REJUVENATING AFRICAN ECONOMIES: THE ROLE OF ENGINEERING IN INTERNATIONAL DEVELOPMENT

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Africa's ability to meet its human welfare needs, participate in the global economy, and protect the environment will require considerable investment in science and innovation in general and engineering in particular. This article argues that viable strategies for building competence in engineering should seek to link engineering training directly to infrastructure projects. The African policy community should launch a global review of the lessons learned from international development efforts over the last fifty years that could guide a new phase of international development cooperation with a focus on the role of science and engineering in sustainable development.

Introduction[1]

Development is easier done than said. This inversion of the old maxim reflects the end of an era in which Africa's development was defined largely as a matter for discourse rather than accomplishment.[2] Focus is now shifting from emergency and relief operations to long-term endogenous solutions based on building endogenous technical competence, stimulating local entrepreneurship, and investing in infrastructure.[3]

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The term "infrastructure" is used here to mean the facilities, structures, associated equipment, services, and institutional arrangements that facilitate the flow of goods and services between individuals, firms, and governments. Infrastructure therefore includes: public utilities, such as energy, telecommunications, water supply, sanitation and sewage, and waste disposal; public works, such as irrigation systems, schools, housing, and hospitals; transport sectors, such as roads, railways, ports, waterways, and airports; and research facilities, such as laboratories and related equipment. Infrastructure services include the provision, operation, and maintenance of the physical facilities of the types of infrastructure listed above. Infrastructure represents a foundational base for applying technical knowledge in sustainable development and relies heavily on civil engineering. Other economic activities require contributions from other fields, making engineering an interdisciplinary field.

The traditional focus on relief and emergency activities is being replaced by a new focus on competence building to enable Africa to solve its own problems. Development partners need to pay more attention to investing in people and promoting technological innovation rather than simply providing short-term palliatives aimed at reducing the visible symptoms of low levels of economic productivity. This shift will involve building capabilities in key areas related to production, project execution, and technological innovation.

Much of the work to build local competence entails training in engineering and related management fields.[4] In the area of industrial production, for example, African countries need to strengthen their production engineering and management capabilities. In other words, the challenge for Africa lies largely in its ability to harness the world's scientific and technical pool and to use it to solve local problems. To effectively execute investment projects, African countries need to enhance competence for personnel training, pre-investment feasibility studies, and project implementation. Finally, the countries need to focus on innovative work related to creating new products and processes. Most of the effort involves engineering and its associated management practices (Amsden 2001). Current investments in infrastructure offer a strategic starting point for building capacity in engineering.

The aim of this article is to explore the technological implications of the transition to a competence-based development cooperation strategy for Africa. It argues that this transition will entail a clear recognition of the role of infrastructure in Africa's sustainable development and a focused investment in the associated engineering fields. It departs from traditional approaches (to capacity building) that have focused on independent, short-term training activities; instead, it proposes that new engineering programs be directly linked to strategic investments in infrastructure development.

This focus on infrastructure is not intended to exclude other economic activities and their associated engineering fields. Similar strategies could be adopted in manufacturing as well. This article uses infrastructure both as a strategic opportunity, given renewed interest in this field, and as an illustration of the linkages between engineering and sustainable development. The article concludes by calling for a major global effort to review the key lessons learned in development cooperation in the post-war era and makes a plea for serious efforts to emphasize the role of engineering in Africa's sustainable development strategies.

This article is divided into five sections. The first section outlines the role of science and innovation in sustainable development. This is followed by a discussion of and specific information regarding the status of infrastructure in Africa. Section three offers case studies on the role of infrastructure in sustainable development. This is followed by an overview of strategic opportunities for using engineering as a set of tools to reinvent African economies. The article concludes with a call for a global review on development lessons to guide future policy making with respect to the role of science and engineering in Africa's development.

Mapping the Terrain

Engineering has been marginal to international development practice in the last two decades. Earlier designs of major infrastructure projects ignored critical socioeconomic and environmental factors and were quite frequently linked to macroeconomic distortions. Over time, development agencies shied away from such projects and underplayed the critical role of infrastructure in sustainable development. However, the failure of subsequent sustainable development strategies has forced the international community to rethink the role of infrastructure and the associated engineering fields in sustainable development.

Engineering can help reduce poverty by contributing to sustainable development and alleviate hunger by providing the physical infrastructure needed to advance agriculture as part of an integrated strategy aimed at improving overall human welfare.[5] A nation's ability to solve problems and to initiate and sustain economic growth depends in part on its capabilities in engineering, which in turn determine the ability to provide clean water, good health care, adequate infrastructure, and safe food.

Building domestic competence in fields like chemical and process engineering is critical to expanding the technological basis for improving healthcare. Engineering-based approaches (e.g., redesigning houses and remodeling landscapes) can help mitigate mosquito breeding and malaria transmission, respectively, complementing efforts to develop new antimalarial drugs and vaccines (Matuschewski 2006).

