The Role of Engineering in Building Africa's Infrastructure

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Abstract:

Africa's ability to meet its human welfare needs and to ensure a sustainable use of its natural resources are currently not addressed by donor agencies that continue to focus on traditional relief and emergency activities., Instead, this would 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 improvement of infrastructure, again, will result in more private sector investment and thus more opportunities for engineers.

Introduction

The international development community is facing increasing pressure from the bottom-up to change its focus from emergency and relief operations to long-term endogenous solutions based on the building of technical competence, stimulating local entrepreneurship, and investing in infrastructure. [1]

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. In other words, the challenge for Africa lies largely in its ability to harness the world's scientific and technical pool and using it to solve local problems. Current investments in infrastructure offer a strategic starting point for building capacity in engineering.

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 represents a foundational base for applying technical knowledge in sustainable development and relies heavily on civil engineering. Moreover,, infrastructure reduces the transaction costs in market exchanges and thus attracts more economic activities and private sector investment.

The following article highlights some the challenges of infrastructure in Africa in transportation, electricity, water treatment, research equipment and ICTs. It further emphasizes the importance of regional integration and higher education to get the critical mass of financial and human capital that is necessary to create and maintain the different types

1. Engineering and international development

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. [2] 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 determines 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-

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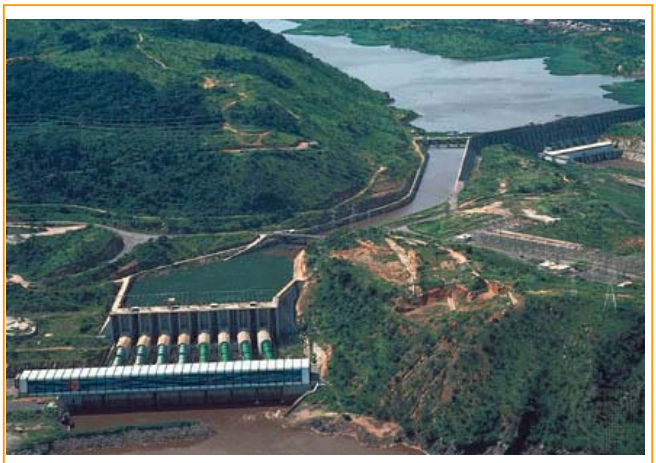
based approaches (e.g., redesigning houses and remodeling landscapes) can help mitigate mosquito breeding and malaria transmission, respectively, complementing efforts to develop new antimalarial drugs and vaccines. [3]

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. [4] 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.

2. The importance of infrastructure

Poor infrastructure and inadequate infrastructure services are among the major factors that hinder Africa's sustainable development. [5] Without adequate infrastructure, African countries will not be able to harness the power of science and innovation to meet sustainable development objectives and be competitive in international markets. Roads, for example, are critical to supporting rural development. Emerging evidence suggests that in some cases low-quality roads have a more significant impact on economic development than high-quality roads. [6] In addition, all significant scientific and technical efforts require reliable electric power and efficient logistical networks. In the manufacturing and retail sectors, efficient transportation and logistical networks allow firms to adopt process and organisational innovations, such as the just-in-time approach to supply chain management.



The Inga falls on the Congo, falls 96 m in 14 km and flows at a rate of about 43,000 cubic m per second, has the potential of providing at least 50,000 megawatt (MW) compared to its current capacity of 700 MW . Good engineering could help.

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. For example, it has been suggested that increasing the stock of infrastructure by 1 percent in a developing country context could add 1 percent to the level of GDP. But in some cases the impact has been far greater: the Mozal aluminium smelter investment in Mozambique not only doubled the country's exports and added 7 percent to its GDP, but it also created new jobs and skills in local firms. [7]

2.1 ICT infrastructure

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. [8]

2.2. General infrastructure services

Globalization of trade and investment demands that countries upgrade their technological capabilities as a source of competitive advantage. [9] Infrastructure con-

tributes 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. [10]

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. [11] Infrastructure is a critical determinant of the destination of foreign direct investment (FDI). [12] 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.

