEPAD is also set to undertake initiatives to accelerate the process of decarbonisation, through the development and implementation of RE projects in the continent, and to facilitate the effective use of the vast untapped RE resources. Current key activities are: selection of RE projects, investor-project matching and resource mobilisation [68]. NEPAD has been involved in the development and operationalization of the regional power pools. An effective implementation of the AU/NEPAD strategy has been defined in the Program on Infrastructure Development in Africa (PIDA). The implementation of PIDA has been jointly sponsored by several actors: (a) NEPAD in coordinating the implementation and facilitating the strategies harmonization, (b) financial institutions (e.g. African Development Bank) in financing and providing technical support for project preparation and capacity building actions, (c) member states, utilities and regional bodies (e.g. Regional Economic Communities - RECs) in leading the execution phases through project financing and monitoring [69]. PIDA promotes regional economic integration by building mutually beneficial infrastructure and strengthening the ability of countries to trade and establish regional value chains for increased competitiveness. In particular, it establishes a strategic framework for the development of regional and continental infrastructure in four sectors (Energy, Transport, Information and Communication Technologies, and Trans-boundary Water Resources), by setting a program over a time horizon up to 2040, and by preparing an implementation strategy and a Priority Action Plan [70]. The PIDA Priority Action Plan (PIDA-PAP) is the more updated action plan, which aims at defining a detailed and immediate program on regional integration and a cross-border market. It was approved in 2012 by the African Heads of State and updated in 2014, mobilizing a total budget of 360 billion USD mostly dedicated to energy and transport projects. One of the objectives is to guarantee access to electricity to more than 60% of people to any African Country by 2040. In order to address this, one component of PAP consists of 15 energy projects that amount to a budget of 40.3 billion USD. These projects include: nine hydro power plants, four transmission corridors, and two pipelines (one for oil and one for natural gas)[71].

Within the African Union, the **African Energy Commission (AFREC)** plays a relevant role in boosting the development of renewable energy resources in Africa. Launched in 2008 [72], the AFREC Program has undertaken a series of actions to support with technical and managerial expertise all Member States, by promoting cooperation and collaboration, supporting technology research and development for electricity generation, enabling new regulatory frameworks , with the objective of enhancing energy security, generating rapid economic and social growth, protecting the environment, eradicating poverty and improving the standard and quality of life of the African populations [73].

The **African Development Bank Group** was established in 1964 aiming at the promotion of economic and social development in Africa. In the last 40 years, the Bank Group assigned around 12% of funds to energy, 90% of which to power supply. Large-scale power generation projects were mainly supported, followed by fossil fuels projects (refined petroleum products and gas), power transmission and distribution, multi-national grid interconnection and rural electrification [74]. The AfDB has recently undertaken a number of initiatives to support African countries to enforce climate resilience and to allow a low-carbon transition, as the Strategy for the period 2013 – 2022 or the Climate Change Action Plan 2016-2020 (phase II), which aims at promoting low carbon development and climate change adaptation and mitigation [75].

Regional and Country Level

At regional level, the economic communities and their respective power pools have undertaken plans, with a common focus on infrastructure development, in terms of generation capacity projects, oil and gas pipeline, transnational transmission lines, with the overall aim of promoting regional economic integration, increasing access to electricity, improving system reliability and quality of supply. Some examples of Plans currently adopted are:

- the Eastern Africa Power Pool (EAPP) updated in 2014 its Master Plan, which promotes the strategy of scaling up access to modern energy services, harmonizing energy policies, and boosting the implementation of infrastructure development, in terms of cross borders interconnections, oil pipeline and regional shared energy projects [76];
- the West Africa Power Pool (WAPP), which adopted a regional Master Plan (updated in 2012), that aims at providing by 2025 new generation capacity to the region (mainly based on hydropower) and transmission lines infrastructures [77,78];
- the recent Southern African Development Community (SADC) Regional Infrastructure Development Master Plan (2012-2027) as part of the PIDA and in collaboration with the Southern African Power Pool (SAPP), which has defined a plan for infrastructure, divided in power generation (identifying nearly 40 GW in future hydropower projects), regional interconnections and storage facilities [79].

Finally, at country level a fragmented and complex framework of energy policies exists, which may vary in the timeframe, refer to certain technology or infrastructure sectors. In some cases the energy policies are , or be part of broader national strategies aiming at boosting socio-economic development and thus trying to link electrification of the country to the quality of the life for the people and the growth of their economic asset (a selection of the most relevant policy may be found in [59]).

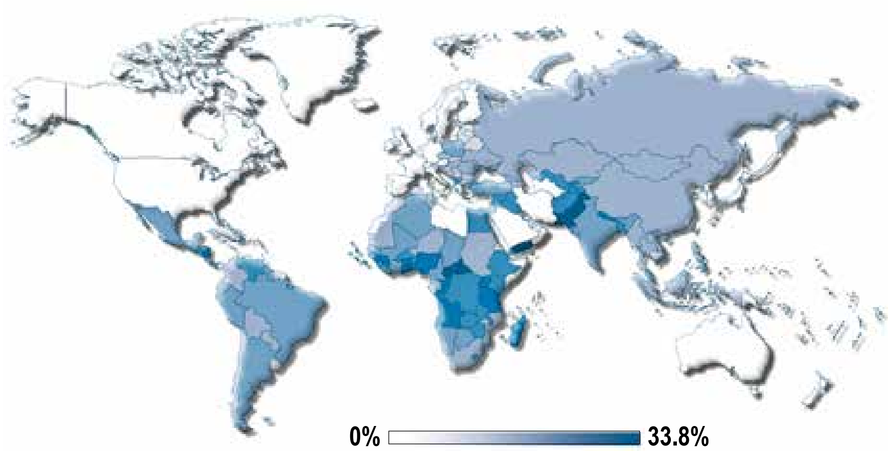
Added value for Prosperity in Africa

Even if the energy situation in Africa is very diverse from region to region, some general consideration may be drawn for the continent to characterize the role of energy infrastructure within the nexus energy-climate-development, the path toward Prosperity and the implementation of NPR in the continent[3].

Modern energy services, though increasing, remains limited and diversified by regions in the continent. For instance, Sub Saharan Africa is strongly affected by an issue of quantity having roughly 60% of its population without access to electricity, more than 80% of which leaving in rural area. Electrification rate in rural areas is not greater than 30% against a bit more than 70% in the urban areas. As already said consumption per capita on average is very low, hardly enough to cover the daily basic need at household level and not certainly targeted to provide community services nor productive uses of energy in the industrial or agricultural sector. Despite it is still difficult to appreciate on the global scale due to small contribution of Africa to the global demand, Africa is un-tapping its domestic renewable resources. Indeed, in the period 2012-2015, 25 million people gained access from low carbon course compared to 5 million in a period 4 time longer from 2000 to 2012. Moreover, in the New Policies Scenario provided by the International Energy Agency, an increase in generation will occur but due to the population growth still more than 0.5 billion people will not have access to electricity [80]. On- grid solution stays the least-cost solution and provide access to the majority of those who gain it within 2030; renewable makes at least the 70% of the additional capacity to provide access. Reliable energy infrastructure with proper regulatory framework are crucial to transform the power sector and contribute to decarbonisation.