Local technological capacity is indispensable for managing complex ecosystems, such as watersheds, forests, and seas, and for helping to predict (and thereby manage) the impact of climate change and the loss of biodiversity. Emerging fields such as industrial ecology offer new opportunities for addressing ecological challenges.[6] The management of freshwater resources is increasingly dependent on technological interventions as well. Attention is also turning to the development of drought-tolerant crops using both conventional breeding methods and genetic engineering.

But technological innovation can only have the desired impact if placed in the context of long-term sustainable development strategies, especially those associated with greater regional diversity and experimentation. In this regard, regional integration efforts across Africa represent a major opportunity to apply technological innovation in sustainable development, which in turn requires significant investment in creating engineering capacity.

Frontier Without Engineers: Poor Infrastructure

Infrastructure and Sustainable Development

Poor infrastructure and inadequate infrastructure services are among the major factors that hinder Africa's sustainable development.[7] Without adequate infrastructure, African countries will not be able to harness the power of science and innovation to meet sustainable development objectives and to be competitive in international markets.

Infrastructure promotes agricultural trade and helps integrate economies into world markets. It is also fundamental to human development, including the delivery of health and education services. Infrastructural investments further represent untapped potential for the creation of productive employment.

The advancement of information technology and its rapid diffusion in recent years could not have occurred without basic telecommunications infrastructure. In addition, electronic information systems, which rely on telecommunications infrastructure, account for a substantial proportion of production and distribution activities in the secondary and tertiary sectors of the economy. It should also be noted that the poor state of Africa's telecommunications infrastructure has hindered the capacity of the region to make use of advances in fields such as geographical information sciences in sustainable development (National Research Council 2002).

Globalization of trade and investment demands that countries upgrade their technological capabilities as a source of competitive advantage (Lall and Pietrobelli 2002). Infrastructure contributes to technological development in almost all sectors of the economy, serving as its foundation and representing, in effect, technological and institutional investment. The infrastructure development process also provides an opportunity for technological learning (Macpherson 2005).

Because infrastructure services act as intermediate inputs into production, their costs directly affect firms' profitability and competitiveness. Infrastructure services also affect the productivity of other production factors. Electric power allows firms to shift from manual to electrical machinery, extensive transport networks reduce workers' commuting time, and telecommunications networks facilitate flows of information. As an "unpaid factor of production," infrastructure increases the returns to labor and other capital. The availability of infrastructure may also attract firms to certain locations, which creates agglomeration economies and reduces production and transactions costs (Holloway 2000). Infrastructure is a critical determinant of the destination of foreign direct investment (FDI) (Dupasquier and Osakwe 2006). It is one of the key factors that all types of investors consider in deciding on the location, scope, and scale of their investments.

Infrastructure and technology development reinforce each other. Expanded use of technology in sustainable development depends on the existence of infrastructure, while the introduction of new technologies contributes to improvements in infrastructure services.

All stages of an infrastructure project (including planning, design, construction, and operation) involve the use of a wide range of engineering inputs and institutional as well as management arrangements. Given their physical, organizational, and institutional complexity, infrastructure facilities and services require adequate technical capabilities on the part of engineers, managers, government officials, and others involved in these projects.

Status Review

Investing in infrastructure is emerging as a critical item on Africa's sustainable development agenda. This interest has been inspired by the growing recognition of the role of infrastructure in sustainable development. It has also been reinforced by the demand for adequate infrastructure in the rapidly expanding urban areas. In 1980, for example, only 28 percent of the African population lived in cities. Today the figure stands at about 37 percent. Africa's annual urban growth rate is 4.87 percent, twice that of Asia and Latin America. This makes Africa the fastest urbanizing continent in the world (Tibaijuka 2004, 1).

African countries inherited a highly dispersed and unevenly distributed infrastructure from the colonial period (Torero and Chowdhury 2004). Colonial development strategies focused solely on connecting natural and mineral resources to ports for export markets (Njoh 1997). They failed to integrate the continent or stimulate local industrial development (Commission for Africa 2005, 109; Ridley and Lee 2005). Africa's demand for infrastructure across sectors is hardly being met for the majority of people, with its worst sectoral performance being in access to electricity (Estache 2005, 35). Even where such access exists, supply is unreliable and the quality of services remains poor (Adenikinju 2003). Generally, access to infrastructure services favors the rich and is more unequal in Africa than in any other part of the world (Gelb et al. 2000, 137). In some cases infrastructure projects may perpetuate historical inequities (Donaldson 2006).

There are major disparities in access to clean water in urban settings. Of Africa's 280 million urban residents, more than 150 million lack access to clean water, and nearly 180 million do not have adequate sanitation. For example, some 48 percent of African urban households have a water connection, compared to only 19 percent of informal settlements. Similarly, 31 percent of urban households are connected to the sewerage system, but the figure for informal settlements is 7 percent (Tibaijuka 2004, 8).