Given their strategic importance to creating and sustaining knowledge, research facilities need to be defined as part of Africa's critical infrastructure and managed as such. Many countries have well established sections of the military that deal with civilian matters on a routine basis. This function does not undermine the military role of the armed forces, but instead gives them new tasks that are consistent with a wider sense of national security. The time has come to rethink the role of the military in sustainable development and find constructive ways in which the armed forces can contribute to long-term sustainable development in general and technological innovation in particular.

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.

2.3. Infrastructure and engineering skills

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.

3. Africa's poor infrastructure

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 and Asia. This makes Africa the fastest urbanising continent in the world. [13]

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. [14] Even where such access exists, supply is unreliable and the quality of services remains poor. [15] Generally, access to infrastructure services favors the rich and is more unequal in Africa than in any other part of the world. [16]

3.1 Water treatment

There are major disparities in access to clean water in urban settings. Of Africa's 280 million urban residents, over 150 million lack access to clean water and nearly 180 million do not have adequate sanitation. In turn, 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 sewage system, but the figure for informal settlements is 7 percent. [17]

3.2. Mobile phones

There is good news, however: the advent of ICTs is transforming the continent. [18] In 2001 Uganda became the

first African country where mobile phones exceeded land fixed lines. [19] The market has expanded from under 20,000 users in 1993 to an estimated 18.2 million in 2003. [20] But despite such phenomenal growth rates, much of Africa still remains disconnected from the rest of the world because of poor communications infrastructure. [21] 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. [22]

3.3 Transportation costs

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. [23] 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. [24] Most of Africa is isolated from major air and maritime routes, which allows access only to high-cost, peripheral routes. [25] 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. [26] Internally, air transport costs across Africa are up to four times the cost of getting the same goods over the Atlantic. [27]

3.4. Low private sector participation

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. [28] 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. [29] Unfortunately, private sector participation in infrastructure investment has not taken off in Africa, contrary to policy opinion. [30] 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 1–2 percent (except in telecoms, 6 percent). [31]

3.5 Military expenditures at the expense of infrastructure

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. [32]

3.6 Natural disasters and the need for engineers

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. [33] 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. [34]

3.7 Climate Change

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. [35] 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. [36]

4 Rejuvenating African economies

Investment in engineering can play a critical role in building Africa's infrastructure and rejuvenating African economies. However, such efforts need to be placed in the appropriate national and regional policy contexts. [37]

4.1. Regional integration

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.

4.2 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.

Innovation: finding answers to real everyday problems

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 (R&D) 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.

4.3 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. [38] Training must suit current conditions and fulfill practical need, anticipate future trends and prepare the next generation of engineers accordingly. [39]

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. [40] 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.

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 MDGs.

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Endnotes

1. "Competence" denotes the ability to perform specific tasks and is used in this paper 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." Anne Whyte, *Landscape Analysis of Donor Trends in International Development*, Rockefeller Foundation Series, No. 2 (New York: Rockefeller Foundation, 2004), p. 24; Moses Oketch, "Determinants of Human Capital Formation and Economic Growth of African Countries," *Economics of Education Review,* Vol. 25, No. 5 (October 2006), pp. 554-564.

2. Djibril Aw and Geert Diemer, *Making a Large Irrigation Scheme Work: A Case Study from Mali* (Washington, D.C.: World Bank, 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." Gareth Thomas, "Innovation, Agricultural Growth and Poverty Reduction," in Juma, *Going for Growth*, p. 80.

3. Kai Matuschewski, "Vaccine Development Against Malaria," *Current Opinion in Immunology,* Vol. 18, No. 4 (June 2006), pp. 449–457.

4. Robert Frosch and Nicholas E. Gallopoulos, "Strategies for Manufacturing," *Scientific American*, Vol. 189, No. 3 (September 1989), p. 152. 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." Suren Erkman, "Industrial Ecology: A Historical View," *Journal of Cleaner Production,* Vol. 5, Nos. 1–2 (1997), p. 1.

