On Capacity and Quality Issues in Engineering Studies across Sub-Saharan Africa: a Review

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***Abstract* - This paper highlights the challenges of 21st century engineering studies and practice relating to infrastructure growth in Sub-Saharan Africa (SSA). Tertiary education in SSA is experiencing explosive growth of 8.6% driven by the higher education institutions (HEI) of which the private sector accounts for 22% of enrolments. The unintended consequences have been the escalation of capacity deficits and quality problems in engineering studies. Capacity deficit for the SSA has also been exacerbated by brain drain and severely small pool of highly qualified academics. The causes of these issues are discussed while considering University as the centrepiece for development of appropriate remedial measures.**

Among the remedies to quality and capacity deficit issues in engineering studies and practice are: setting up internal quality assurance systems and rigorous implementation of accreditation requirements, promoting inter-Africa university collaborations, research networks in engineering, and advanced engineering degree programs. It is known that some of these initiatives are already operationally active in some disciplines but not adequately so in engineering.

***Keywords* – Quality, capacity, engineering education, Sub-Saharan Africa, Infrastructure, accreditation, research networks**

I. INTRODUCTION

Among most African countries, the contribution of engineering to economic development, sustainability and poverty alleviation has generally been overlooked or sidelined while attention is paid to basic societal needs such as health, environment, food, water and sanitation at community levels. While the significance of these various basic needs is certainly undisputable, it may be appreciated that engineering is an underlying essential element for sustainability to be achieved in most of the developmental programs, and absence of an endogeneous engineering capacity undermines long-term development. Such has been the past experience with most programs in developing countries. In the past 50 years, trillions of dollars in International Aid have been used in Africa but it is now common knowledge that Aid has failed to improve Africa's economy. It has been found that the poor who received Aid have not seen much betterment in human welfare than those who received little or no Aid [1]. It is important to realize that engineering is an essential discipline, that addresses challenges associated with alleviation of poverty and innovation for sustainable development. The engineering and infrastructure field, for example, contributes to these societal needs by:-

- Providing physical infrastructure needed by businesses, financial institutions and rural communities to conduct economic activities such as agriculture, trade and industry
- Raising productivity of local industries to enhance self-reliance and high value product chain capable of promoting industrial competitiveness for economic transformation
- Reversing the current technical brain drain which flows from rural to urban areas, and from developing to developed countries, through creation of employment opportunities such as labour intensive approaches; enterprise development, research and innovation

II. BACKGROUND

The role of engineering in development is evident from examining emerging economies that have made progress in economic development and poverty alleviation. It has been shown that the most important factors responsible for rapid economic transformation in these countries have been, *firstly* the creation of large basic infrastructure, promotion of enterprise development along with a pool of technical personnel for operation, repair and maintenance of enterprise industry, and *finally*, government support and funding of higher education institutions including technological and engineering sciences.

It is recognized that lack of adequate, quality infrastructure and its operational maintenance is one of the key factors that has hindered sustainable development in Africa. Poor infrastructure is a two-pronged problem, partly being a question of physical works of engineering, and partly being shortage of engineering capacity and technical competence. The problem is compounded by technical brain drain of the limited engineering capacity from developing countries to developed countries as a result of enticing opportunities offered to attract technically qualified personnel to sustain the developed international economies. This scenario in itself reinforces the known experience that technical and scientific personnel are indispensable in developing new economies as well as sustaining full grown economies at any one point. In most developed countries, the engineering skills present are continuously assessed to ensure adequate availability of required professional skills while identifying any presence of possible skills gaps to be filled either through domestic training

or scouting of highly - qualified foreign engineering personnel to be offered immigration visas. This is related to the nature of modern economies, being primarily industrial driven and represented in terms of the gross domestic product (GDP). Attempts by various African countries to attract investments is sometimes hampered as investors point out existing infrastructure and capacity as one of the major criteria in deciding their investment destinations.

