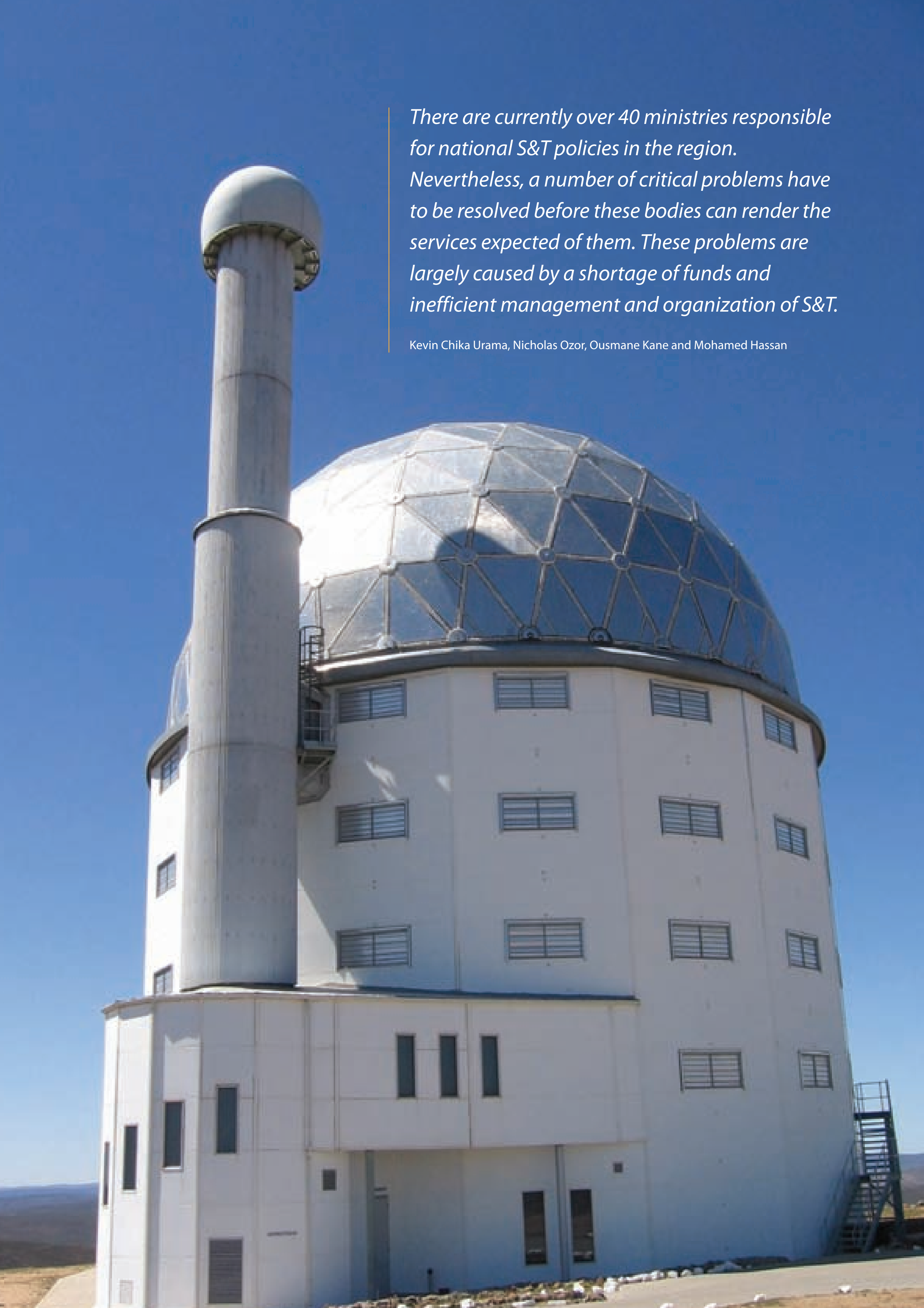


There are currently over 40 ministries responsible for national S&T policies in the region. Nevertheless, a number of critical problems have to be resolved before these bodies can render the services expected of them. These problems are largely caused by a shortage of funds and inefficient management and organization of S&T.

Kevin Chika Urama, Nicholas Ozor, Ousmane Kane and Mohamed Hassan

14 · Sub-Saharan Africa

Kevin Chika Urama, Nicholas Ozor, Ousmane Kane and Mohamed Hassan

INTRODUCTION

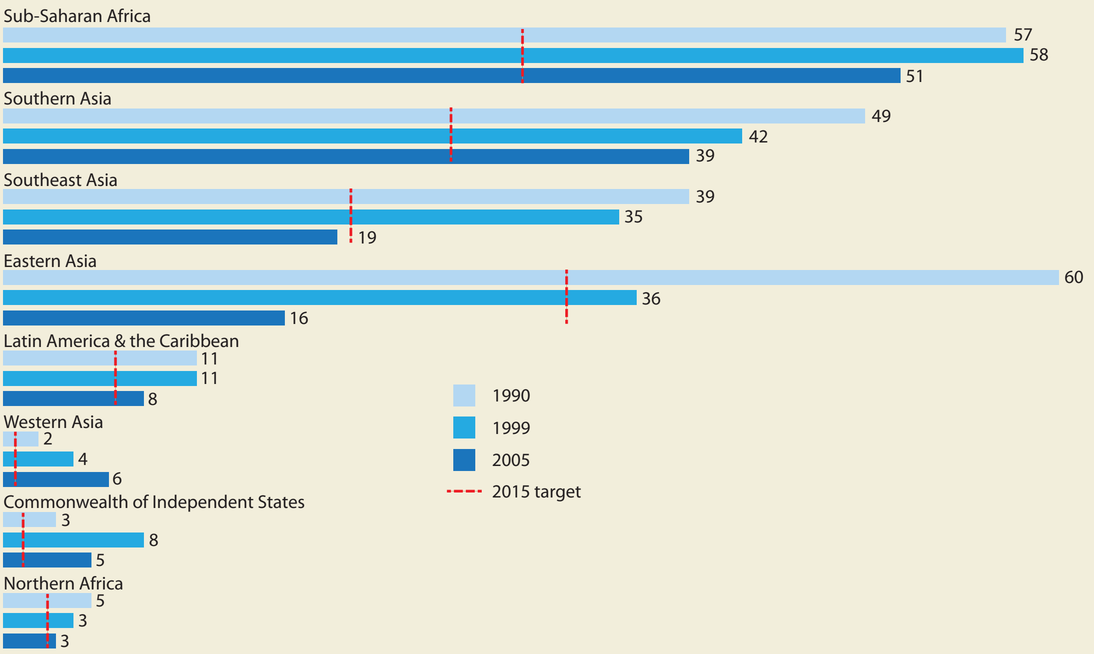
The Millennium Declaration set 2015 as the target date for achieving the eight Millennium Development Goals. These goals established quantitative benchmarks for halving extreme poverty in all its forms (*see Annex II*). As the date approaches, the world finds itself mired in an unprecedented economic recession. In sub-Saharan Africa and Southern Asia, both the number of poor and the poverty rate increased in some of the least-growth economies in 2009, a factor exacerbated by the growing burden of catastrophes caused by climate change and natural disasters. Current projections suggest that overall poverty rates in the developing world fell in 2009 but at a much slower pace than before the downturn (UNDESA, 2009). For some countries, this may mean the difference between reaching, or not, their poverty reduction target.