There is good news, however: the advent of information and communications technology (ICT) is transforming the continent (Oyelaran-Oyeyinka and Lal 2005). In 2001 Uganda became the first African country where mobile phones exceeded fixed land lines (Hamilton 2003). The market has expanded from fewer than 20,000 users in 1993 to an estimated 18.2 million in 2003 (Guislain, Ampah, and Bescangon 2005). But despite such phenomenal growth rates, much of Africa still remains disconnected from the rest of the world because of poor communications infrastructure (Britz et al. 2006). Access to high bandwidth services remains beyond the reach of most individuals and institutions. Similarly, prospects for enhancing private-sector participation through improved telecommunications are being undermined by poor infrastructure (Overå 2006).

Transportation costs in Africa are the highest of any region in the world. With landlocked countries having to figure in transport costs of up to 75 percent of the value of their exports, the continent faces extreme challenges to compete in global markets.[8] In Uganda, for example, transport costs add the equivalent of an 80 percent tax on clothing exports. Freight charges for imports are 70 percent higher in West and East Africa than in Asia. Africa's landlocked countries pay more than double the rate of Asian countries for comparable transport services (Gelb et al. 2000, 136). Most of Africa is isolated from major air and maritime routes, which allows access only to high-cost, peripheral routes (Commission for Africa 2005, 53). More than 20 percent of African exports reach the United States by air. It is estimated that air transport costs account for up to 50 percent of the value of exports to the United States (Amjadi and Yeats 1995; Commission for Africa 2005, 269). Internally, air transport costs across Africa are up to four times the cost of getting the same goods over the Atlantic (Gelb et al. 2000, 136).

A loss of focus on the importance of economic growth in poverty reduction and a failure to appreciate the importance of infrastructure investment led to a drop in infrastructure spending in Africa. Development policy in the 1980s and 1990s asserted that infrastructure would now be financed by the private sector (Gómez-Ibáñez, Lorrain, and Osius 2004). From 1990 to 2002 infrastructure investment in Africa stood at US $150 billion, of which only US $27.8 billion came from the private sector. Nearly two-thirds of this amount (US $18.5 billion) was for telecommunications (Ndulu n.d.; Commission for Africa 2005, 234). Unfortunately, private-sector participation in infrastructure investment has not taken off in Africa, contrary to policy opinion.[9] Over an almost twenty-year period, Africa has only managed to generate 230 projects in partnership with foreign operators, about half of which are located in South Africa. Irrespective of the South African bias of the data, the total number of projects is small and so is the average size of projects in Africa. The average project size is indeed less than half of that in other developing countries. Africa's share of total (mostly foreign) private investment attracted by infrastructure across all sectors in the developing world is roughly 1 to 2 percent (except in telecoms, which is 6 percent) (Estache 2005, 17).

Additional funding approaches now include private-public partnerships such as the Emerging Africa Infrastructure Fund set up by the Private Infrastructure Development Group (PIDG). The group was founded in 2002 by the Department for International Development (DFID), the Swedish International Development Cooperation Agency, the Netherlands Ministry for Development Cooperation, and the Swiss State Secretary for Economic Affairs.

The war-torn economies in Africa are perhaps the hardest hit by the inadequate provision of infrastructure services, where physical infrastructure stocks (e.g., telecommunications, airports, ports, roads, and bridges) are often key targets during war. Although only a fraction of a country may be directly affected by war, infrastructure investment and maintenance is neglected in favor of military expenditures (Gelb et al. 2000, 135).

Africa is highly vulnerable to external shocks arising from natural disasters such as cyclones, floods, droughts, and earthquakes. The economic fragility arising from natural disasters often deepens precarious economic and social situations. Natural disasters tend to divert a large portion of government and donor resources from otherwise essential infrastructure investment to emergency relief operations (Oyelaran-Oyeyinka 2006). But natural disasters can also serve as a stimulus for investing in engineering for disaster preparedness. Disaster management could therefore serve as a foundation for building expertise in ecological engineering (Mitsch and Sven Jørgensen 2003).

An equally important dimension in Africa's future is the possible impact of climate change on infrastructure development. Africa's high rate of urbanization is partly reinforced by declines in rainfall in parts of Africa (Barrios, Bertinelli, and Strobl forthcoming; Andrew Simms 2005). These trends suggest that African countries will need to invest in technologies needed for adapting climate change, most of which will involve the use of a wide range of engineering capabilities.[10]

Learning from Experience

Contemporary development history offers a wide range of lessons on the role of engineering in sustainable development in general and technological innovation in particular. These lessons range from the role of technical universities in economic reconstruction to business incubation. Africa and its international development partners can benefit considerably from these experiences. The rest of this section provides illustrative examples that demonstrate the linkages between engineering and sustainable development.