Electricity is not the only concern affecting local development. **Bioenergy** in Africa, mainly fuelwood and charcoal, is still the dominant source of energy. In Sub-Sa-

FIGURE 16. VALUE LOST DUE TO ELECTRICAL OUTAGES
% of sales



Source: Own elaboration based on The World Bank, "Doing Business | Data." [Online]. Available: (https://www.indexmundi.com/facts/indicators/IC.FRM.OUTG.ZS). [Accessed: 13-Sep-2017], [82]

(3) These considerations are taken and connect the common features emerged by outlooks [61,64,80]

FIGURE 17. COST AND TIME TO GET ELECTRICITY

% of income per capita.

	Time (days)	Cost to get electricity (% of income per capita)
Sub Saharan Africa	120	3,873
Middle East and North Africa	82	772

Source: Own elaboration based on The World Bank, "Doing Business | Data." [Online]. Available: http://www.doingbusiness.org/data/exploretopics/getting-electricity. [Accessed: 13-Sep-2017], [82]

haran Africa, a bit less than **80% of the population relies** on the traditional use of solid biomass affecting the health of hundred thousand people and the expected 1.1% annual rise in demand until 2030 by a growing population, will exacerbate stress on environment (such as forestry stocks) and health (induced by indoor pollution). In the areas where progress will occur and in the IEA scenarios, **LPG is the most common solution to clean cooking access**, with over half of those gaining access by 2030 relying on LPG. This is particularly crucial from an infrastructure perspective since a lack of proper distribution networks as well as adequate affordability of LPG may slow down progress in rural areas, where biomass alternative is often free of monetary costs [80].

The power sector is often weakly reliable in the African countries. From the *production* side, severe and frequent power shortages are threatening the development of the agriculture and industrial sector and the consolidation of a stable socio-economic prosperity within the region. From the *transmission and distribution* side, the losses in poorly maintained networks are often twice the world average and contribute to increase the overall primary energy used in the country, reducing efficiency of transformation. This structure of the power supply has a large impact on the productivity of African businesses [81]: according to the World Bank Enterprise Survey [82, 83] data business owners find electricity services as one of the three main biggest obstacles to their activities mainly due to:

1. roughly 5% of **annual sales** are estimated to be lost due to electrical outages, figures are diversified by country but incidence is always not marginal (Figure 16);
2. electricity tariffs are, in many cases, among the highest in the world and the frequent recourse to emergency back-up oil-fuelled generators or captive power may induced consequences on **electricity costs** (for businesses and households) and affect **product competitiveness;**
3. time and cost to get electricity connection are high, affecting **business development** (Figure 17);
4. poor supply **reduces utility revenues** due to non-payment, constraining the **availability of finance for further investment**.

As a general consideration, since GDP growth of more than 5% per year in

FIGURE 18. POWER GENENERATION, INSTALLED CAPACITY AND INVESTMENT ACCORDING TO THE IRENA: RENEWABLE ENERGY ORIENTED SCENARIO (HIGH RES) AND RENEWABLE ENERGY LIMITED SCENARIO (LIMITED RES)

IRENA 2015

		HIGH RES		LIMITED RES	
		Min	Max	Min	Max
Power Generation TWh	All sources	1,813	2,165	1,842	2,117
	Large Hydro	257	367	258	307
	Other RE	276	857	147	174
Installed Capacity GW	All sources	431	620	391	444
	Large Hydro	72	94	74	83
	Other RE	91	283	41	50
Investment (2015-2030) Billion $	All sources	424	793	458	538
	Large Hydro	84	128	94	113
	Other RE	165	505	87	120
	T&D	340	391	269	397

Source: International Renewable Energy Agency, "Africa Power Sector: Planning and Prospects for Renewable Energy.", 2015, [64]

Africa has been achieved despite poor electricity supply, it is not difficult to forecast the impact of a more reliable and affordable energy infrastructure on the economic and social development in the continent. A higher quality power network is expected to raise the productivity of African companies: every additional $1 invested in the power sector may generate more than $15 in incremental GDP [59].

According to different outlooks, the power demand will increase from the current value up **to three or four time to 2040**, and as a consequence installed power generation capacity must rise from present levels to almost 400-600 GW by 2040. Forecasting different penetration of renewable energy will also imply a different level of investment as reported in Figure 18. Keeping investment around an annual level of $50 billion for generation, transmission and distribution [59][61][64][80], assuring the proper infrastructure and regulatory framework are in place, RES penetration could assess at 20-30% of the total power generated. PIDA [61] suggests that Africa will save on electricity production costs a considerable share of the annual need through power interconnectors which will integrate the African power market through Power Pools and enable large-scale hydropower projects while increasing access to power in the low generating area through inter-regional trade.

In this configuration, the role or regional smart and integrated infrastructure will be crucial and it is also suggested by IRENA [64] and IEA [59,80] both of them include deeper regional co-operation and integration to facilitate new large-scale generation in their recommendations to policy maker for a successful energy transition in Africa. Integration will also call for stronger inter-sectorial synergies [61] since the energy sector need to be addressed with other infrastructure modes:

- ICT sector through the coordinated development of optical fibre cable and transmission lines.
- Transport sector through coordinated investment manly in road, rail and ports.
- Water sector since hydro development will impact water basin management in terms of regulation of water flows, flood control and allocation of water uses.

This approach will require a coordinated and multi-sector governance to be adopted between the relevant infrastructure sector, for joint planning and prioritizing energy, water and telecommunications regional investment programs. Finally, integration will call for a Life cycle perspective. Indeed, the path toward decarbonisation, alongside with a shift toward renewable energies and efficient technologies within each country, requires fair allocation of responsibility for energy consumptions among the national economies and their productive sectors in order to highlight "hotspots" for reducing impact. This is even more relevant considering the reshoring of productive activities that may be entailed by the implementation of the Next Production Revolution.

The debate between top-down or bottom-up approach is going to be overcome in the perspective of providing universal access giving space and relevance to both approaches in order to mitigate the rural-urban divide. In the IEA New Policy Scenario, on-grid connections remain the least-cost solution for electrification: it accounts for a bit less than 80% of the total population that gains access in 2030 and over roughly 75% of investment; 4/5 of on-grid investment is for renewables-based generation (hydropower followed by solar PV, bioenergy, wind and geothermal). The number of people who gain access from decentralised power solutions asset around 15% as technology costs continue to decline, while mini-grids contribution around 2% remain marginal. In the perspective of increasing the quality and level of access for household (the IEA Universal Access Scenario), beyond the basic needs and promote productive uses for community services, agriculture or rural industries the contribution of distributed (off-grid, 37%) and decentralised generation (mini-grid, 5%) meet the more than 42% of the need of those who gain access in the period showing the relevance these technologies may have in rural areas. Distributed and decentralised solutions have the double advantages to increase the share of renewable energies and reduce the investment needed for transmission and distribution.