Replete with natural resources, intellectual capital, indigenous knowledge and culture, Africa is nevertheless at a comparative disadvantage when it comes to overall development because of its low investment in science and technology (S&T). This results in poor infrastructure development, a small pool of researchers and minimal scientific output. The situation is exacerbated by population growth, conflicts, poor governance and political instability, food insecurity, poverty and disease, among other factors.

The continent has made several bold attempts to turn around its development fortunes through treaties that include the Monrovia Strategy (1979), the Lagos Plan of Action (1980), the Abuja Treaty (1991) establishing the African Economic Community and, most recently, the adoption of *Africa's Science and Technology Consolidated Plan of Action* (CPA) by the African Union[1] in January 2007. Despite these efforts, Africa remains the poorest and most economically marginalized continent in the world (Figure 1). The continent has often adopted a short-term view of human development, persisting in a reliance on

1. Although the African Union embraces the entire continent, we shall be focusing in the present chapter on countries south of the Sahara, since North Africa is covered in Chapter 13.

Figure 1: Poverty levels in sub-Saharan Africa, 1990, 1999 and 2005 (%)



Note: Proportion of people living on less than US$ 1.25 a day

Source: UNDESA (2009) *The Millennium Development Goals Report*

The Southern African Large Telescope was inaugurated in 2005. It is the largest in the southern hemisphere.

Photo: Wikipedia Commons

Table 1: Investment in sub-Saharan Africa, 2008 or most recent year available
Selected countries

	Military expenditure (% of GDP)	Total expenditiure on health (% of GDP)	Public expenditiure on education (% of GDP)	Expenditure on tertiary education (% of total expenditure on education)	GERD (% of GDP)	GERD (in PPP$ thousands)	GERD (per capita PPP$)
Angola	2.9	2.7	2.6^{-2}	8.7^{-2}	–	–	–
Benin	1.0	5.3	3.6^{-1}	20.2^{-1}	–	–	–
Botswana	3.5	7.2	8.1^{-1}	27.5^{-1}	0.5^{-2}	111 714^{-2}	60.7^{-2}
Burkina Faso	1.8	6.4	4.6^{-1}	15.2^{-1}	0.1^{a}	18 392^{a}	1.2
Burundi	3.8	3.0	7.2	21.2	–	–	–
Cameroon	1.5	5.2	2.9	9.0	–	–	–
Cape Verde	0.5	5.6	5.7	11.3	–	–	–
Central African Rep.	1.6	3.9	1.3^{-1}	21.3^{-1}	–	–	–
Chad	1.0	3.6	1.9^{-3}	18.7^{-3}	–	–	–
Comoros	–	3.2	7.6**	14.6**	–	–	–
Congo	1.3	2.1	1.8^{-3}	25.9^{-3**}	0.1^{-4*}	–	–
Côte d'Ivoire	1.5	3.8	4.6	25.1^{-8**}	–	–	–
Dem. Rep. of Congo	0.0	4.3	–	–	0.5$^{-2,v}$	75 217$^{-2,v}$	1.3$^{-2,v}$
Equatorial Guinea	–	1.5	0.6$^{-5,**}$	31.4^{-6}	–	–	–
Eritrea	23.6^{-5}	4.5	2.0^{-2}	19.4^{-2}	–	–	–
Ethiopia	1.5	4.9	5.5^{-1}	39.0^{-1}	0.2^{a}	106 753^{a}	1.4^{a}
Gabon	1.1^{-1}	3.7	–	–	–	–	–
Gambia	0.7^{-1}	4.3	2.0$^{-4,**}$	12.2$^{-4,**}$	–	–	–
Ghana	0.7	6.2	5.4^{-3}	20.8^{-3}	–	–	–
Guinea	2.0^{-4}	5.7	1.7	34.4	–	–	–
Guinea-Bissau	4.0^{-3}	6.2	–	–	–	–	–
Kenya	1.7	4.6	7.0^{-2}	15.4^{-2}	–	–	–
Lesotho	2.6	6.7	12.4	36.4	0.1$^{-3,a}$	1 563$^{-3,a}$	0.8$^{-3,a}$
Liberia	0.5^{-1}	5.6	2.7	_	–	–	–
Madagascar	1.1	3.2	2.9	15.4	0.1^{a}	25 753^{a}	1.4^{a}
Malawi	1.2^{-1}	12.3	4.2^{-5}	_	–	–	–
Mali	2.0	6.0	3.8	16.1	–	–	–
Mauritius	0.2^{-1}	4.3	3.4^{+1}	11.0^{+1}	0.4$^{-2,v}$	47 014$^{-2,v}$	37.5$^{-2,v}$
Mozambique	0.9	4.7	5.0^{-2}	12.1^{-2}	0.5^{-1}	83 105^{-1}	3.9^{-1}
Namibia	3.1	4.9	6.5	9.9	–	–	–
Niger	0.0^{-3}	4.0	3.7	9.4	–	–	–
Nigeria	0.0	4.1	–	–	–	–	–
Rwanda	1.5	10.4	4.1	25.4	–	–	_
Senegal	1.6	5.4	5.1**	24.5**	0.1$^{-2,a,*}$	16 252$^{-2,a,*}$	1.4$^{-2,a,*}$
Seychelles	1.0	6.8	5.0^{-2}	17.9^{-2}	0.3^{-2}	4 519^{-2}	54.5^{-2}
Sierra Leone	2.3	3.5	3.8$^{-3,**}$	_	–	–	–
South Africa	1.4	8.6	5.4^{+1}	12.5^{+1}	0.9^{-1}	4 100 875^{-1}	84.3^{-1}
Swaziland	2.1^{-1}	5.9	7.9	21.3^{-2}	–	–	–
Togo	2.0	5.5	3.7^{-1}	21.4^{-1}	–	–	_
Uganda	2.3^{-1}	7.2	3.3^{+1}	13.3^{+1}	0.4	128 012	4.2
United Rep. of Tanzania	0.9	5.5	6.8	–	–	–	–
Zambia	1.8	5.2	1.4	25.8^{-3}	0.0$^{-2,a}$	3 840$^{-2,a}$	0.3$^{-2,a}$
Zimbabwe	3.8^{-3}	8.4	4.6^{-8**}	16.6^{-8**}	–	–	–