Economic Reconstruction: The Case of Rwanda

Rwanda experienced one of the worst human tragedies of the post–World War II period, with much of the country's physical infrastructure and skill base destroyed. Rwanda's decision in 1997 to convert the premises of a military academy into a base for a new technical university, the Kigali Institute of Science, Technology and Management (KIST), showcases the high-level emphasis on the role of engineering in economic reconstruction.

KIST was set up as a project of the United Nations Development Programme (UNDP), with the German Agency for Technical Cooperation (GTZ) as the implementing agency. The initial funding came from UNDP's core fund and a UNDP trust fund supported by Japan and the Netherlands. KIST started with major degree programs in engineering and management with compulsory courses including English (or French language) and remedial basic sciences. The institute was officially inaugurated in April 1998 and held its first graduation ceremony in 2002.

KIST continues to strengthen its programs and enjoys a growing number of international partners. It has introduced courses in computer and information technology; automotive, mechanical, and electronics technology; and electrical, civil, and environmental engineering. Additional courses have been established in applied chemistry, biology, and physics.

Efforts are also being made through the Girls Empowerment Programme to improve the participation of girls in science and engineering subjects at KIST. The program was launched in 2006 with more than 200 girls taking a one-year foundational course to meet the requirements to study technology-related subjects.

After receiving the Ashden Award for Sustainable Energy in 2001 for developing an energy-efficient oven, KIST established the Centre for Innovation and Technology Transfer (CITT) to develop renewable energy technology solutions for rural areas. CITT is also working on low-cost, environmentally friendly building techniques. Using a combination of prefabricated low-cost buildings and low-cost brick-making techniques, CITT is developing methods to construct classrooms and offices at half the cost of conventional buildings.

In less than a decade, KIST has shown that a new generation of engineering-based universities can significantly contribute to economic reconstruction.

Technology Diffusion and Government Policy: The Case of Algeria

The construction industry in Algeria is a good example of how government policies regarding technology transfer contracts for infrastructure construction can influence the degree of technology acquisition by a developing country (Markusen and Venables 1999).

Since the 1970s, the construction industry has been considered in the Algerian Central Plan as one of the "industrializing industries." The government initially encouraged the purchase of complex and advanced, though costly, systems of technology from foreign firms. Sophisticated and highly integrated contracts, such as turnkey and product-in-hand contracts, were used to assemble and coordinate all the project operations, from conception through implementation to installation, into one package. The aim was to transfer the entire responsibility to the foreign technology supplier.

These types of contracts did not lead to as much technology transfer as the government hoped. The turnkey contracts did not include the sourcing or training of local skills. There was continuous reliance on external assistance for management and skilled operations, while operations by local management remained inefficient due to a lack of understanding and skill. The use of turnkey contracts (which emphasized hardware acquisition) required an appropriate level of knowledge, skill, and experience that was not adequately available when Algeria started using the integrated contracts.

The problem existed even with the product-in-hand contracts, which were supposedly an improved version of the turnkey contracts, as they included the procurement and training of a local labor force required by the projects.[11] However, there were limited opportunities for local managers and construction organizations to gain hands-on experience in project design, implementation, and installation often resulting in unsuccessful technology transfer.

Learning from past failures, the Algerian government later supported "decomposed" or "design and installation supervised" contracts, where infrastructure projects were more fragmented and involved more local firms than before. Local firms could now take charge of the phases prior to installation, such as exploration and planning, with the technical assistance and supervision of foreign suppliers. This approach reduced uncertainty in implementation, facilitated the accumulation of technological capabilities in local firms through learning-by-doing, and contributed to the development of investment and managerial capabilities of local managers.

Engineering and Business Incubation: The Case of Zambia

The case of Zambia's[12] telecommunications sector shows how some African countries are reorienting universities to play a greater role in national development.

In 1990, the director of the computer center at the University of Zambia (UNZA) connected a few personal computers to exchange e-mails within the institution, Rhodes University (South Africa), and with the rest of the world. In 1994, Zambia became the first sub-Saharan country outside South Africa to connect to the Internet.

Unfortunately, the successful connectivity project at the UNZA failed to garner any direct support from donors. Early in 1994, the university decided to establish a campus-based company called Zamnet Communication Systems to link the institution to the Internet and provide service to commercial customers. The World Bank expressed interest in lending start-up capital on the condition that the university would offer some shareholding in the unit to the public.

The administration worked with customers and other interest groups and intensified marketing. The university provided most of the manpower and the operational space for four years. The number of commercial accounts grew from 5 to 165 between January and June 1995, and seven months before the lapse of the World Bank loan, Zamnet was generating enough income to buy new equipment.

The commercialization of Zamnet demonstrated that the provision of Internet services could be good business even in poor countries. Soon after Zamnet's launch, the link to South

Africa became saturated. Other institutions soon followed suit. Using the experience gained from Zamnet, the national regulator, Zambia Telecommunication Corporation, developed a new unit that specialized in Internet service provision.