Among the important physical infrastructure are transport networks including roads, railways, water, air, ports; energy and electricity infrastructure such dams; water, sanitation and irrigation systems; housing and buildings for end users such as hospitals, schools, recreation and sports, offices, hotels. Infrastructure is a critical intermediate input to the end product but it is also foundational to technological development and human welfare services. Agriculture, health and medical services, water supplies, education services, among others are to a great extent dependent on physical infrastructure. Good roads and bridges are critical agents for rural development in various ways; they enable trade of goods to and from remote communities, facilitating income generation. Good road networks reduce the communing time of workers, in turn improving productivity. It has been suggested that poor roads cause more adverse effect on the economy than the impact of good roads. Innovative engineering design of houses and modelling of landscapes can be applied to minimize mosquito breeding therefore reducing malaria the major killer disease in Africa. Dams for hydro-electricity generation are, in some African countries, the only source of electricity necessary for industrial activity as well as domestic use. Dams for irrigation projects are essential for both large-scale and subsistence agricultural economy, as well as livestock that sometimes are the main source of livelihood for certain areas such as the semi-arid regions. Furthermore, African countries are experiencing high population growth rates along with urbanization which is aggravating already existing poor and inadequate housing conditions. Governments and the private sector alike have not been able to develop adequate solutions and are faced with this ever growing challenge.

III. INFRASTRUCTURE AND THE ECONOMY

Infrastructure is considered to be the engine of economic growth [2]. In Sub-Saharan Africa (SSA), the crucial need for infrastructure as a necessary input towards implementation of programs for poverty alleviation and economic development is quite apparent as it creates local employment opportunities, re-distributes wealth with particular relevance to rural areas, and harnesses the power of science and technology for domestically developed innovations that provide solutions in problem solving.

Physical infrastructure is classified into the six categories of *energy, water management, transportation, communication, measurement networks*, and *waste management*. The main challenge facing African countries is creation of the required infrastructure and engineering capacity to serve the societal needs for development and economic growth. It is unfortunate that the change in stock of infrastructure in African countries over the past decades, does not correspond to the population and economic growth requirements, with demand for infrastructure exceeding its supply. It becomes further aggravating to realise that even the existing infrastructure tends to deteriorate rapidly, stemming from poor construction practices and lack of adequate maintenance, the hallmarks of dependence on foreign expertise and technologies with no local capacity. The significance of infrastructure is directly related to socio-economic growth of any country. The national income or GDP per capita of a country correlates linearly with its stock of infrastructure as shown in Fig. 1 [3]. It can be derived from the graph that a deliberate investment of any nation to increase its stock of infrastructure (and by implication its engineering capacity) will have a corresponding impact of increasing its national income, as a result of the roles that physical infrastructure plays in the economy. Compared to countries from other regions of the world, it is also clear that African countries have the lowest income per capita, confirming the disparaging levels of poverty already known to currently exist.

The extent of infrastructure deficits in Africa have been documented and compared, with those from low income countries (LIC) and middle income countries (MIC) of other parts of the world. Fig. 2 shows that SSA countries lag behind other LIC and MIC in all the different kinds of infrastructure. It can be seen that the largest gaps occur in paved roads, mainline and mobile phone coverage, and power generating capacity [4].

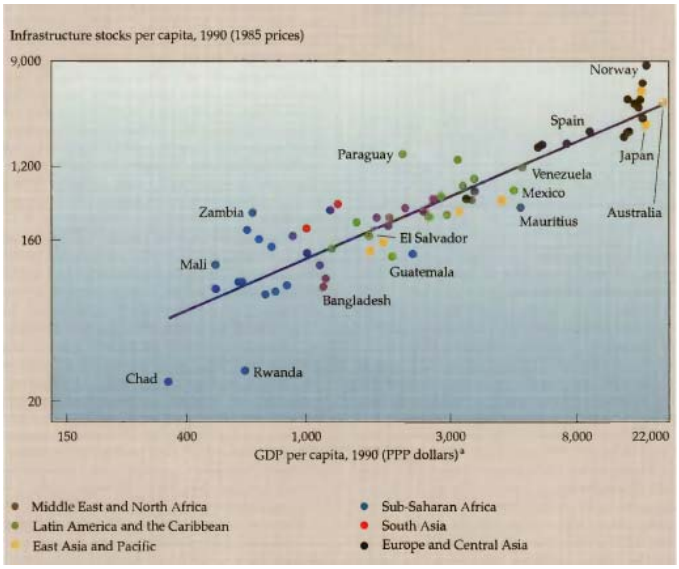


Fig.1 Relationship between economic growth and infrastructure [3]