-n/*+n* = data refer to *n* years before or after reference year
* national estimate; ** UNESCO Institute for Statistics estimation; a = partial data; v = overestimated or based on overestimated data

Source: for expenditure on education and GERD: UNESCO Institute for Statistics; for military expenditure: World Bank, World Development Indicators, June 2010; for health expenditure: WHO (2009) *World Health Statistics* reliance on external financial support, which often targets short-term goals. As a result, the continent has failed to invest in science, technology and innovation (STI) as drivers of economic growth and long-term sustainable development (Mugabe and Ambali, 2006). This is evident in Africa's low public expenditure on research and development (GERD) [Table 1]. Countries will need to design and implement policies, as well as create institutional arrangements, which promote the development and application of S&T to solving specific problems related to each of the Millennium Goals.

The need for change was acknowledged by the Malawi President Bingu wa Mutharika in January 2007, at the African Union summit in Addis Ababa, Ethiopia. He affirmed that building S&T capacity was the only sure way to break the long-standing cycle of extreme poverty that has gripped the African continent for decades. 'We have depended on donor countries for scientific development for so long,' he noted. 'It is time we committed more resources in our national budget to advance S&T.'

In the past decade, a number of African countries have been progressively enhancing their S&T capacity as a strategy for extricating themselves from the grips of poverty, hunger and disease, and as a means of achieving industrial development and social transformation. Attempts have been made by many African governments to develop national STI policies for their respective countries. In 2008 alone, 14 countries formally requested UNESCO's assistance with science policy reviews: Benin, Botswana, Burundi, Central African Republic, Côte d'Ivoire, Democratic Republic of Congo, Madagascar, Malawi, Morocco, Senegal, Swaziland, Togo, Zimbabwe and Zambia.

African countries have begun to recognize that, without investment in S&T, the continent will stay on the periphery of the global knowledge economy. A number of countries are taking steps to establish a national innovation system in an approach generally borrowed from the Organisation for Economic Cooperation and Development (OECD). These efforts are most visible in South Africa, where GERD as a percentage of GDP grew from 0.73% in 2001 to 0.94 in 2006, according to the UNESCO Institute for Statistics.

However, as we shall see in the pages that follow, sub-Saharan Africa still has a long way to go to reach the eldorado of the knowledge economy, not only in terms of innovation but also as regards the other three pillars of the knowledge economy: a sound economy and institutional regime; an educated, creative population capable of utilizing knowledge effectively; and a dynamic information infrastructure. Although GDP per capita rose in most African countries between 2002 and 2008, it remains low by world standards, with the notable exception of Angola and Equatorial Guinea where a surge in oil exploitation in recent years has led to a meteoric rise in national income. Oil production and related activities contribute about 85% of GDP in Angola and fuelled growth averaging more than 15% per year from 2004 to 2007, even if GDP contracted in 2009 (-0.6%) as a result of the drop in oil prices and the global recession. In Equatorial Guinea, the discovery of large oil reserves caused GDP to bound by approximately 22% in 2007 and 12% the following year before falling oil prices plunged the economy into a negative growth of about 1.8% in 2009 (CIA, 2010). This example highlights the need for oil-rich African countries to diversity their economies in order to improve their resilience to fluctuating global oil markets, a policy adopted by Nigeria in recent years (*see page* 309).

In many African countries, subsistence agriculture occupies most of the population, even though it contributes a much smaller share to GDP. Subsistence farming still predominates in Angola, Burundi, Burkina Faso and Equatorial Guinea, for instance. Moreover, in all African countries south of the Sahara, enormous hurdles remain in achieving more equitable access to both education and information and communication technologies (ICTs).

AN INVENTORY OF STI CAPABILITIES IN AFRICA

Persistently low investment in STI

As we have seen in Table 1, R&D attracts less public investment in sub-Saharan Africa than the military, health or education sectors. Only South Africa is approaching the target of a 1% GERD/GDP ratio, the level recommended by UNESCO and, more recently, by the African Union summit in January 2007. Even more worrisome is that many countries either have no record of the share of GDP they devote to R&D or simply allocate no funds at all to R&D. This is most saddening for a continent desirous to develop STI. All African countries would do well to take a leaf out of South Africa's book.

An underexploited pool of human resources

Rising school rolls

At 62%, sub-Saharan Africa holds the unenviable world record for the lowest adult literacy rate, followed closely by South and West Asia, at 64%. Despite this low rate, many countries have achieved steep rises in adult literacy rates over the past decade, including some with the farthest way to go; Burkina Faso and Chad, for example, doubled and almost tripled their literacy rates respectively between 1999 and 2007. Public expenditure on education in sub-Saharan Africa rose from 3.5% of GNP in 1999 to 4.5% in 2007, placing it on a par with the mean for developing countries but still behind the mean for developed countries (5.3%). Public expenditure on education as a percentage of total government expenditure was actually higher in sub-Saharan Africa in 2007 (17.5%) than the mean for the developed world (12.4%) [UNESCO, 2010*a*].

The picture is brightest for primary education, where the sub-continent registered strong progress between 1999 and 2007. During a period in which the size of its school-age population increased by 20 million, sub-Saharan Africa reduced its out-of-school population by almost 13 million, or 28%. The strength of the region's progress can be gauged by a comparison with the 1990s: had the region progressed at the same pace as in the 1990s, 18 million more children would be out of school today. Nevertheless, one-quarter of sub-Saharan Africa's primary school-age children were still out of school in 2007 and the region accounted for nearly 45% of the world's entire out-of-school population. Progress in the region has been uneven. Some countries with large out-of-school populations in 1999 have made great strides, including Ethiopia, Kenya, Mozambique, Tanzania and Zambia. Countries making only limited progress include Liberia, Malawi and Nigeria (UNESCO, 2010*a*).