5. Emerging evidence from South Africa shows the long-term implications of infrastructure investment for development: Johann Fedderke, P. Perkins and J. Luiz, "Infrastructural Investment in Long-Run Economic Growth: South Africa 1875–2001," *World Development,* Vol. 34, No. 6 (June 2006), pp. 1037–1059. Further historical evidence of the role of infrastructure in long-term economic development can be found in L. Cain, "Historical Perspective on Infrastructure and US Economic Development," *Regional Science and Urban Economics,* Vol. 27, No. 2 (April 1997), pp. 117–138.

6. A recent study of China shows "that low-quality (mostly rural) roads have benefit-cost ratios for na-

tional GDP that are about four times greater than the benefit-cost ratios for high-quality roads. Even in terms of urban GDP, the benefit-cost ratios for low-quality roads are much greater than those for high-quality roads. As far as agricultural GDP is concerned, high-quality roads do not have a statistically significant impact while low-quality roads are not only significant but also generate 1.57 yuan of agricultural GDP for every yuan invested. Investment in low-quality roads also generates high returns in rural non-farm GDP. Every yuan invested in low-quality roads yields more than 5 yuan of rural non-farm GDP." Shenggen Fan and Connic Chan-Kan, *Road Development, Economic Growth, and Poverty Reduction in China*, Research Report No. 138 (Washington, D.C.: International Food Policy Research Institute), pp. vii–viii.

7. Commission for Africa, *Our Common Interest*, p. 225.

8. See, for example, National Research Council, *Down to Earth: Geographic Information for Sustainable Development in Africa* (Washington, D.C.: National Academies Press).

9. For a detailed discussion of this point, see Sanjaya Lall and Carlo Pietrobelli, *Failing to Compete: Technology Development and Technology Systems in Africa* (Cheltenham, U.K.: Edward Elgar, 2002).

10. Allan Macpherson, "Learning How to Grow: Resolving the Crisis of Knowing," *Technovation,* Vol. 25, No. 10 (October 2005), pp. 1129–1140.

11. See, for example, Garth Holloway et al., "Agroindustrialization through Institutional Innovation: Transaction Costs, Cooperatives and Milk-market Development in the East-African Highlands," *Agricultural Economics,* Vol. 23, No. 3 (September 2000), pp. 279–288.

12. Chantal Dupasquier and Patrick Osakwe, "Foreign Direct Investment in Africa: Performance, Challenges, and Responsibilities," *Journal of Asian Economics,* Vol. 17, No. 2 (April 2006), pp. 241–260.

13. Anna Tibaijuka, *Africa on the Move: An Urban Crisis in the Making,* submission to the Commission for Africa, London, 2004, p. 1.

14. Antonio Estache, *What Do We Know about Sub-Saharan Africa's Infrastructure and the Impact of its 1990s Reforms?* Draft Working Paper (Washington, D.C.: World Bank, June 2005), p. 35.

15. Adeola Adenikinju, "Electric Infrastructure Failures in Nigeria: A Survey-based Analysis of the Costs and Adjustment Responses," *Energy Policy,* Vol. 31, No. 14 (November 2003), pp. 1519–1530.

16. Alan Gelb et al., *Can Africa Claim the 21st Century?* (Washington, D.C.: World Bank), p. 137.

17. Anna Tibaijuka, *African on the Move: An Urban Crisis in the Making,* submission to the Commission for Africa, London, 2004, p. 8.

18. Banji Oyelaran-Oyeyinka and Kaushalesh Lal, "Internet Diffusion in sub-Saharan Africa: A Cross-country Analysis," *Telecommunications Policy,* Vol. 29, No. 7 (August 2005), pp. 507–527.

19. Jacqueline Hamilton, "Are Main Lines and Mobile Phones Substitutes or Complements? Evidence from Africa," *Telecommunications Policy,* Vol. 27, Nos. 1–2 (February/March 2003), pp. 109–133.

20. Pierre Guislain, Mavis Ampah, and Laurent Bescangon, *Connecting Sub-Saharan Africa: A World Bank Group Strategy for Information and Communication Technology Sector Development*, Working Paper No. 51 (Washington, D.C.: World Bank, 2005).