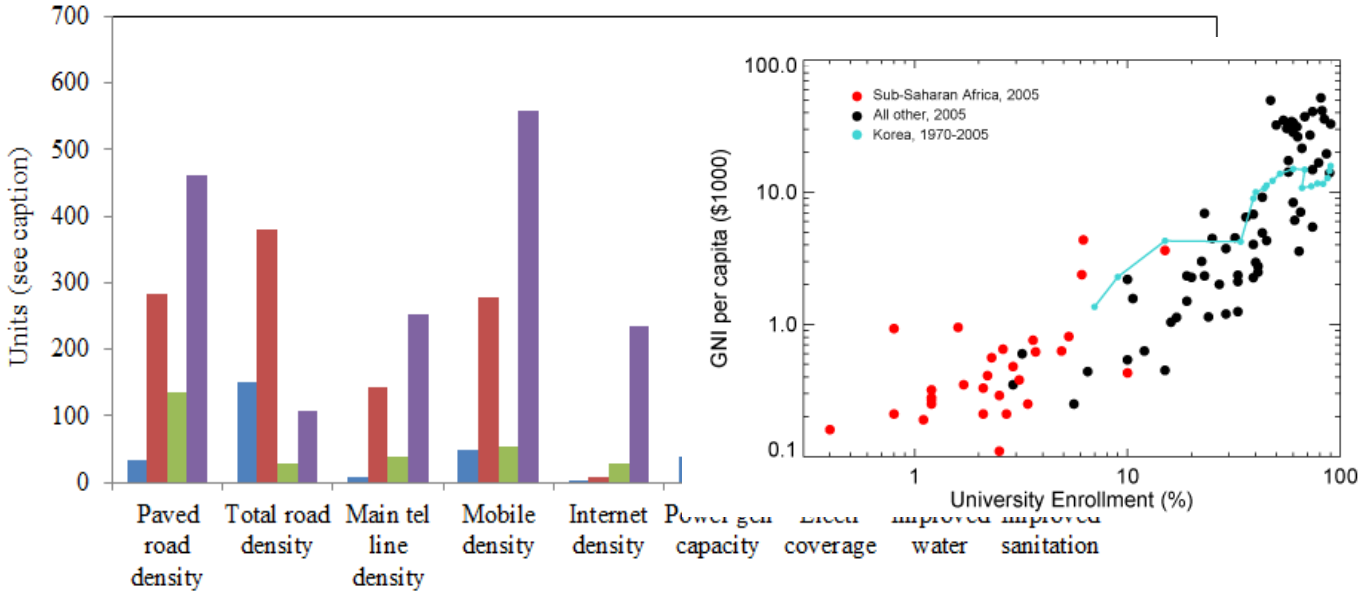


Fig. 2 Infrastructure deficits in Sub-Saharan Africa (Units: Road density in km /100 Km^2 of arable land; Telephone density in lines per thousand population; power generation capacity in megawatts per million population; electricity, water, and sanitation coverage in % of population); constructed from[4]

IV. HIGHER EDUCATION IN SUB-SAHARAN AFRICA

The SSA, an extensive geographical block consisting of 46 countries and an estimated population of over 973 million in 2014 (World Bank: http://data.worldbank.org/region/SSA) is relatively highly underdeveloped; it bares the shared historical paranoia of colonialism, pandemics, ravaging conflicts and diseases, which have contributed to high poverty and high mortality. Education is seen as the key to future growth and development in SSA. Studies [5] have shown that higher education in Africa is the lowest in comparison to regional blocks worldwide, as seen in Fig. 3. Evident in the figure is the strong relationship between per capita income and university enrolments. These observations are consistent with the findings of Moser and Ichida [6] showing that economic growth increases education enrolments. Indeed the latter reported that 10% per capita increase in GDP leads to increased primary education enrolment of 3 to 4%, 1% increase in life expectancy and 4% reduction in infant mortality. Higher education in SSA is generally being recognized as an important sector in driving economic development [7]. Fortunately, recent trends in tertiary education in SSA are reported to be showing remarkable increase. UNESCO [8] reported an average of 8.6% growth in HEI enrolments between 1970 to 2008 compared to a corresponding growth of 4.6% globally. It is depicted that SSA is playing accelerated catching up in higher education. Between 1990 to 2007, the number of public institutions is reported to have doubled from about 100 to 200 while the private sector HEIs have grown much faster from 24 to 468 institutions, a growth of 1850%. Francophone countries such as Senegal (41 HEIs), Democratic Republic of Congo (39 HEIs) account for

53% of all enrolments, while Anglophone countries had enrolments of only 34% [9].