Despite commitment to international treaties and declarations by most countries south of the Sahara, access to secondary and tertiary education in sub-Saharan Africa remains limited to a minority, with one-quarter of countries showing gross enrollment rates of no more than 26% for secondary education and just under 4% for university enrollment in 2008. Holding many countries back is the substantial gender gap, with schooling often remaining the privilege of boys. Gender disparities in primary education increase with the level of education, as can be seen in the drop in the percentage of girls between the secondary and tertiary levels of education (Table 2). Empirical studies find a distinct correlation between university enrollment rates and growth in national income in many countries (Moyer, 2007, cited in Urama, 2009). Analyses show that attaining full primary education for all, which has been the main focus of government policies in many African countries, may be necessary but is not sufficient in itself to drive development in most countries. For example, Togo and Madagascar have attained over 90% primary school enrollment rates but this has not translated into higher national income (Urama, 2009). University enrollment rates in sub-Saharan Africa are among the lowest in the world. Overall, the contribution of higher education in Africa to gross national income is very low (Moyer, 2007; Botman *et al.,* 2009).

A more in-depth analysis provided by Moyer (2007, cited in Urama, 2009) suggests that the relative cost of higher education per student as a proportion of gross national income is higher in Africa than in the developed countries. This situation leaves African higher education in a dilemma, as African governments are the primary source of funding. Therefore, if higher education does not significantly contribute to growth in national income, it is most likely that governments will prioritize other development challenges such as poverty alleviation, climate change adaptation, water insecurity, peace and so on (Urama, 2009). However, it should be noted that investment in higher education has a long-term impact on national development.

Challenges for higher education

Africa entered the Millennium with severe education challenges at every level, as underlined in the African Union's *Plan of Action for the Second Decade of Education for Africa* (2006–2015). To cope with these challenges, conferences of ministers of education have reiterated the need to broaden access to education, improve quality and relevance, and ensure equity. Specific challenges for African higher education systems include:

- poorly equipped laboratories and overcrowded lecture rooms;
- a need to adapt the higher education system to the bachelor's–master's–doctorate triumvate, which is the norm around the world;

Table 2: Education in sub-Saharan Africa, 2008
Selected countries

Country	Secondary education: Gross enrollment ratio	Secondary education: Female students (%)	Tertiary education: Gross enrollment ratio (%)	Tertiary education: Female students (%)	Tertiary education: Enrollment in S&E fields % of total	Tertiary education: Female students in S&E fields as a % of total enrollment in S&E fields	Adult literacy rate (%)**
Angola	17.3$^{**,-6}$	45.7$^{**,-6}$	2.8^{-2}	39.9$^{*,-6}$	18.3^{-6}	–	69.6
Benin	36.3$^{**,-3}$	35.4$^{**,-3}$	5.8^{-2}	19.8$^{**,-7}$	–	–	40.8
Botswana	80.2^{-2}	51.1-2	7.6^{-2}	53.2^{-2}	–	–	83.3
Burkina Faso	19.8^{+1}	41.9^{+1}	3.4^{+1}	32.1^{+1}	15.3^{+1}	12.9^{+1}	28.7^{-1}
Burundi	17.9**	41.4**	2.7^{+1}	30.5$^{**,-2}$	9.6^{-6}	13.1^{-6}	65.9
Cameroon	37.3	44.1	9.0^{+1}	43.9^{+1}	21.8^{+1}	–	75.9
Cape Verde	67.7^{-4}	52.2^{-4}	11.9	55.5	16.2	30.8	84.1
Central African Rep.	13.6^{+1}	36.2^{+1}	2.5^{+1}	30.5^{+1}	12.3^{+1}	–	54.6
Chad	19.0^{-1}	30.8^{-1}	1.9	12.7	–	–	32.7
Comoros	45.8$^{**,-3}$	42.5$^{**,-3}$	2.7$^{**,-4}$	43.2$^{**,-4}$	10.7^{-5}	27.3^{-5}	73.6
Congo	43.1$^{**,-4}$	46.0$^{**,-4}$	3.9$^{**,-5}$	15.8$^{**,-5}$	11.1^{-6}	15.5^{-6}	–
Côte d'Ivoire	26.3$^{**,-6}$	35.6$^{**,-6}$	8.4^{-1}	33.3^{-1}	23.9^{-1}	16.2^{-1}	54.6
Dem. Rep. of Congo	34.8*	35.5*	5.0	25.9$^{*,-1}$	–	–	66.6
Equatorial Guinea	26.2$^{**,-6}$	36.4$^{**,-6}$	3.3^{-8}	30.3^{-8}	–	–	93.0
Eritrea	30.5**	41.5**	2.0^{+1}	24.5^{+1}	37.0^{+1}	19.7^{+1}	65.3
Ethiopia	33.4	41.9	3.6	23.8	14.4	18.9	35.9
Gabon	53.1$^{**,-6}$	46.3$^{**,-8}$	7.1^{-9}	35.7^{-9}	–	–	87.0
Ghana	55.2	45.9	6.2^{-1}	34.2^{-1}	–	–	65.8
Guinea	35.8	36.2	9.2	24.4	28.7	19.6	38.0
Guinea-Bissau	35.9^{-2}	35.4^{-8}	2.9^{-2}	15.6$^{**,-7}$	–	–	51.0
Kenya	58.3	47.6	4.1^{+1}	41.2^{+1}	29.1^{-7}	18.3^{-7}	86.5
Lesotho	39.9$^{**,-1}$	56.8$^{**,-1}$	3.6^{-2}	55.2^{-2}	23.9^{-3}	53.7^{-3}	89.5
Liberia	31.6	42.9	17.4^{-8}	42.8^{-8}	11.2^{-8}	41.7^{-8}	58.1
Madagascar	30.1	48.6	3.4	47.2	18.9	26.7	70.7
Malawi	29.4	45.6	0.5^{-1}	33.6^{-1}	32.7^{-9}	–	72.8
Mali	38.3^{+1}	39.0^{+1}	5.5^{+1}	28.9^{+1}	9.9^{+1}	13.3^{+1}	26.2^{-2}
Mauritius	87.2**,$^{+1}$	49.8$^{**,+1}$	25.9**	53.3**	–	–	87.5
Mozambique	20.6	42.8	1.5^{-3}	33.1^{-3}	23.8^{-3}	16.1^{-3}	54.0
Namibia	65.8	53.8	8.9	56.8	12.4	43.2	88.2
Niger	11.6^{+1}	37.9^{+1}	1.4^{+1}	29.0^{+1}	10.1	10.2	–
Nigeria	30.5^{-1}	43.0^{-1}	10.1^{-3}	40.7^{-3}	–	–	60.1
Rwanda	21.9	47.8	4.0	39.0$^{**,-3}$	–	–	70.3
Sao Tome and Principe	51.3^{+1}	52.2^{+1}	4.1^{+1}	47.6^{+1}	–	–	88.3
Senegal	30.6	44.3	8.0*	35.3*	–	–	41.9^{-2}
Sierra Leone	34.6^{-1}	41.0^{-1}	2.0$^{**,-6}$	28.8$^{**,-6}$	7.7^{-7}	27.1^{-7}	39.8
Somalia	7.7$^{**,-1}$	31.5$^{**,-1}$	–	–	–	–	–
South Africa	95.1$^{**,-1}$	51.0$^{**,-1}$	–	–	–	–	89.0
Swaziland	53.3^{-1}	47.1^{-1}	4.4^{-2}	49.8^{-2}	8.8^{-2}	26.7^{-2}	86.5
Togo	41.3^{-1}	34.6$^{**,-1}$	5.3^{-1}	–	–	–	64.9
Uganda	25.3	45.7	3.7	44.3	10.5-^{4}	20.5^{-4}	74.6
United Rep. Tanzania	6.1$^{**,-9}$	44.8$^{**,-9}$	1.5^{-1}	32.3^{-1}	24.2^{**-3}	19.2^{**-3}	72.6
Zambia	45.6	45.2	2.4$^{**,-8}$	31.6$^{**,-8}$	–	–	70.7
Zimbabwe	41.0^{-2}	48.1^{-2}	3.8$^{**,-5}$	38.8$^{**,-5}$	–	–	91.4