21. J. Britz, P. Lor, J., I. Coetzee, I. and B. Bester, "Africa as a Knowledge Society: A Reality Check," *International Information & Library Review,* Vol. 38, No. 1 (March 2006), pp. 25–40.

22. Ragnhild Overå, "Networks, Distance, and Trust: Telecommunications Development and Changing Trading Practices in Ghana," *World Development,* Vol. 34, No. 7 (July 2006), pp.1301–1315.

23. Commission for Africa, *Our Common Interest*, p. 53. "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." Gordon Brown, "Forward," in Calestous Juma, ed., *Going for Growth: Science, Technology and Innovation in Africa* (London: Smith Institute, 2005), p. 5.

24. Gelb et al., *Can Africa Claim the 21st Century?* p. 136.

25. Commission for Africa, *Our Common Interest*, p. 53.

26. Azita Amjadi and Alexander Yeats, *Have Transport Costs Contributed to the Relative Decline of Sub-Saharan African Exports?* World Bank Policy Research Working Paper No. 1559 (Washington, D.C.: World Bank, 1995); and Commission for Africa, *Our Common Interest*, p. 269.

27. Gelb et al., *Can Africa Claim the 21st Century?* p. 136.

28. José Gómez-Ibáñez, Dominique Lorrain, and Meg Osius, *The Future of Private Infrastructure*, Working Paper (Cambridge, Mass.: Kennedy School of Government, Taubman Center for State and Local Government, April 2004).

29. Benno Ndulu, *The Challenges for Improving Access to Infrastructure Services in Africa*, background paper prepared for the Commission for Africa, London; and Commission for Africa, *Our Common Interest*, p. 234.

30. "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." Commission for Africa, *Our Common Interest*, p. 80

31. Estache, *What Do We Know about Sub-Saharan Africa's Infrastructure and the Impact of its 1990s* Reforms?, p. 17.

32. Gelb, *Can Africa Claim the 21st Century?* p. 135.

33. Banji Oyelaran-Oyeyinka, *Learning to Compete in African Industry: Institutions and Technology in Development* (Burlington, Vt.: Ashgate, 2006), p. 117.

34. William Mitsch and Sven Jørgensen, "Ecological Engineering: A Field Whose Time Has Come," *Ecological Engineering,* Vol. 20, No. 5 (October 2003), pp. 363–377.

35. Salvador Barrios, Luisito Bertinelli and Eric Strobl, "Climatic Change and Rural–Urban Migration: The Case of Sub-Saharan Africa," *Journal of Urban Economics* (forthcoming). See also Andrew Simms, Africa—*Up in Smoke?* Second Report of the Working Group on Climate Change and Development (London: New Economics Foundation, June 2005).

36. The importance of technological innovation in mitigation strategies is illustrated in Harald Winkler et al., "What Factors Influence Mitigative Capacity?" *Energy Policy* (forthcoming). The following publication addresses climate change in developing countries, FAO. 2007. Coping with water scarcity in developing countries: What role for agricultural biotechnologies?. Summary Document to Conference 14 of the FAO Biotechnology Forum (5 March and 1 April 2007): http://www.fao.org/biotech/logs/C14/summary.htm

37. 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 Ronald Tobey, *Technology as Freedom: The New Deal and the Electrical Modernization of the American Home* (Berkeley: University of California Press, 1996).

38. For additional information on this theme, see, Calestous Juma, *Reinventing African Economies: Technological Innovation and the Sustainability Transition*, The John Pesek Colloquium on Sustainable Agriculture (Ames, Iowa: Iowa State University, April 2006) and Calestous Juma, "Reinventing African Universities," *Falmer*, No. 44 (Summer 2006), pp. 8-10.

39. James Wei, "Engineering Education for a Post-industrial World," *Technology in Society,* Vol. 27, No. 2 (April 2005), pp. 123–132; National Academy of Engineering, *Engineer of 2020: Visions of Engineering in the New Century* (Washington, D.C.: National Academies Press, 2004).

40. Jens Hansen and Martin Lehmann, "Agents of Change: Universities as Development Hubs," *Journal of Cleaner Production,* Vol. 14, Nos. 9–11 (2006), pp. 820–829.