Although the economic impact of Zamnet has yet to be fully assessed, Zamnet's market share is estimated at between 70 percent and 80 percent of Zambia's Internet users. The impact of Zamnet in encouraging enterprise development, and thereby creating employment opportunities and livelihood, is immense.

This case demonstrates how countries can utilize and channel international resources through universities to achieve national objectives. It also shows the importance of local management of projects through an accessible and transparent implementing mechanism under which different players feel comfortable, as well as the importance of a supportive government and policy environment.

Redesigning African Economies

The cases provided in the previous section underscore the important role that investment in engineering can play in society. They also represent a wide range of practical models available both to African countries and their development partners for broadening and building engineering capacity for sustainable development. But such efforts need to be placed in the appropriate national and regional policy contexts.[13]

Regional Integration

While it is prudent for Africa to emphasize international trade, doing so requires greater investment in developing capabilities to trade, including technological innovation, development of business and human resources, and institutional strengthening. The impact of larger markets on technological innovation, the economies of scale, and the diffusion of technical skills arising from infrastructure development are among the most important gains Africa could obtain from regional integration (Murenzi 2005).

A common feature of African regional integration agreements is their recognition of the importance of engineering in sustainable development. Individual African economies are small and poorly endowed with the human, physical, and financial resources necessary to develop and harness engineering capabilities. The cost of building science and technology infrastructure often appears to be an overwhelming task for national economies, especially in smaller and poorer states.

Cooperation in engineering can take various forms, including joint projects, information sharing, conferences, building and sharing joint laboratories, setting common standards for research and development, and exchange of expertise. Furthermore, the sheer magnitude of the necessary infrastructure development actually requires regional cooperation in project design and implementation to not only reduce costs but also facilitate greater learning.

Improving Governance

Issues related to science and innovation will need to be addressed in an integrated manner at the highest level possible in government (King 2005). Bringing engineering to the center of Africa's economic renewal will require "concept champions" who spearhead the task of shaping their economic policies around science and innovation.

Advice on science and innovation needs to be part of the routines of policy making. The advisory functions should be supported by some statutory, legislative, or jurisdictional mandate to advise the highest levels of government.

Successful implementation of science and innovation policy requires civil servants to have policy analysis capacity (which most civil servants currently lack). Providing civil servants with training in technology management, science policy, and modeling and foresight techniques can help integrate science and innovation advice into decision making. For example, strengthening the competence of civil servants with negotiating roles to engage technological issues is an essential aspect of international relations. International public servants and diplomats increasingly depend on expertise to make their policy decisions, although many currently do not receive systematic advice.

Building competence in science and innovation policy will require investment in specialized courses of study and degree programs on the subject. This could be accomplished by graduate schools of science and innovation policy that can then cooperate with similar programs in other countries through a variety of training programs (including mechanisms such as summer schools).

Discussing governance in Africa would be incomplete without addressing the continent's pandemic of corruption (Guest 2004). Fighting corruption has become an important standard against which public leadership is judged in Africa. But victory will remain elusive unless the efforts are accompanied by deeper institutional reforms that involve aligning public expectations with the makeup of the legislature and the proper use of executive authority by presidents.

The reinvention of public service should involve leadership training at all levels in the governance of public affairs in general and innovation and ethics in particular. Dedicated "schools of governance" or their equivalent are needed to provide leadership training for every elected official before taking office.

Identifying Strategic Opportunities

A key strategy in building up engineering capabilities in Africa is to link training programs to infrastructure projects in growing fields. For example, expanding geothermal energy production in Eastern Africa (covering Djibouti, Eritrea, Ethiopia, Kenya, Tanzania, Uganda, and Zambia) could be linked to engineering and environmental programs at various universities.

Transportation projects also provide similar opportunities. For example, the Maputo Corridor joint initiative of South Africa and Mozambique was aimed at addressing the poor state of transport infrastructure while also creating linkages with other sectors. The corridor's plans included upgrading and constructing road links, improving rail facilities, updating port and harbor operations, setting up a new, integrated border post, and improving telecommunications and other non-transport-related facilities.

Although foreign construction and engineering firms will continue to be the main sources for infrastructure development, African governments should devise policies both to encourage technology transfer and build local capabilities in infrastructure projects.

Research and development activities for infrastructure should be established with research networks as part of Africa's critical infrastructure. Existing research facilities can be networked as part of regional research cooperation, reducing duplication in the availability of such facilities and enhancing mobility and cooperation among researchers.

Reinventing Engineering Education

African countries need to create indigenous capacity by training scientists, technologists, and engineers in relevant fields. The most damaging legacy of the African system of higher education is the separation between research, training, and practical activities (Juma 2006a; Juma 2006b). Training must suit current conditions and fulfill practical need, anticipate future trends, and prepare the next generation of engineers accordingly (Wei 2005; National Academy of Engineering 2004).