-n: data refer to *n* years before reference year * National estimate **UNESCO Institute for Statistics estimation

.

Source: UNESCO Institute for Statistics

Table 3: Researchers in sub-Saharan Africa, 2007 or most recent year available
Selected countries

Country	Total number of researchers (FTE)	Share of women researchers (%)	Researchers per million inhabitants (FTE)	Technicians per million inhabitants (FTE)	Researchers by sector (FTE)			
					Business enterprises	Government	Higher education	Private non-profit
Benin	1 000*	–	119*	–	–	–	–	–
Botswana[-2,h]	1 732*	30.8	942	222	159*	692*	859*	22*
Burkina Faso[a,h]	187	13.4	13	27	–	165[b]	1[b]	15[b]
Cameroon[-2,a,h]	462	19.0	26	–	–	462	–	–
Cape Verde[-5]	60	52.3	132	33	–	–	–	–
Central African Rep.[a,h]	41	41.5	10	–	–	–	41	–
Congo, Rep.[-5,a]	102	12.8[F]	34	37	–	–	–	–
Côte d'Ivoire[-2,a]	1 269	16.5	66	–	–	29	1 240	–
Dem. Rep. of Congo[-2,h]	10 411	–	176	26	–	877	9 534	–
Ethiopia[a]	1 615	7.4	21	12	–	1 361	254	–
Gabon[-1,a,h]	150	24.7	107	30	–	150	–	–
Gambia[-2,a,h]	46	8.7	30	18	–	–	–	–
Guinea[-7,a,h]	2 117	5.8	253	92	–	1 096	1 021	–
Lesotho[-3,a]	20	55.7	10	11	–	11	9	–
Madagascar[a]	937	35.2	50	15	–	262	675	–
Mali[-1,a]	513	12.1	42	13	–	227	286	–
Mozambique[-1,a,h]	337	33.5	16	35	–	337	–	–
Niger[-2,a]	101	–	8	10	–	–	–	–
Nigeria[-2,a,h]	28 533	17.0	203	77	–	1 051	27 482	–
Senegal[a]	3 277*	9.9*	276*	–	–	418*	2 859*	–
Seychelles[-2,a]	13	35.7	157	640	–	8	–	5
South Africa[-1]	18 574	39.7	382	130	6 111	2 768	9 491	204
Togo	216	12.0	34	17	–	26	190	–
Uganda[h]	891	41.0	29	18	71	473	321	26
Zambia[-2,a]	792	27.4	67	106	4	565	146	77

* national estimate; a = partial data; b = the sum of the breakdown does not add up to the total; h = for these countries, data are only available for headcount; F = full-time equivalent (FTE) instead of headcount

Source: UNESCO Institute for Statistics

- the fact that women are not only much less represented than men in tertiary education but are also often confined to so-called 'feminine' fields, such as the social sciences, humanities, services and health-related courses, which do not boost their chances of equal job opportunities with men. What men and women choose to study is a key issue in the debate about gender equality;
- an inadequation and fragmentation of curricula and research programmes;
- the lack of a 'culture' of evaluation for teachers, researchers and programmes;
- a lack of co-operation and partnerships with other institutions at national, sub-regional, regional and international levels ;
- excessive bureaucracy in management procedures, together with frequent strikes by students, teachers, researchers or administrative staff, among others, which considerably hamper the stability and performance of institutions;
- a lack of linkages between academic research and innovation, hampering socio-economic progress.

A small pool of researchers

Table 3 shows that Nigeria counted the greatest number of researchers in Africa in 2005. However, when the number of researchers is assessed per million inhabitants, Nigeria slips to fifth place behind Botswana, South Africa, Senegal and Guinea. The percentage of women researchers across the continent remains low, as does the number of scientists and technicians per million inhabitants. Also worrisome is the dearth of researchers employed in the business and private non-profit sectors.

Low scientific productivity in all but a handful of countries

South Africa dominates scientific publishing

Sub-Saharan Africa produced just 11 142 scientific articles in 2008. Its share of the world's output has risen, however, since 2002 from 0.9% to 1.1% (*see page* 10). Within the sub-continent, South Africa produced almost half (46.4%) of the total, followed by Nigeria (11.4%) and Kenya (6.6%) [Figure 2]. In other words, these three countries alone produce two-thirds of the sub-continent's scientific articles, a reflection of their relatively sophisticated level of R&D.

Most African countries were unable to produce 100 publications in the natural sciences in 2008. According to Bernardes *et al*. (2003), these figures are well below the theoretical threshold that would trigger a virtuous interaction between S&T. This threshold was in the neighbourhood of 150 papers per million population in 1998 and has since risen. Of some comfort is the consistent, if modest, progression across the region in the number of scientific papers recorded in Thomson Reuters, Science Citation Index. Moreover, the language barrier may be hampering the visibility of scientific research from French- and Portuguese-speaking African countries in international databases, even though many other factors also come into play. See, for example, the case of Mali (*see page* 307).