Fig. 3 University enrolments in Sub-Saharan Africa [5]

Public HEIs hold a prestigious position and occupy top rankings in the continent, while private HEIs appear to somehow play a backup role to absorb students who cannot gain access to public institutions [10]. Despite the current significant growth in enrolments, it is reported that only 6% of eligible age group is enrolled in HEIs in SSA compared to the world average of 26%, as seen in Fig. 4. The 6% enrolment lags all global continental blocks whose enrolments are 70, 84, 38, 25/26, 21, 13% respectively for N. America/W.Europe, E. Europe, Latin America, Asia/the pacific, Arab states, S/W. Asia. More recent data shows that SSA student enrolments in HEIs rose to 8% but remains relatively dismal compared to other world blocks. Engineering education enrolments can be expected to be much less and in dire need of improvement [11]. de Villiers and Nieuwoudt [12] discuss the global trends in higher education pointing out the shift that appears to be occurring from *elite* systems which have enrolments of only about 15% among the eligible age group to *mass* systems which accommodate 15 to 50% enrolments.

In some ways, these global trends appear to be affecting SSA enrolments positively by way of influencing deliberate policies to strive towards expansion of higher education in the African sub-continental block. Two of the main factors that are thought to be responsible for recent increase in enrolments at higher education in SSA are the policies leading to mass increase in primary and secondary education such as the "universal primary education" policy etc. and the privatization of higher education. It is reported [13] that in 2006, private higher education was responsible for 22% of enrolments in HEIs in Africa. But factors associated with affordability of higher education across the continent cannot be neglected, as earlier underscored in Fig. 3.

V. CHALLENGES OF ENGINEERING STUDIES AND PRACTICE

Given a favourable socio-political and economic environments, the crucial technical issues relating to engineering studies in SSA fall into the two categories of *quality* and *capacity*. While the capacity aspect is an endemic problem in SSA that has existed predominantly from the times of colonisation, poor quality appears to have taken on a new level directly as a result of expansion of the current education system, through the free enterprise of the private sector institutions.

A. Escalation of quality problems in engineering studies and practice

As already mentioned above, the general enrolments in HEIs are growing but still lagging, with the actual enrolments being only 6% in SSA relative to the 26% world average. An article by Mohamedbhai [11], summarises the main issues associated with quality, including the use of outdated curricula often "copy and paste" from Western countries, which may not appropriately serve the practical needs of Africa. The lack of adequate and cutting-edge facilities such as laboratories for practicals and experiments, highly undermine relevant teaching. Modern teaching methods require use of in-class and out-of class technologies, which allow speedy coverage and distribution of course contents to students. These include the use of projectors, internet based-teaching, online approaches. The limited availability of reliable telecommunication infrastructure among African universities i.e internet networks etc. is a major bottleneck to implementation of technologies in teaching. Although, these issues have long existed traditionally among African universities, they have been aggravated by expansion of the education system. There is now a perception that the explosive growth of HEIs in SSA is occurring at the expense of quality of program delivery. Evidence of these core quality problems have been observed across SSA [11,14]:-