Reduction of costs and greater attention to energy efficiency, social entrepreneurial promotion, disruptive penetration of digital technology, facilitated and supported by a variety of national and international policy[4], will be crucial for the future relevance that distributed generation may gain. They may rely on new business models centred on decentralised renewable energy systems that capitalize on the digital revolution to become more massively at the disposal

(4) such as the Addis Ababa Action Agenda on financing for development, 2030 Agenda and the Paris Agreement

of citizen, assure management by smaller entities and payment of services. Moreover, provided an enabling environment facilitates their involvement, private sector working together with NGOs or local training institutions can also play a crucial role, supporting government target to meet universal access.
Energy infrastructure 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 people. For these reasons, people should be at the center of any strategy to promote energy access. As stated in the Sustainable Energy Annual Report by the World Bank with reference to the special feature "The Power of Human capital" [84] the debate on access toenergy has tended to lean mostly on technology,finance, and policy as key drivers. Thanks to this approach, there has been some progress in expanding global energy access\u2014although the goal of universal access is still far off and is likely to remain so for the next two decades. Scaling up the strategies for access to energy requires a different perspective and an innovative approach to capacity building. In line with the ethical imperative of the 2030 Agenda for Sustainable Development of \u201cno one left behind\u201d and its focus on people, the cross-cutting role of human capital(individually and collectively, as communities and institutions, human capital needs to be promoted as a precious resource (renewable) capable to valorise and sustain local ownership, promote economic growth and ensure long term impact. In this perspective energy solutions needs to be designed for the people, by the people and with the people and adequate informative awareness campaigns to inform and drive people on hot to use the potentiality coming from electricity for their income generating activities and quality of life.

MOBILITY: THE GOAL OF CONNECTING PEOPLE AND GOODS 3.3

Transport of goods and people is a prerequisite for a prospering economy. The recent G7 Transport Ministers Meeting has recognized the key role of the **transport infrastructure for shaping mobility patterns, contributing to innovation and productivity while triggering economic, environmental and social benefits**. Transport infrastructure enables the connection of people to jobs, education and health services. It spurs the interactions among people that generate knowledge and visions for long-term development [85] the G7 Ministers of Transport and the European Commissioner for Transport, reaffirm our commitment to fostering investment in high-quality Infrastructure as a key strategy to reignite and sustain economic growth. We recognize that investment in infrastructure can shape mobility patterns, can contribute to innovation, automation, productivity improvement and digital solutions for mobility, and can trigger economic, environmental and social benefits. At a time when national economies are recovering from an unprecedented economic crisis, we are challenged to simultaneously maintain existing infrastructure and identify funding sources for new infrastructure investments. We recognize the importance of promoting well-planned, continuous and sufficient investment, focusing on effects on improved quality of life, improved productivity and economic growth (so-called \" stock effects \").

Especially, future transport systems need to comply with many constraints in terms of quality and affordability, social and environmental impacts. Transport accounts for about 64% of global oil consumption, 27% of primary energy demand and 23% of total anthropogenic GHGs emissions. Today, Africa's utilization of oil products is 3.6 mb/d and this value is expected to reach 6.2 mb/d in 2040 [86] to meet growing demand for transport services; for each barrel of oil no longer used in Europe, almost one barrel more will be used in the Africa. Globally, air pollution from vehicles causes almost 185,000 deaths and roads' accidents contribute to more than 1.25 million deaths per year, 90% belonging to low and middle income countries. In particular, Africa has the primacy for the risk of a road traffic death resulting in about one-fifth of total fatalities from road crashes worldwide although the share of global registered vehicles is only 2% (more than 40,000,000 vehicles in Africa compared with more 1,750,000,000 at global level). Noteworthy, road accidents in low and middle-income countries cause economic losses equal of up to 5% of GDP [87].

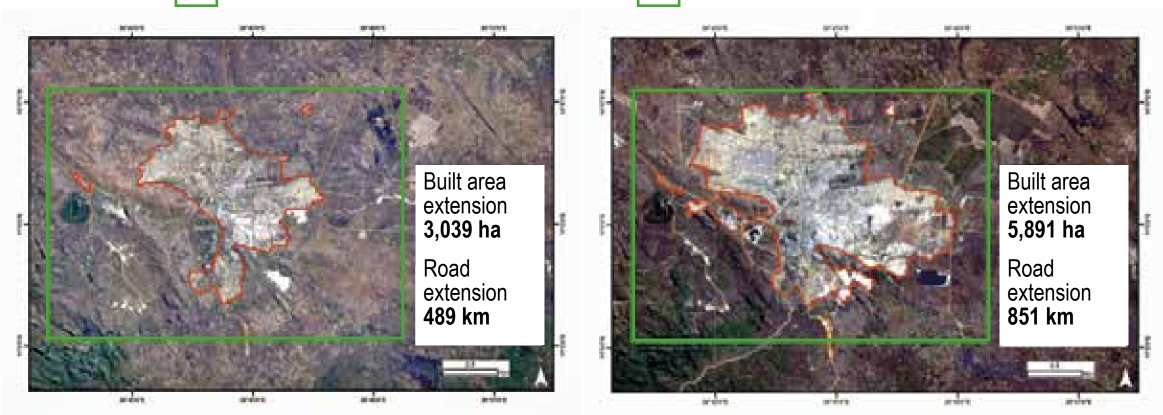
By 2050, global transport volume for passengers and goods will double as result of fast-growing population and emerging economies with a consequent strain on the global transportation system. As a result, significant investment will be required in the transport infrastructure to increase capacity and improve productivity. Similarly, there will be the need of more efficient and reliable

FIGURE 19. DIGITAL TECHNOLOGIES TO SUPPORT TRANSPORT INFRASTRUCTURE PLANNING AND MONITORING

Urban sprawl and mobility issues in likasi, drc.

Built up area 2000
Area of interest

Built up area 2017
Area of interest



Source: Own elaboration

vehicles relying on more sustainable energy sources.
Developing countries and Africa will experience a rapid urbanization having the opportunity to build more sustainable transport infrastructure. Technology advances, especially in the field of digitalization will deeply reshape the global transport system. Emerging cities will be designed with more sustainable and inclusive transport infrastructure leapfrogging old costly and polluting mobility modes. New digital technologies, spurring intelligent transport systems, can help big cities improving the quality and efficiency of transport solutions for citizens by increasing productivity of existing transport infrastructure. Future freight transport is a critical concern as well and an integrated multimodal transport network has been indicated as a key option to successfully manage local and global supply chains.
Therefore, a great development of Mobility can be disruptive in Africa's efforts to improve its habitant's life quality, to support the Next Productive Revolution and contribute to the achievement of the SDGs. Indeed, as stated in the SDG 11, the international community recognized urbanization and city growth as a transformative force for development. By 2030, this specific goal should be fulfilled by providing access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons. For this aim, monitoring the urban sprawl in less developed countries, is considered one of the main preliminary activities, being able, using multi-temporal data, to deliver added value information concerning the relationships existing between urbanization and mobility (both in term of density and accessibility to primary services). In Figure 19, Likasi, a small town in DRC, has been investigated using a multi-temporal approach with the aim to fully understand what kind of information can be extracted to characterize the fragile equilibrium between urban sprawl and road network. It is important to notice that the roads-built up ratio is decreasing over last years, highlighting how urban growth is often not accomplished by ad adequate road network expansion.