African scientists publish mostly in the fields of clinical medicine, biology and biomedical research, followed by Earth and space science (Figure 3). In Kenya, the life sciences represented as much as 93% of scientific articles in 2008, compared to just 4% for Earth and space sciences. In Nigeria, 84% of published articles concerned the life sciences, compared to 6% for engineering and technology and 5% for Earth and space sciences. South Africa, on the other hand, has a more diversified research system. Although two-thirds of South African publications relate to the life sciences, the remainder of articles are fairly evenly spread among the other major fields of science, including chemistry, mathematics and physics.

Utility patents dominate intellectual property earnings

Table 4 shows the number of patents awarded to African inventors by the United States Patents and Trademark Office (USPTO) during 2005–2009. The continent produced 706 patents during this period, compared to 633 in 2000–2004 (Pouris and Pouris, 2009). It is interesting to note that, if the continent produces 2.0% of the world's knowledge, as manifested in research publications, it produces less than 0.1% of the world's inventions. Between 2005 and 2009, South Africa produced two-thirds of the continent's utility patents (65%) but 87% of USPTO patents, a share comparable to that for 2000–2004 (88% of the total).

NATIONAL STRATEGIES FOR DEVELOPING TECHNOLOGICAL RESPONSIBILITY IN AFRICA

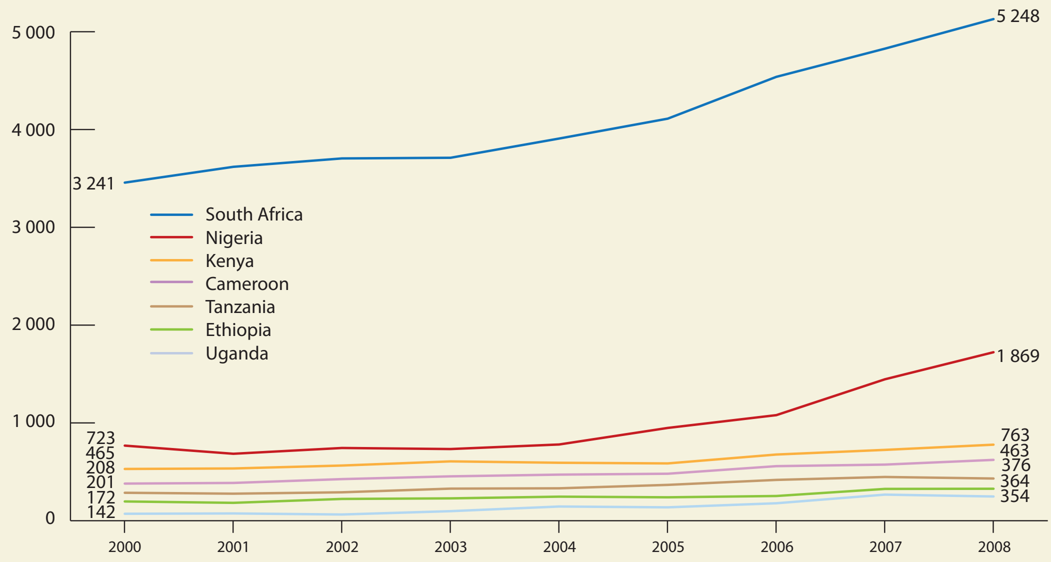
Strengthening STI development in Africa will require a shift from the business-as-usual approach to a more proactive and engaging culture of technological responsibility. An abundance of natural resources and low-cost labour do not necessarily constitute in themselves decisive comparative advantages for the continent, as the parameters of international competitiveness are increasingly S&T- based. African countries must improve their competitiveness not by relying on low labour costs but rather by improving their technical capacity. According to UNECA (2005) – the source of inspiration for many of the recommendations that follow –what Africa needs is nothing less than leadership and democratization. If we are going to mobilize S&T for sustainable development, all key stakeholders must be involved in both policy formulation and implementation. This is the way to avoid academic and elitist policies and to define and strengthen the role of public institutions, international partners, universities, non-governmental organizations (NGOs), women's organizations, civil society and the private sector. This is also the way to ensure that policies are tailored primarily to meet the specific needs of end-users and clients.

Improving governance

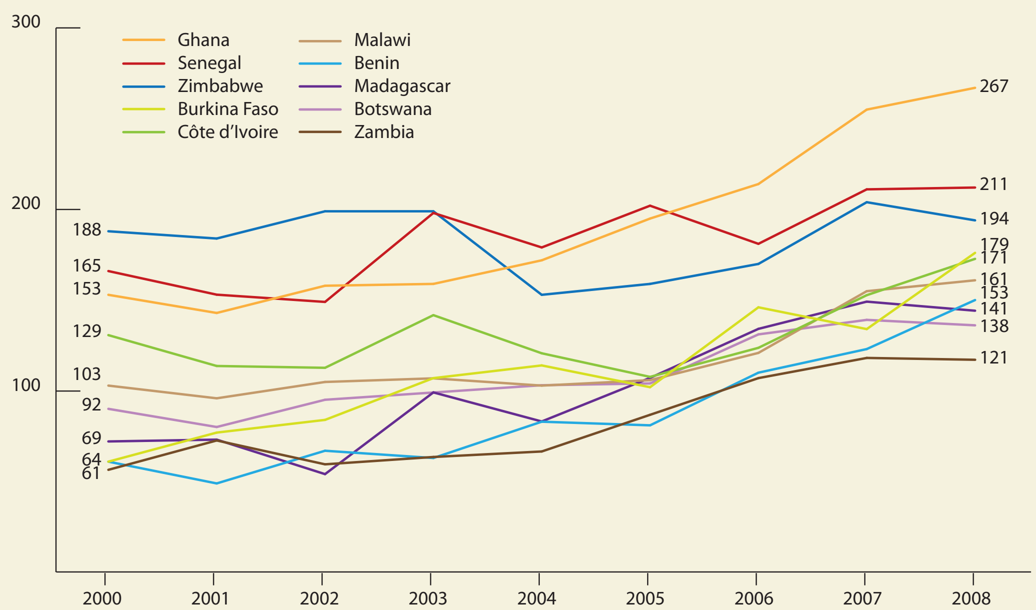
Today, in many African countries, there is a lack of stable political leadership capable of providing a clear vision and objectives for STI. The frequency of cabinet reshuffles in many countries results in instability among top officials in the ministries responsible for S&T, in turn leading to shifting priorities and disturbances in programme execution. This results in weak strategies for innovation and technology transfer, which in turn foster inadequate higher education and research systems with little innovative or inventive potential. This critical

Figure 2: Scientific publications in sub-Saharan Africa, 2000–2008
For those countries that produced more than 100 publications in 2008

Top 7 countries in terms of productivity



Next 10 most prolific countries



Source: Thomson Reuters (Scientific) Inc. Web of Science (Science Citation Index Expanded), compiled for UNESCO by the Canadian Observatoire des sciences et des technologies, May 2010 phenomenon requires a clear understanding by the head of state and/or prime minister of the need for a strong, transparent STI policy owned by all stakeholders and fully articulated with the national socio-economic development plan. In this regard, the idea of presidential fora put forward by the late Professor Thomas Odhiambo is worthy of consideration.