Broadening Africa's technical skill base will involve increasing the number of women who train in engineering. Providing incentives that encourage the participation of women in higher education would place Africa in a strategic position to become an important locus for research and technology development.

Addressing the sustainability challenge requires greater investment in the generation and utilization of scientific and technical knowledge. This goal can be achieved by aligning the missions of universities and other institutions of higher learning with their government's development goals, including those related to business incubation.

In addition to providing degree training, a new view is emerging that places universities and research institutions at the center of community development (Hansen and Lehmann 2006). In facilitating the development of business and industrial firms, universities can contribute to economic revival and growth in their regions. This approach is based on the strong interactions between academia, industry, government, and relevant sections of civil society.

Although most universities in Africa are located in urban areas, they have little connection with municipal authorities. Much can be gained by adjusting the curricula, pedagogy, and management of urban universities to address challenges such as sanitation and the improvement of the conditions of slum dwellers. Similarly, universities and research institutions located in rural areas could serve as the locus for research, training, and outreach on the management of natural resources. Furthermore, universities could help strengthen science and math education in high schools. In turn, high schools could serve as critical nodes in local "learning communities" across Africa.[14]

Government and other support is necessary to rehabilitate and develop university infrastructure — especially with regard to information and communications facilities — to help them be part of the global knowledge community and network with others around the world. Such links will also help strengthen their research connections with the rest of the world (Oyelaran-Oyeyinka and Catherine Adeya 2004).

There is an urgent need to bring research, teaching, and community outreach together in new institutional designs. For example, medical schools should be more integrated into hospitals just as agricultural research stations should have a larger teaching role. Similarly, strong links should be forged between universities and the agribusiness community. This process may involve reforming universities, creating new ones, or upgrading other existing institutions.

African countries such as Uganda and Nigeria are experimenting with measures that include providing government scholarships and lowering tuition fees for those going into the sciences.

There are other long-term measures to support technical higher education, which include providing tax incentives to private individuals and firms that create and run technical institutes on the basis of agreed government policy. This is an area that Africa has hardly utilized as a way to extend higher technical education to a wider section of society. Mining companies, for example, could support training in the geosciences. Similarly, agricultural enterprises could help to create capacity in business. Institutions created by private enterprises can also benefit from resident expertise.

Governments too need to formulate policies that allow experienced government, industry, and civil society staff and other professionals to serve as faculty and instructors in these institutions. This can be implemented as part of a national service system or as an effort to expose students to practitioners. Such programs would also provide opportunities for students to interact with practitioners in addition to the regular faculty. Much of the corporate social responsibility investments by private enterprises in Africa could be better used to strengthen the continent's technical skill base.[15] Additional sources of support could include the conversion of the philanthropic arms of various private enterprises into technical colleges located in Africa.

Spurring Business and Social Entrepreneurship

For Africa to promote the development of local technology, it needs to review the incentive structures already in place for business development (Juma n.d.). There is a range of structures suitable for creating and sustaining enterprises, from taxation regimes and market-based instruments to consumption policies and sources of change in the national system of innovation.[16]

Small and medium-sized enterprises (SMEs) should play leading roles in the development of new opportunities and the use of technology. Governments need to support business and technology incubators, export processing zones and production networks, as well as help sharpen the associated skills through business education (Lalkaka 2003). Banks and financial institutions also need to play key roles in fostering technological innovation in SMEs.

Civil society has played an important role in promoting a wide range of sustainable development activities in Africa (Tripp and Velde 2005). Civil society organizations are often adapted to local needs and guided by narrowly defined objectives, giving them the capacity to respond quickly to immediate challenges that might arise. Indeed, civil society organizations could be an important platform for social entrepreneurship that will complement the work of the private sector. In this regard, their participation would help facilitate the adoption of new technologies.[17]

These entities can support innovation in a variety of ways. First, they can help to bring social justice to the application of engineering in sustainable development and redress some of the inequities associated with the use of new technology. Second, they can serve as an important mechanism for bringing civic engagement in technological innovation. This is an important aspect of democratic decision making and practice. Finally, they can help define demand-oriented strategies for technological development.

Protecting intellectual property rights is a critical aspect of business development and international partnerships. But overly protective systems could have a negative impact on creativity. It is therefore important to design intellectual property protection systems that take the special needs of African countries into account.

African countries are steadily enhancing their capacity to use scientific and technical knowledge to solve local problems. They are investing in communication infrastructure and improving technology policies. For such measures to be effective, African countries also need greater access to the world's pool of knowledge. Emerging efforts to promote "open access" systems will make it easier for Africa to have access to technical information available in the public domain (Juma and Yamey forthcoming).