Transport infrastructure enabling the Next Production Revolution

Undoubtedly, it is imperative to bridge the transport infrastructure gap of Africa in terms of new capacity and modernization of existing assets. On the other hand, following the current path for the implementation of new infrastructure may be unsustainable in terms of financial resource required and environmental impact.
A step change is required, similarly to energy that is considered the lifeblood of the modern society, **information and communication technology (ICT) are the nerve system of future mobility patterns and multimodal transport**. This is even more relevant in a future scenario where global transport volume for passengers and goods will double and solutions will be needed to increase the sustainability and quality of existing transport infrastructure beyond deploying new concrete and steel to expand capacity. Especially, disrupting technologies are reshaping the mobility landscape with major trends in autonomous driving, shared mobility, connectivity, and electrification.

Box 5

Volunteered Geographic Information (VGI) for sharing knowledge

The term volunteered geographic information (VGI), introduced by Goodchild in 2007, describes the process of collecting spatial data by individuals, usually on a voluntary basis. VGI is sometimes the cheapest and often the only source of geo-information, particularly in areas where access to geographic information is considered an ancillary option and/or an issue of national security.

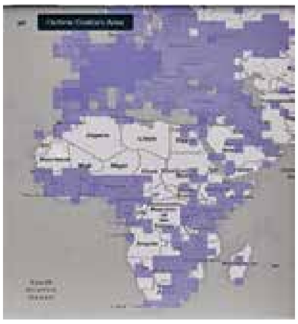
In most cases, the contributed VGI is collected in a database or file system structure and sometimes freely available to other interested Internet users. Stating that the information has to match a geographic position, this can either be achieved by digitizing it from georeferenced aerial/satellite imageries or by actively collecting GPS tracks with a designated device. Furthermore, a broadband Internet connection and additional hardware in the form of a smartphone or personal computer are needed. VGI contributions lead to a number of diverse platforms and projects utilizing the data and technologies in spatial decision making, participatory planning and citizen science. VGI data also experienced more attention, due to its successful implementation for humanitarian or crisis mapping purposes.

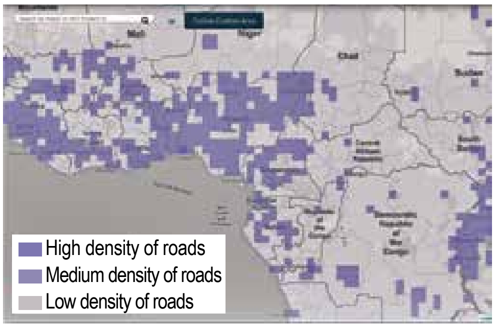
In this framework, the Humanitarian OpenStreetMap Team (HOT) obtained an important role. Since 2009, it has coordinated the creation, production and distribution of free mapping resources to support humanitarian relief efforts in many places around the world. More in general, OSM (OpenStreetMap) project has developed into one of the largest and well-known VGI projects of the past seven years. Many different OSM-based maps have been created in recent years, tailored to different purposes, such as public transportation, by rendering the collected information in a particular way. More advanced projects, such as OpenRouteService, OTM (Open Transport Network) have shown that collaboratively collected geo-information by volunteers can be a reliable data source for mobility assets.

Box 5

The maps shows the current road network mapping density in Africa and part of Europe (left) and zoom on the West Africa (right).

From this map, especially comparing the European current status, is very clear that a very consistent effort in mobility data acquisition should be paid in the African continent. Apart from South Africa, Guinea gulf, Indian ocean and Mediterranean sea countries, most part of the area is not covered. Anyway, the situation is even worse when zooming in the central part of Africa (right side); entire countries (e.g. Democratic Republic of the Congo, Central African Republic, Chad, Sudan, etc.) have very little data (and when acquired, only in big cities), resulting in a lack of data and therefore leading to the impossibility to draft any possible strategy.





Infrastructure is a major enabler for a faster uptake of new solutions both in the field of transport of goods and people. In particular, key ICT technologies have been identified to foster future mobility, including cloud computing and mobile communication technologies, advances in interface technologies and internet of things.
Cloud computing and wireless communication offer ubiquitous connectivity and network services that enable real time monitoring and control across the whole supply chain of goods. The growing of communication network (e.g., 5G Technology) could increase connectivity of vehicles thus improving quality of transport services and spurring multi-modal solutions.
Interface technologies have gained popularity recently in logistics industry with relevant examples such as hands-free operation and voice control. Furthermore, they have been transforming customer interface in passenger transport.
Finally, the use of sensors embedded into single objects, including infrastructural components, can track individual assets or containers, enabling an internet of things capable to sense information about transport conditions and georeferenced tracking. A higher deployment of sensors and processing solutions in the transport infrastructure management, such as machine learning, accelerate the uptake of autonomous driving for both personal mobility, freight transports and logistics.
In particular, the potential to harness customers' own smartphones as sensors leads to the opportunity for 'crowd sourcing' that can give high value in order to achieve a more sustainable transport service.

A last mobility trend, electrification, has a high relevance in terms of future infrastructure planning meaning the need for building distributed charging stations and the integration of renewable systems and storage devices within transport infrastructure.

Status and number

African continent has an enormous territorial extension comparable to USA, Europe, China and India combined with a strategic position to trade routes and the abundance of natural resources. Despite all these characteristics, the transportation and logistics industry is not sufficiently developed.-

Mobility strategies in Africa should be addressed with reference to the different mobility modes: roads, rail, air and water ones [88]. At continent level, the infrastructure endowment is very inhomogeneous (ranging from South Africa, Mediterranean countries to Sub-Saharan ones), so that it is not possible to provide a truthful analysis of the average African mobility. In this perspective, the very low total intra-African trade in 2011 – 11% of African trade with the rest of the world [89], states the poor internal connection among the countries and the region.

More in detail, Africa's terrain variety has an impact on critical transport and in general, there is a **huge range of maturity in terms of infrastructure**. For example, Angola has just 4 km of roads per 100 square kilometers of land, Ghana's road density is more than 10 times as high, while South Africa has 62 km of roads per 100 square kilometers [88].