Institutions responsible for policy-making and development are weak in many African countries, particularly the smaller ones. Countries such as Angola, Chad, the Democratic Republic of Congo, Djibouti, Eritrea, Gabon, Gambia, Mauritania, Liberia, Sierra Leone and Swaziland, among others, could benefit from programmes that build institutional capacity in S&T policy formulation and implementation. STI policy and operational institutions created in the 1960s and 1970s with the aid of the United Nations Economic Commission for Africa (UNECA) need to be reviewed in light of the new challenges posed by globalization and technological innovation.

Current macro-economic policies and programmes also tend to allocate too many resources to large public enterprises concentrated mostly in urban areas, thereby discriminating against small and medium-sized enterprises. Even where policies designed to realize development goals are in place, experience shows that most African governments find it difficult to implement them for reasons that include lack of finance, lack of transparency, inadequate human resources and an undue politicization of issues. In a vicious circle, low investment in education and R&D in both the public and private sectors has led to a penury of qualified personnel, eroding the quality of science and engineering education at all levels. Worse still, the infrastructure for R&D has been neglected and is decaying. Universities and research institutions are thus hard-pressed to acquire state-of-the-art facilities to conduct basic research, forcing them to depend on foreign institutions.

To strengthen Africa's technological regime will require strong political leadership and a better integration of cross-cutting STI policies with overall development policies, including economic, financial, budgetary, fiscal, labour, agricultural, industrial and micro-enterprise development. This has far-reaching consequences for policy-making, as it implies that S&T should move from the periphery to the centre of the development policy processes and pervade all relevant policy areas, impacting on the development and utilization of S&T. Success in this realignment and 'recentering' requires strong political commitment vis-à-vis S&T and the full engagement of the S&T community. This recentering may be facilitated by the setting-up or strengthening of parliamentary committees on S&T. Such committees are already in existence in a number of African countries, including Kenya, Nigeria, South Africa and Uganda. The African Ministerial Conference on Science and Technology (AMCOST) has also set up its own parliamentary committee. Recentering S&T may also be facilitated by the appointment of high-profile, credible and respected S&T advisors to the president, as in Nigeria, for example (*see page* 309). The creation of interdepartmental S&T fora comprising focal points from various ministries and government institutions dealing with S&T issues may also be useful in 'demonopolizing' S&T responsibilities and in bringing S&T issues to the heart of the development policy process.

Ensuring reliable data and indicators

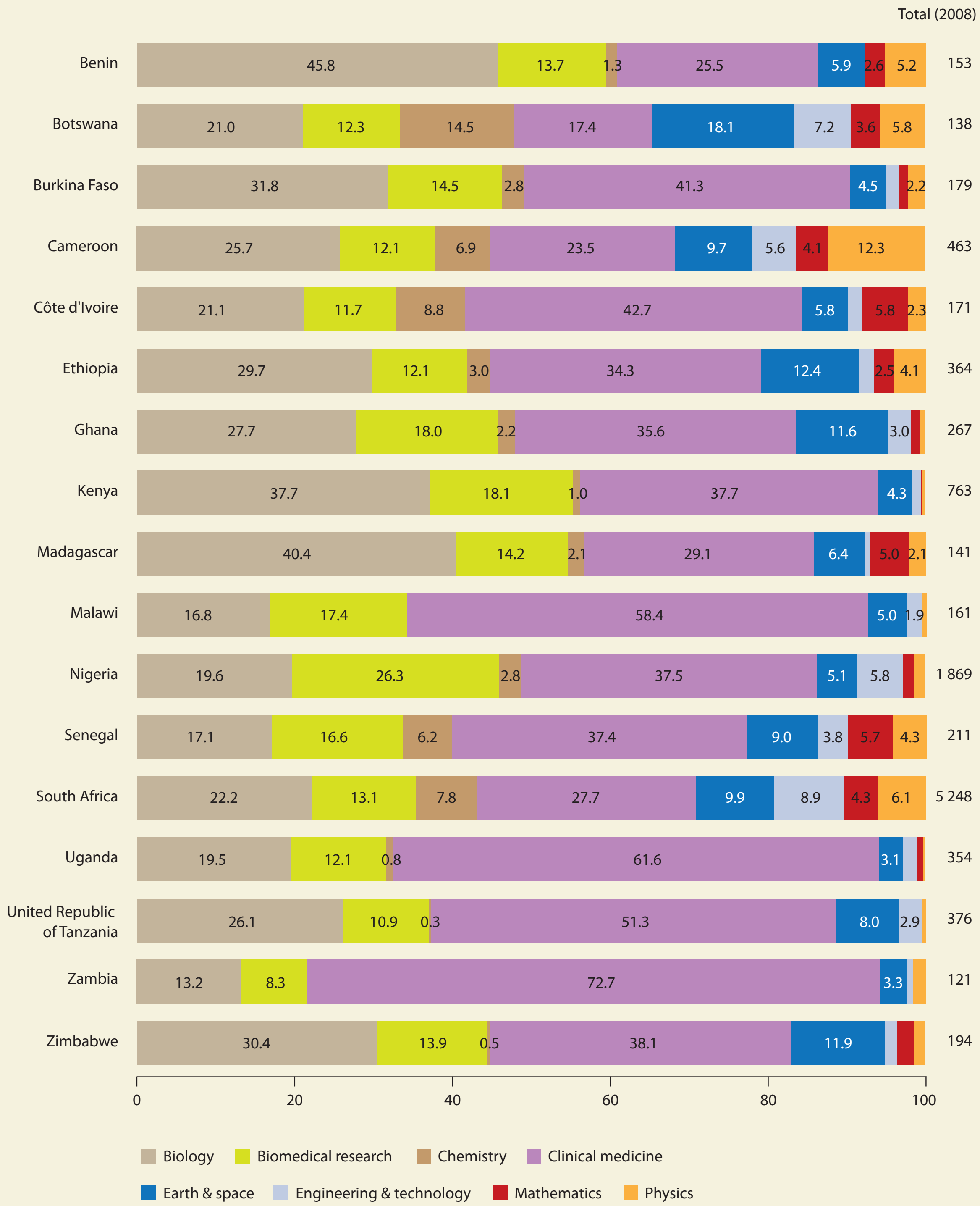
Also hampering the elaboration of effective STI policies in Africa is the lack of up-to-date, reliable data and indicators on the current status of S&T, mostly due to the absence of trained experts and organizational difficulties. African institutions, ministries and organizations have not yet adopted a culture of record-keeping and data banks. This is a serious issue of concern which our governments and institutions need to address urgently as a key deliverable in the process of realizing their development goals.
One of the objectives of *Africa's Science and Technology Consolidated Plan of Action* is to remedy this situation (*see page* 297).