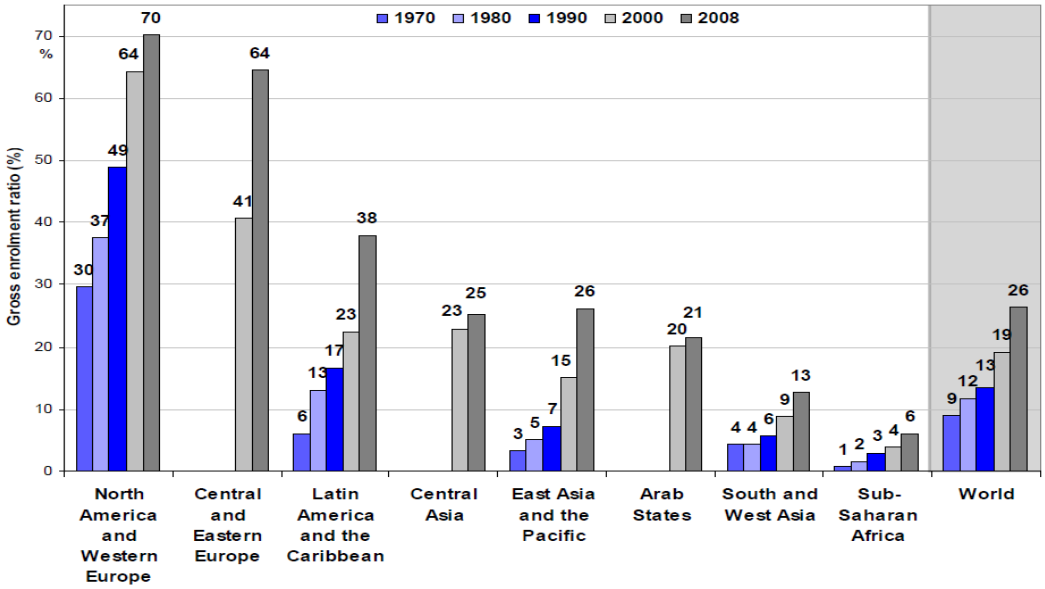
- Non-accredited academic programs: The absence of sufficiently qualified academic staff, poor curricula, and inadequate infrastructure has seen rejection or withdrawal of accreditation from universities offering engineering programs. This has occurred in various countries including Nigeria, Kenya and other SSA countries. In Kenya for example, only 25 of the 70 engineering programs offered in the country, are accredited.

- Registration of practicing engineers: Many graduates of engineering programs in SSA are practicing without acquiring professional registration from the appropriate governing body, such as the national Engineers Registration Board (ERB), for example. This problem is partly related to non-accredited engineering programs, whose degrees cannot be recognized. [illegible] only 25% of applicants to the ERB in registration status.

Fig. 4 Comparison of gross enrolments worldwide [8]

B. Engineering capacity deficit in Sub-Saha

Delivery of infrastructure in SSA is largely characterised by inadequacy of local capacity to supply technical capabilities required for project implementation at all its stages from planning, design, construction, and operation. In most cases, local construction firms may be able to handle small project works while leaving large construction projects to the employ of international consulting and construction companies due to lack of local capability for large project works. Capacity deficit is related to the critical underlying issue of training for engineers and technical personnel [3]. The gravity of lack of high-level engineering skills among African countries is known to be of a very high scale as shown in Table 1 [15]. The population served by a single engineer in Africa is up to 13,000 persons compared to 100 to 300 persons in most developed and emerging economies. For example, one civil engineer in local government in South Africa serves a population of up to 33,000. Again, these numbers can be higher for other African countries [16]. As discussed earlier, engineering capacity deficit is compounded by technical brain drain of the already limited engineering capacity in SSA.



C. Higher qualifications and academic research

In addition to the primary role of universities in providing graduate and postgraduate degree training, basically developing high level human capital necessary for economy, HEI's are also research and development centres for industry, serving the purpose of incubating research ideas that can be turned into industrial products and services. HEI's have also become agents of community development and often work closely in partnership with industries towards achieving sustainable development [1,17].

Although the number of HEI's in Africa have grown considerably in numbers and enrolments, engineering education in particular faces considerable difficulties:- there is shortage of qualified teaching staff partly as a result of the small pool of locally available graduates and due to unattractive salaries. It is usual for a lecturer to leave a university career for better paying positions in government civil service or private sector. For lecturers who continue with university careers, it is common for some to have other work places for generation of additional income, thus sharing out their time which would otherwise be solely devoted to the academic institution.