Roads represent the main mode of goods transport in Africa. The most of continent's roads are unpaved or in poor condition and quality tends to reduce in case of non-international truck roads. The situation is particularly critical in the Democratic Republic of the Congo and Angola. Also in Kenya, presenting a better road quality, only 14% of roads are paved. Road accidents is a major issue for Africa causing significant economic losses (ranging within 1-5% of the GDP). It results by the fact that deaths and injuries strongly affect economically active people. Expensive medical care and the loss of a breadwinner highly reduce families' standard of living. At a higher level, costs related to health, insurance and legal systems are extremely relevant [87]. Formally speaking a network of **trans-African highways** exists, to potentially permit people and goods travelling across African countries, but their impact is limited by the poor quality of some of them. Indeed, where road infrastructure is adequate, road maintenance is a worrying problem reducing dramatically the percentage of road in good or fair condition.

Africa's **rail** networks have severe infrastructural problems and deficiencies: generally, rail lines date back to colonial period and are poorly maintained. An exception is represented by South Africa where in the last decade more than US$5 billion were invested.

Ports are the most important transportation mode to access the African continent especially for goods. Nevertheless, ports are not enough to handle existing traffic. Durban is the most important port of Africa (not only in southern Africa). The Suez Canal in Egypt is the most important shipping route in North Africa. East and West

Africa present problems in term of capacity and performance [90].
There exist several **international airports** for passenger traffic [91].
The busiest hubs are OR Tambo International Airport in Johannesburg (South Africa) and Cairo International Airport in Egypt. When considering goods instead, air transportation is not enough developed. In the East Africa, the Jomo Kenyatta International airport plays the role of hub while in West Africa there is not a recognized principal airport hub.
Overall, one of the main issue in dealing with African infrastructure is related to a general lack (at least for the majority of the countries) of **reliable and comprehensive data** that would be needed to get a clear view of the actual situation, as well as to drive the right enabling policies. Mobility infrastructures are indeed, as already mention, crucial to promote equitable prosperity both from a natural resources perspective (e.g., land, water, energy, forestry, raw materials…) and from a socio-economic dimension also considering the opportunity to reduce the urban-rural divide providing services and goods even in scattered regions.
Taking into consideration the central role of **citizen science** and possibly **crowdsourcing push** (both enabling collaborative and community centred policies), the **rigorous and organized** (considering a general access to a sufficient bandwidth) representation, for the whole continent, of the mobility network and all the possible links related to mobility shift modes is now possible to be created. Indeed, from the technological point of view, this basic activity is enabled **by three different factors**:

1. the broad availability of **remotely sensed data** (both from aerial and satellite platforms), often open sourced distributed (e.g. NASA Landsat programme, ESA Sentinel constellation, etc.) where it is possible to extract information from raw data (for example completed and updated road networks);
2. a **community self-organized set of platforms**, where in a fully crowd-mapping approach, VGI (Volunteered Geographic Information) could be extracted, organized on the base of clear and well known data models, and freely distributed to everyone (see Box 5);
3. the **consolidated availability of hardware** (e.g. smartphones and tablet) when coupled with localization devices (mainly GPS), allow both data digitalization and a LBS (Location Based Services) approach.

Policy in place

Several Policies related to transportation and logistics are already in place.
They can be divided mainly in “continental” initiatives (conducted by African states and African commissions) and “foreign” initiatives (conducted by extra-African nations in exchange of commercial agreements).

Continental level

The main initiatives have been launched through the Programme for Infrastructure Development in Africa (PIDA). This initiative, provides a shared framework to build fundamental infrastructures for transportation and trading improvement (but also ICT, energy and water) manly defining projects and programmes for short, medium, and long term (up to 2030). PIDA was approved in 2012 by the African Heads of State and Government during the 18th AU Summit in Addis Ababa. The ambitious mission related to transportation consists in the development of free movement of goods and passengers. The key interventions required to reach these goals are:

- connections between main Africa capitals and centers with paved roads and rail;
- a functional African Regional Transport Infrastructure Network (ARTIN) at the least economic cost, with priority for landlocked countries, while minimizing the environmental impact and including gateway ports and air transport services, increasing efficiency, cost, reliability and safety.

In PIDA, 24 transport infrastructure projects are defined as priorities and 16 of them consist in corridor development projects. Projects cover almost all African states and involve different transportation modes (roads, ports, airports and rail). They present different timeframes and planning stages. Just to cite a few of the most important, the TAH (Trans African Highway) is a continental connectivity programme that aims to complete and standardize the TAH missing links by 2030; especially to complete the missing links in the network between Nigeria, Niger, Algeria, Chad, Sudan, Ethiopia and Djibouti. The project is still in the early stages of implementation and the financing plan and design standards need to be finalized. The first expected result consist in an upgrading of 1,582 kilometers of earth track between Chad and Sudan and the construction and rehabilitation of 1,950 kilometers of paved roads in Algeria and Niger. In the first stage, two highways will be completed, namely the TAH2 (Algiers-Lagos) and TAH 6 (Ndjamena-Djibouti).

The North-South Multimodal Transport Corridor consists in the design and implementation of a smart corridor system for both road and rail on the multi-modal African Regional Transport Infrastructure Network in Southern Africa. In detail, it will improve border crossings for both passengers and goods between South Africa, Botswana, Zimbabwe, Zambia, Malawi and the Democratic Republic of Congo in term of efficiency and capacity of the transport sector. The more efficient transport system will speed up regional integration and will increase regional trade, while leading to cost savings. Railways will become more competitive with road transport. The project includes 560 kilometers of highway and 900 kilometers of road. It also entails the construction of 180 kilometers of railway line and the modernization of the rail network. The construction of four one-stop border posts is also in the pipeline.

The Abidjan-Lagos Coastal Transport Corridor involves the modernization and upgrading of the most travelled West African corridor on the African Regional Transport Infrastructure Network. The countries to benefit from this project are Ghana, Cote d'Ivoire, Togo, Benin and Nigeria, all of which form part of the Economic Community of West African States. Some sections of this programme are already being implemented as national projects and the countries concerned are rolling out one-stop border posts as part of an on-going trade and transport facilitation project. The norms and standards for this project still need to be harmonized and the project may need expansion in future due to capacity shortages and increased tariff rates. The project includes the roll-out of five road-related smart corridor modules, which comprise the modernization of a 384 kilometer stretch of highway, the upgrading of 288 kilometers of road and the creation of four one-stop border posts.

Foreign initiatives

There exist also few projects funded by foreign nations in exchange of commercial agreements. China, for example, is investing in transport infrastructure in Africa. In Angola, as part of an 'infrastructure for oil' trade agreement, China is funding both transport and everyday infrastructures (like housing area of Kilamba Kiaxi) [92]. In Kenya, China signed a US$5 billion deal that includes, among the others, a rail link construction from Mombasa to adjoining Uganda [93]. Moreover, China is supporting transport infrastructure building in other countries like Tanzania, Ghana, Mozambique and South Africa.