Harnessing Expertise in the Diaspora

Africa has a large pool of engineers working in the diaspora whose expertise could be leveraged to support local sustainable development efforts. A number of countries have adopted policy measures aimed at attracting expatriates to participate in the economies of their countries of origin and serve as sources of input into national technological and business programs. These measures include hosting investment conferences, creating rosters of experts, and promoting business networks.

The onus is on the governments to design programs and offer incentives that enable expatriates to contribute to national efforts (Séguin, et al. 2006). They also need to promote a culture of respect for professionalism and create flexibility in existing institutions to encourage the participation of the diaspora in local educational activities. Countries that do not make full use of local expertise are unlikely to make effective use of the diaspora.

Significant experiments are underway around the world to allow countries to make effective use of their diaspora. The Swiss government has converted part of its consulate in Cambridge, Massachusetts, into a focal point for interactions between Swiss experts in the United States and their counterparts at home. In another innovative example, the National University of Singapore has established a college at the University of Pennsylvania to focus on biotechnology and entrepreneurship. India is introducing a number of policy measures — including granting dual citizenship to Indians in countries of strategic interest — aimed at strengthening the role of diaspora in national development. These approaches can be adopted by African countries, where the need to forge international technology partnerships may be even higher.

These examples illustrate the need to complement concern over the "brain drain" with new approaches that make effective use of the opportunities provided by the existence of large pools of expertise among the diaspora.[18] Such efforts will require countries to look at globalization in a new light and identify the opportunities that it offers. The old-fashioned metaphor of "brain drain" needs to be replaced by a new view of "global knowledge flows" (Sagasti 2004).

Managing Technological Risks

Technological risks to society and the environment have become an integral part of global public policy.[19] Managing these risks and responding to public perceptions of them are necessary if engineering is to be effectively deployed to meet sustainable development needs. In some cases the risk of doing nothing may outweigh the challenges associated with investing in new responses to social challenges.

In the past, technological risks were confined to countries in which new technologies emerged or even to the sectors in which they were applied. Globalization gives technological risk a wider meaning and turns local debates over certain products into mass movements. This is, in itself, a source of new risks.

A focus on technological risks can overshadow the possible benefits of an emerging technology, which are often difficult to predict. Technological risks have to be weighed against both the risks of existing technologies and the risks of not having access to new technologies.

On the other hand, there are also numerous cases in which society has underestimated the risks posed by new technologies or adopted them without possessing adequate knowledge of their dangers. Managing technological uncertainty will require greater investment in innovative activities at the scientific and institutional levels. Technological diversity is essential to ensuring that society is able to respond to emerging challenges with the appropriate knowledge at its disposal. Technological diversity demands greater investment in scientific enterprises as well as the creation of measures to facilitate access to available technical options. It also requires flexibility in institutional arrangements to enable society to respond swiftly to technological failure. Such flexibility can be built into the design of technological systems themselves.

Conclusion

Africa's ability to meet its human welfare needs, participate in the global economy, and protect the environment will require considerable investment in science and innovation in general and engineering in particular. Weak infrastructure, for example, imposes critical limitations on Africa's capacity to utilize its abundant natural resources. This situation is also closely associated with limited opportunities for engineering education in African universities. A number of international organizations are responding to this challenge by offering a variety of "capacity building" projects in engineering.

Most of these efforts focus on training individuals and are not directly related to regional sustainable development efforts in Africa. This article argues that viable strategies for building competence in engineering should seek to link engineering training directly to infrastructure projects. Africa's focus on regional integration provides a policy context in which such efforts should be embedded. Considerable innovation will be needed both in the design of infrastructure projects and the functioning of training institutions. Support from governments and other sources of funding for such activities represent an important step in these advancing efforts to implement the UN Millennium Development Goals.

The political basis for pursuing the ideas presented in this article already exists. For example, the G8 nations have "agreed to invest more in better education, extra teaching and new schools, and to help develop skilled professionals for Africa's private and public sectors by supporting networks of excellence between Africa's and other countries' institutions of higher education and centers of excellence in science and technology" (King 2005, 120). But this will not happen unless there is complementary leadership in Africa to put science, technology, and innovation at the center of the sustainable development process.

Africa's development cooperation strategies have hardly been modeled after successes in other parts of the world. Many of the development policies advocated for African countries in the past two decades have generally failed to draw from experiences elsewhere.

An obvious step forward would be for the African policy community to launch a global review of the lessons learned from international development efforts over the last fifty years.[20] The focus of such a study should be to identify good practices and inspirational models, not simply to measure the impact of technology and engineering on sustainable development.[21] Such a review would focus on identifying critical lessons that could then be used by African policy makers to guide a new phase of international development cooperation. It would build on the growing recognition of the role of science and engineering in sustainable development (House of Commons Science and Technology Committee 2004; National Research Council 2006; Netherlands Development Assistance Council 2005). These studies (and the associated good practices) could also provide a basis upon which to conduct dialogues on critical issues related to engineering and international development.