There is also low level of research output in SSA and poor connectivity to global knowledge. The lack of research is partly linked to inadequate research facilities and funding as well as severely inadequate number of highly qualified academics. A large proportion of academic staff in African universities do not have higher degrees at master's and PhD levels. For example, in Rwanda's HEIs, the number of science lecturers with PhD and Masters level degrees were only 24% and 45% respectively, while the rest had only first degrees or less [18]. It is not surprising to find that most African HEI's have few or no master's and PhD level degree programs, due to lack of necessary teaching capacity, most especially in engineering and sciences.

TABLE 1
COMPARISON OF TRAINED ENGINEERS FOR AFRICA AND OTHER CONTINENTS [15], (*REGISTERED ENGINEERS ONLY)

Country	Population per Engineer	Country	Population per Engineer
Norway	122	Australia	455
China	130*	Hong Kong	463
Finland	136	Malaysia	543
India	157*	Chile	691
Greece	172	Poland	748*
Denmark	179	Singapore	1,341
Canada	179	Korea	2,135*
Sweden	209	Hungary	2,214
Germany	217	Romania	2,909
Brazil	227	**South Africa**	**3,166**
Iceland	280	Sri Lanka	5,595
France	276	**Tanzania**	**5,930**
Ireland	280	**Namibia**	**6,346**
Japan	303*	**Zimbabwe**	**6,373**
UK	311	**Swaziland**	**12,238**
Argentina	453	**Zambia**	**12,783**
USA	339	**Ghana**	**12,992**

VI. REVERSING DEFICITS AND PROBLEMS

The University is central to reversing the current trends and deficits identified in engineering studies. But this can only happen through deliberately planned initiatives intended to address these issues with practical and measureable outcomes. Some suggested strategies that may be employed are discussed:

- Establishment and implementation of quality assurance (QA) systems in HEIs. These are needed to improve the quality of programs by ensuring that universities conduct their own internal quality assessments. However, this occurs as a university-wide QA system. The program specific QA system, administered by industry boards such as the ERB, is also extremely important. In SSA, however, such professional based QA systems do not presently exist except, in very few countries such as South Africa where the Engineering Council of Southern Africa (ECSA) is tasked with national accreditation of professional engineering degree programs.
- Training of Africans by Africans in advanced academic studies: This concerns the current shortage of academic staff in most African universities, and its association with lack of sufficient research output in engineering. There are currently very few universities that offer high quality engineering course programs at master's and PhD postgraduate levels. Collaborations among African universities can be focussed to locate existing programs and/or assist to develop relevant advanced programs in HEI's within engineering and infrastructure fields.
- Mobility: The mobility of HEI staff and students within SSA sub-continental region can be one of the most instrumental vehicles which can allow specific arrangements to be established for cross-linked undertaking of high quality academic studies, teaching, research, and training. In so doing, several benefits related to strengthening and capacity building can be achieved at institutional, national, regional and multi-lateral levels through active partnering amongst HEI's [19].
- Harnessing of brain gain, circulation and knowledge flows: Deliberate effort is needed to scout potential African students who are in the diaspora. These candidates can be engaged and supported to participate fully in Africa's development in an effort to counteract brain drain and achieve brain gain. Also, academics and professionals in the diaspora can be engaged to contribute to course programs at African universities, in areas such as curricula development, delivery of guest lectures etc., amongst others.

VII. SUMMARY

Engineering studies and practice are an indispensable part of the growth trajectory for the 21st century infrastructure in Sub-Saharan Africa. The sub-continental block, which is underprivileged and lags behind all other regions of the world in development, needs to amass a high stock of infrastructure. Consistent with this need, is the necessity to develop and sustain strong engineering capacity of high quality.

It is essential that the present growth in higher education is sustained, while engineering capacity deficits and quality problems must be contained. Measures are discussed which may contribute some remedies, including: establishing quality assurance systems and intensifying accreditation requirements for engineering degrees, collaborations to provide advanced degree programs with other nearby African countries as opposed to travelling overseas, enhancing the inter-Africa mobility of students and staff to undertake academic programs, mitigating brain drain and reversing the trend to brain gain. Some of these measures are already in place but need to be enhanced. Each country needs to know the required number of engineers and technicians at a national planning level, and then set up strategies and action plans to achieve these requirements.

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