Added value for Prosperity in Africa

Smart transport infrastructure and logistics represent a key option for speeding up the uptake of the Next Production Revolution in Africa and promoting Prosperity.
Closing the Sub-Saharan Africa's infrastructure quantity and quality gaps is extremely challenging. Transport infrastructure in Africa presents the lowest road and railroad densities and quality among developing regions and Sub-Saharan Africa is the only region where road density has declined over the past 20 years. Railroad network density, especially, is extremely low (less than 0.002 km per square km of surface area by 2014). Furthermore, the World Bank has reported a positive correlation between real income per capita and road density originated by increased opportunity of connecting people to jobs and goods to markets. Therefore, it is urgent to increase the infrastructure capacity of Africa to sustain economic growth.
Introducing digital technologies into existing transport infrastructure can **increase productivity thus changing old paradigms basing solely on capacity** (e.g., road density) and calling for the introduction of new indexes capturing the value of SMART-I Infrastructure.
Finally, road traffic increases air pollution and crashes that are major responsible of death among people aged 15–29 years, especially in developing countries causing significant economic losses.
Integrated and intelligent transport network is able to sense demand, measure performance and monitor the health of physical assets thus enabling radical new ways of monitoring and maintaining roads, track and runways. Real time response enables managing capacity also predicting and avoiding disruption. Cognitive technology can improve automation and safety of vehicles. Finally, connected and automated vehicles are likely to lead to modifications in terms of security, safety, emissions reduction and time management while travelling on roads.
Smart transport and logistics infrastructure enable the Next Production

Revolution by the digitisation and **integration of vertical and horizontal value chains**, the development of new digital business models and customer access platforms. Overall, digitisation has a high potential to improve internal operations of companies in a wide variety of areas including asset management and the delivery of new investments. In particular, transport and logistics companies can benefit from the use of machine learning algorithms for the implementation of predictive maintenance and fleet management. Autonomous picking and autonomous vehicles offer the potential of automated movement and transportation on-site and between sites.

The implementation of smart transport and logistics solutions can stimulate **more decentralized and small business** offering a greater flexibility that could overcome financial barriers. Finally, intermodal transport solutions can be promoted thus increasing the productivity of the whole transport and logistic value chain.

Transport infrastructure needs to shift for speeding up the disrupting change coming from the new personal-mobility landscape with a major trend in **shared mobility**. Cities have been indicated as the most relevant segmentation dimension that will determine mobility behaviour and, thus, the pace of transport changes. Low-income, dense cities will see an increased presence of shared vehicles to overcome congestion fees, traffic jams and reduce air pollution. Therefore, shared mobility solutions will provide user-centered mobility services empowering people and changing the approach to operations and planning based on users' choice and priorities.

A people-centred approach is also required to develop capacity and skills that drive transformation as the lack of **digital culture** has been recognized as a major barrier for the implementation of smart transport infrastructure. Finally, crowdsourcing gives empowerment to people in a global perspective by changing the granularity of measures, monitoring and planning. So, crowd data on temperature and weather conditions sensed by millions of vehicle everyday could be harnessed to drive substantial improvement in weather forecasting, air pollution and other areas.

Remarkably, smart and integrated infrastructure can promote sustainable mobility ensuring more inclusive and healthy transport services. Furthermore, electrification of transport infrastructure could promote the use of **more sustainable energy resources and carriers** thus helping the penetration of renewable energy in a final sector with a strong lock-in with carbon-based fuels. On the other hand, using electric vehicles as power grid infrastructure for energy storage option provides a higher flexibility of the energy system as a whole helping a **higher penetration of renewable power sources**.

4 Smart and Integrated Infrastructure in Africa: recommendations for an Action Agenda

4.1 POLICY RECOMMENDATIONS RELYING ON SMART-I INFRASTRUCTURE

Deploying SMART-I Infrastructures for Africa needs to be recommended to promote Prosperity. Ten key recommendations emerge from the data and policy analysis in the different sectors of digitalisation, decarbonisation and smart mobility:

1. *Broadband penetration needs to be widen in the continent to support sustainable development.*
2. *Digital transformation is crucial to enable a new asset for African manufacturing and productivity.*
3. *Digital Technologies can boost people engagement and empowerment.*
4. *Renewable Energy & Efficiency need to be top priorities to unleash access to modern services.*
5. *Increased power capacity and reliability need to boost local economy and business development.*
6. *Interconnections and Networking of energy systems cannot wait longer to increase trade and savings.*
7. *Distributed energy system may complement on grid option to increase inclusion and empowerment.*
8. *Smart transport infrastructure is prodromal of prosperity in Africa.*
9. *Digitalization of transport and logistics spurs African manufacturing and productivity.*
10. *Systemic integration and effective resource management need to be on top of the Africa Agenda to unveil the potential of Smart-I Infrastructure.*

The attributes of SMART-I Infrastructures also complement and characterise the needed transformation of the African Socio-Economic asset toward the NPR adoption in the continent. Though very diverse and articulate here below some principal elements are reported for giving food for thoughts for the ICA plenary conference of October 2017.

ECONOMIC EFFECTIVE

- The positive impact of broadband penetration opens a new era for the infrastructure development and an innovative asset for the national economy.
- Reliability and affordability of energy supply contribute to business development in the industrial and agricultural sector, annual sales saving, electricity costs reduction and product competitiveness.
- Smart and integrated transport and logistic can contribute to reduce operational costs, thus increasing the productivity of the whole transport and logistic value chain affecting GDP in a positive way.
- Closing the Africa's infrastructure quantity and quality gaps cannot be postponed longer to take profit from the positive correlation with income, boosted by connecting people, jobs, goods and markets.

ENVIRONMENTAL FRIENDLY

- The positive impact of broadband penetration on GDP needs to be coupled with positive effect of digitalisation on the environment, by enabling a more efficient use of energy and natural resources and promoting an appropriate monitoring and control systems.
- Africa cannot lose momentum to investigate low carbon and efficient alternatives in order to prepare the years after 2035 to avoid a sudden raise of emissions.
- Reliable energy infrastructure and shared mobility with proper regulatory framework allow cleaner energy services and avoid lock-in in the transportation sector.

SOCIAL INCLUSIVE

- SMART-I Infrastructures need to act on the social divide affecting job opportunities or equitable access to basic services, like health care and education.
- By creating value for consumers, Internet can also decrease search and information costs while enhancing trust and transparency.
- SMART-I Infrastructures can boost productive uses in the industrial or agricultural sector.
- Additional capacity and services reliability support fair conditions for business development by reducing the upfront cost of investment that otherwise could be met only by higher income categories.