Based on knowledge obtained from reviews of the kind mentioned above and from other studies, African policy makers could play key roles in providing advice to governments and other institutions involved in international cooperation. More specifically, agencies responsible for international development in various sectors of government, industry, and civil society could benefit from such independent studies.

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2 "Africa" is used in this article to mean "sub-Saharan Africa."

3 "Competence" denotes the ability to perform specific tasks and is used in this article to reflect the practical nature of Africa's sustainable development challenges. It is a subset of the larger concept of "capacity development." The word "capacity" is often defined by the United Nations to mean the "ability of individuals, organizations, and societies to perform functions, solve problems, and set and achieve goals." See Whyte 2004 and Oketch 2006.

4 "Engineering" means the application of scientific and technical knowledge to solve specific problems.

5 From Aw and Diemer 2005: "The presence of supporting infrastructure is often fundamental to uptake of effective innovation and was a major factor in Asia's successful green revolution. Roads are critical to supporting input and output marketing, but the expansion of irrigation probably constituted the most important element of supportive investment." Also see Thomas 2005.

6 From Frosch and Gallopoulos 1989: Industrial ecology involves efforts to "understand how the industrial system works, how it is regulated, and its interaction with the biosphere; then, on the basis of what we know about ecosystems, to determine how it could be restructured to make it compatible with the way natural ecosystems function." Also see Erkman 1997.

7 Emerging evidence from South Africa shows the long-term implications of infrastructure investment for development: See Fedderke, Perkins, and Luiz 2006. Further historical evidence of the role of infrastructure in long-term economic development can be found in Cain 1997.

8 From Commission for Africa 2005: "Our task now is to equip the poorest, through investment, with the capacity to compete, so companies can take advantage of trade in the rest of the world. But building capacity to trade is about more than investment in infrastructure; it must also be about investment in people and their education, skills and entrepreneurial potential." Also see Brown 2005.

9 From Commission for Africa 2005, 80: "Slashing the state indiscriminately will not build effective development. We learned this in the 1980s and 1990s when — to take one example — many development agencies and bilateral donors withdrew, or cut back sharply on, financial support for public infrastructure. The mantra then was that infrastructure financing should be a private sector activity, when in fact not much more than 25 percent of infrastructure in developing countries — and probably even less in Africa — is likely to be privately financed for the foreseeable future."

10 The importance of technological innovation in mitigation strategies is illustrated in Winkler et al. forthcoming.

11 For a discussion of the role of procurement in technology development and employment generation in South Africa's housing industry, see Watermeyer 2006.

12 For more details see Konde 2004.

13 Industrialized countries have been called on to launch the equivalent of the Marshall Plan for Africa. This metaphor, however desirable, may be misplaced. The New Deal launched by U.S. President Franklin D. Roosevelt in the 1930s provides a more appropriate inspiration model for relief, recovery, and reform for the kinds of economic crises that Africa faces. For a pertinent and provocative study of rural electrification under the New Deal, see Tobey 1996.

14 It has been noted in Umakoshi 2004 that "elite private universities of science and technology — such as Pohang University of Science and Technology, which could get top marks in every aspect of university evaluation — were founded in provincial cities, and they are achieving a level comparable to that of the traditional private universities of high social prestige in Seoul [in South Korea]."

15 For a survey of corporate social responsibilities approaches, see Mackie, et al. 2006.

16 From Ebner 2006: "The evolution of the modern state mirrors the emergence of a distinct sphere of self-interested economic activity in the private sector. While the state is concerned with the provision of common goods, its economic impact needs to be assessed with regard to the social interests that mark its relationship with the private sector. This holds for the evolution of fiscal systems as well as for other domains of government activity, involving the temporary carrying out of the entrepreneurial function."

17 This view would run counter to the "slow race" hypothesis that involves greater civil society participation as put forward in Leach and Scoones 2006.

18 From Hart forthcoming: "A global knowledge economy built on policies that foster mutual gain would be both richer and fairer than one premised on a war for talent. The more that imaginative people from different places are able to share and build on one another's ideas, the more knowledge will be discovered and the more diverse uses of it will be invented.

19 From Bugliarello 2006: "Since the beginning of civilization, the twin innate human quests to understand nature in its physical, biological and social aspect — what has come to be called science — and to modify nature and build artifacts — the vast activity encompassing endeavors such as engineering, medicine and agriculture, that we can call technology — have had a fundamental impact on the evolution of human societies. They have also been indissolubly interconnected, because to modify nature, we must understand it and to understand it, often we must manipulate it and build artifacts." See also Amadei 2004.

20 Such an effort could take a variety of forms and could include some of the elements outlined in Rowitt Beckmann 2006.

21 The work of measuring the impact of the science and technology on development is critical and continues to attract research attention. For a discussion of some of the methodological issues involved in such research, see Varsakelis 2006.