SAFE AND RESILIENT

- Proper infrastructure for distribution networks (electricity and roads for instance) are crucial for reducing the divide among rural and urban area.
- Adequate affordability of LPG and relative distribution network need to be pushed in rural areas to fasten the adoption of modern, healthy and safe energy services for cooking needs.
- Integrated and intelligent transport network may measure performance or traffic without affecting air pollution or crashes, enabling new ways of monitoring and maintaining roads, track and runways.
- Connected and automated vehicles are likely to modify the sector in terms of security, safety, emissions reduction and time management.
- Data collected from sensors and machines enable rapid decision-making and improve productivity, operational safety and maintenance.
- The introduction of new digital products and services allows customer-specific solutions.

INTEGRATED BY DATA, FUNCTION & GOVERNANCE

- Introducing digital technologies and proper governance into existing transport infrastructure increases productivity thus changing old paradigms based only on capacity like road density.
- Electrification of transport infrastructure is requested promoted the penetration of renewable energy in a sector with a strong lock-in with carbon-based fuels.
- Electric vehicles can be used as storage to increase flexibility of the energy system.
- Integrated infrastructure and deeper regional co-operation within the power pools is expected to facilitate large-scale generation, promoting trades between productive and consuming region.
- Inter-sectorial synergies are crucial among energy, transport and ICT but also water and other services.
- New ways of interaction and cooperation with suppliers and customers enable open innovation and crowdsourcing.
- Good Governance needs to be the backbone on which SMART-I Infrastructure development is promoted for joint resource planning and for fair allocation of resource consumptions responsibility.

PHYSICALLY AND FINANCIALLY DECENTRALISED

- A new ecosystem of digital entrepreneurs need to flourish associated to new business models like distributed manufacturers, starting with little capital and using the earnings to finance expansion.
- Decentralised solutions, boosted by cost reduction, energy efficiency, social entrepreneurship, disruptive digitalisation, increase the share of renewable

energies and reduce investment costs.

- Off-grid infrastructure represents an option to make energy accessible, enlarge the funding opportunities capitalize on digitalisation, assure management by smaller entities and service payment
- The implementation of smart transport and logistics solutions can stimulate more decentralized and small business offering a greater flexibility that could overcome financial barriers.

LIFE CYCLE PERSPECTIVE-BASED

- Life cycle perspective need to be a new paradigm on which SMART-I infrastructure development is promoted for assessing a fair allocation of resource consumptions responsibility.
- Digital technologies can also contribute to increase GHG emissions and e-waste, a lifecycle accounting perspective is thaus to avoid geographical shift in emission and production of wastes.
- Dense cities foresee a shift from personal-mobility landscape to share mobility to overcome traffic jams and reduce air pollution
- A systemic perspective need to include analysis of supply chain of vehicle production, trades of goods and import/export of raw materials.

PEOPLE CENTRED

- New products and services as well as new business models are characterised by an emphasis on high value-added digital technology where people are the centre of the stage and see a shift from simple customers to partners
- Decentralised and Distributed generation need to be driven by local need, respond to capacities, and aspirations of people and be absorbed within the local culture, adapted and improved by local people.
- Shared mobility solutions need to be foster to provide user-centered mobility services empowering people and changing the approach to operations and planning based on users' choice and priorities. As with crowdsourcing, this approach give empowerment to people in a global perspectives.
- Developing local capacity (technical, managerial, institutional) for designing need-driven infrastructure and planning strategies, can increase local ownership and avoid lock-in solution for the long run while facilitating the NPR promotion as stated at the G7 Africa Outreach in Taormina 2017.

4.2 SMART-I INFRASTRUCTURE REQUIRES A NEW PARADIGM

SMART-I Infrastructures need to be developed in order to displace non-renewable resources, assessing and possibly taking advantage of the eventual synergies and feedbacks among different economic sectors, even those that are not directly linked to primary energy uses.

Definition of energy policies has been performed based on the traditional energy accounting paradigm, called *Production-Based Approach* (PBA). This approach describes how the energy is produced, traded and directly consumed by each sector of the analyzed economy. Results of the traditional PBA accounting method can be complemented by means of the so-called *Consumption-Based Approach* (CBA). This approach enables to broaden the scope of energy accountings in a Life Cycle perspective, quantifying the energy directly and indirectly invoked (i.e. embedded, or grey energy) to produce the goods and services exchanged among economic sectors, thus revealing and highlighting the underlying economic shifts that help to explain trends in energy consumptions and to support the identification of hidden structural links among productive sectors in different national economies [94]–[97].

As an example, results of the joint application of the two accounting paradigms to South Africa and Botswana are presented in the Sankey diagrams of Figure 20, where industries are grouped into Energy, Transport, Goods and Services: grey arrows represent the physical flows of energy , while the blue ones represent the energy embedded into goods and services, that is the primary energy actually required to support their production in a Life Cycle perspective. In 2013, South Africa overall resulted as a net fossil energy exporter but shifting from Total Primary Energy Supply (TPES – gray arrows) to Total Embodied Energy Supply (TEES – blue arrows), its role as an energy exporter is even greater, since it globally exports energy also as embedded into goods and services to support industrial activities of other countries (mainly the neighboring regions of Namibia and Botswana). In a similar way, the difference among TPES and TEES for Botswana reveals a strong and hidden energy dependency of Botswana due to the international trades of products from neighboring countries (mainly from South Africa).

The complementary use of PBA and CBA allows to better understand the infrastructural links among sectors and economies, providing further insights on the energy metabolism of the analyzed economies that could be a valuable support to decision makers in the process of environmental policy design at the local and global scales, avoiding unforeseeable consequences. For instance:

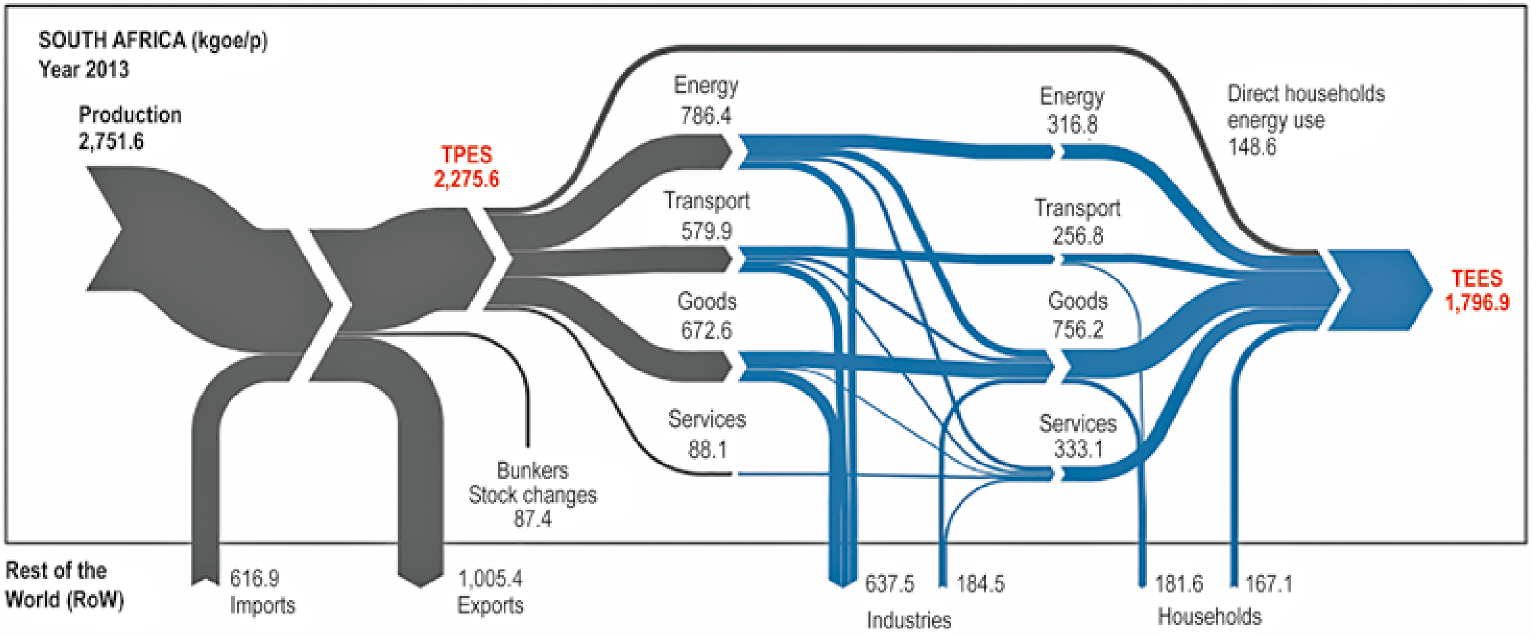
- In South Africa, the amount of primary energy directly consumed by Energy and Transport sectors is largely devoted to support the endogenous production of Goods and Services industries. Therefore, efficiency efforts could be devoted in increasing production efficiency of these sectors, defining alternative production and consumption pathways.

- Results of CBA reveal that one possible and non-trivial way to indirectly foster the energy efficiency of South Africa and to reduce the energy dependency of Botswana consists in reducing their international trades of products, thus enhancing international cooperation by supporting the development of the industrial infrastructure of Botswana.
- The joint use of PBA and CBA highlights the relevance of well-posed policies that may avoid an additional outsourcing of goods and services from abroad, shifting the energy dependency of the country instead of reducing it.

CBA method here applied to the energy might be extended to a multiplicity of environmental indicators, such as consumption of water, or soil, pollutants and GHG emissions, in order to assess and to support the reduction of environmental impact of economic systems.

FIGURE 20. ENERGY METABOLISM OF SOUTH AFRICA BASED ON A STANDARD AND LIFE-CYCLE PERSPECTIVES (RESPECTIVELY THE GREY AND BLUE ARROWS).

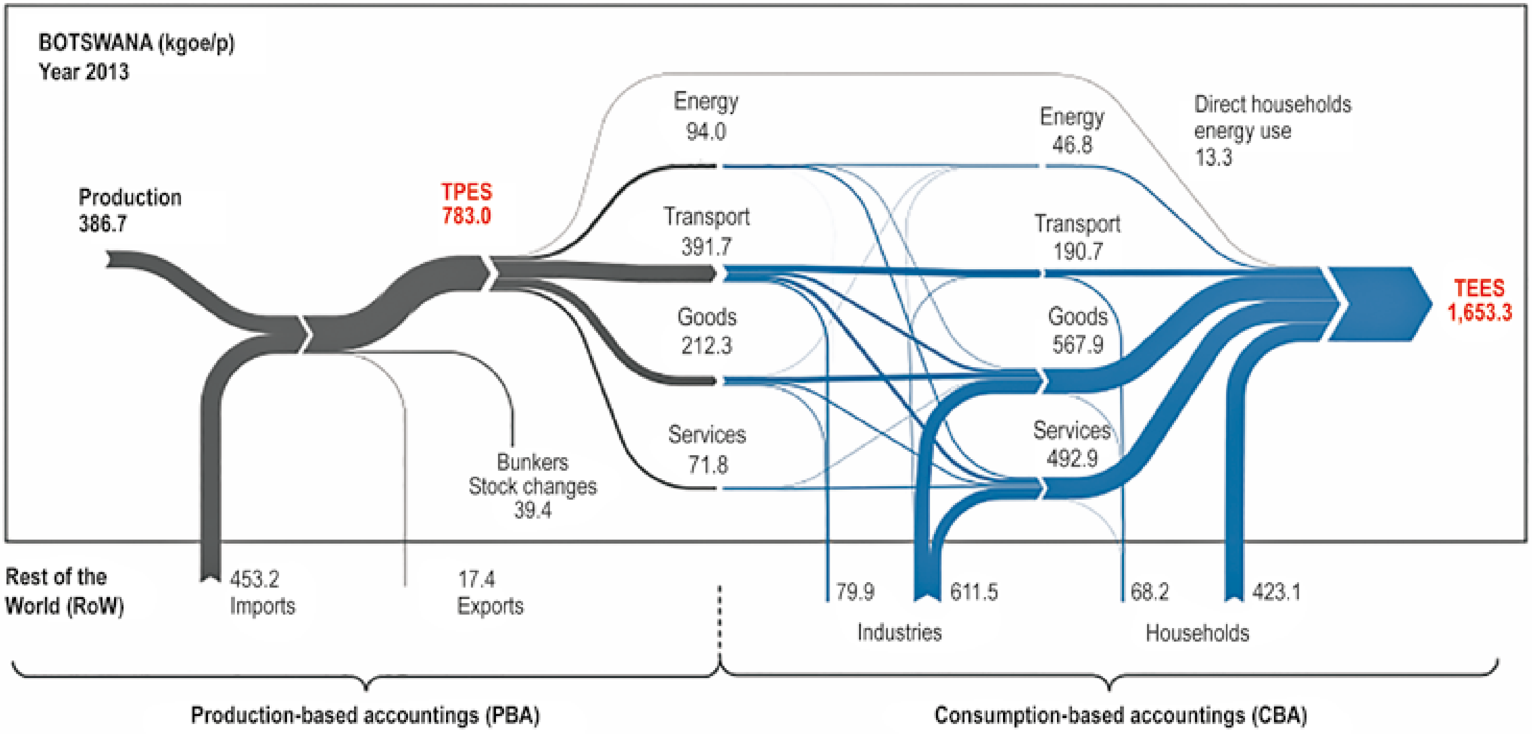
All values are expressed as kg of oil equivalent per capita.



Source: Own elaboration based on Eora MRIO Data Base (2013)

FIGURE 20. ENERGY METABOLISM OF BOTSWANA BASED ON A STANDARD AND LIFE-CYCLE PERSPECTIVES (RESPECTIVELY THE GREY AND BLUE ARROWS).

All values are expressed as kg of oil equivalent per capita.



Source: Own elaboration based on Eora MRIO Data Base (2013)

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