African economies also need to adopt new indicators to evaluate skills and competencies acquired in traditional sectors and assess their ability to promote linkages between actors in the adoption and absorption of new technologies.

Grouping STI programmes into a single national system

To ensure the successful implementation of STI programmes and activities in different countries of Africa, there is a need for proper co-ordination and integration of programmes and activities in the innovation system into all national socio-economic planning issues. Presently, co-ordination of STI programmes and activities seems to fall within the purview of the sole ministries of science and technology. While it is proposed that these ministries continue to serve as the main scientific advisory

Figure 3: Publications in sub-Saharan Africa by major field of science, 2008 (%)
For those countries which produced more than 100 publications in 2008



Source: Thomson Reuters (Scientific) Inc. Web of Science, (Science Citation Index Expanded), compiled for UNESCO by the Canadian Observatoire des sciences et des technologies, May 2010

Table 4: Patents awarded to African inventors by USPTO, 2005–2009

	2005				2006				2007				2008				2009				Total			
	Utility	Design	Plant	Reissue	Utility	Design	Plant	Reissue	Utility	Design	Plant	Reissue	Utility	Design	Plant	Reissue	Utility	Design	Plant	Reissue	Utility	Design	Plant	Reissue
Sub-Saharan Africa:																								
Benin									1												1			
Burkina Faso																	1				1			
Cameroon									1								1				2			
Chad													1								1			
Ethiopia									1												1			
Gabon									1												1			
Ghana									1												1			
Kenya	9	1			3				1				4				7				24	1		
Mauritius														1								1		
Namibia									1												1			
Seychelles					2									1							3			
South Africa	87	16	5		109	13	5		82	30	3		91	32	1		93	39	6	1	462	130	20	1
Zimbabwe	1				1				1								4				7			
Arab states in Africa:																								
Algeria					1																1			
Egypt	7				4				12				2				3				28			
Morocco	1				3				1				4				1	2			10	2		
Tunisia	1				2								2								5			

Note: The country of origin is determined by the residence of the first-named inventor. Utility patents are for new inventions.

Source: data from United States Patents and Trademark Office

committee for successful implementation of STI policy, there is an urgent need to begin weaving all STI programmes and activities into a single national system. This will bring together existing capabilities and help to avoid wastage of resources and duplication of effort, while encouraging interaction and linkages.

Improving infrastructure and capacity to develop innovative solutions

Africa's sustainable development will depend more and more on its capacity to find innovative solutions to its particular problems, including in the area of food production, and its capacity to produce and market competitive, innovative products and services. In this regard, policies need to be put in place to develop national innovation systems by filling existing gaps and strengthening interaction between critical elements of the system. Entrepreneurial capacities should be reinforced, inter-firm partnerships should be encouraged and linkages between the public and private sectors strengthened. This new technological regime calls for special attention to be paid to such key areas as agriculture, industry, energy and water. In these areas, the generation of new knowledge, the development of new technologies and the promotion of innovation are crucial to achieving food security, diversifying manufactured products, reducing poverty and protecting the environment and the natural resources base.

In this regard, UNECA and UNESCO both support the commitment by the New Partnership for Africa's Development (NEPAD) to create sub-regional centres and networks of excellence for higher education and research, with a view to promoting S&T in niche areas of high priority for sustainable development.

Nor should African countries underestimate the potential of South–South co-operation for developing these niche areas. Brazil, China, Egypt, India and Mexico have all developed world-class research institutions in recent years and are increasingly involved in South–South co-operation. One recent example concerns the development of biofuels in Sudan in co-operation with Brazil and Egypt (Box 1).

Box 1: South–South co-operation on biofuels: the case of Sudan

In June 2009, Sudan inaugurated its first biofuel plant. In the next two years, the plant is expected to produce 200 million litres of ethanol from sugarcane. The plant was built in co-operation with the Brazilian company Dedini, drawing on the long-standing experience of Brazil in the area of biofuels.

Another major project for the development of biofuels in Sudan is being carried out in collaboration with Egypt. At a cost of US$ 150 million, it is producing second-generation biofuels from non-edible crops, including agricultural waste such as rice straw, crop stalks and leaves. This is proving to be a good strategy, as it has a positive impact on both the environment and food security. By diverting agricultural waste towards the production of ethanol, the waste does not need to be burned, thereby reducing pollution. The use of agricultural waste also avoids sacrificing food supplies to energy production.

Source: authors

Strengthening the relationship between academia, government and industry

In most African countries, there is very little interaction between universities and industry, and very few universities in the region conduct research and training programmes pertinent to industrial needs. This shortcoming is coupled with a mismatch between R&D activities and national strategies and goals for industrial development. As a result, local industries lack access to research findings from public research institutions, particularly small and medium-sized enterprises. It is common knowledge that the biggest obstacle to the development of technological enterprises in sub-Saharan Africa is not the lack of resources but their isolation. Current S&T policies emphasize R&D input, forgetting that innovation does not spring from an aggregation of different forms of technological infrastructure but rather from the quality of the organization and the circulation of available resources.

The Africa Commission Report (2009) concluded that African universities were insufficiently geared to meeting the needs of industry. The report maintained that graduates often struggled to find employment, while many small businesses lacked staff with the education and skills needed to drive innovation. Essentially, the relationship between the demands of the private sector and what universities teach is too weak. The isolation of researchers and R&D institutions is cited by many African scholars as being one reason for the weak performance in building technological capabilities. The lack of linkages between the needs of enterprises, communities and R&D institutions is a real problem for the development of innovation. Despite the concentration of R&D in some fields like agriculture and medicine, community services remain a peripheral appendage to the university system in most African countries.

To bridge the gap between scientists, technologists and industrialists, African governments should encourage and support the establishment of interdisciplinary research and training centres within universities in those areas of S&T most relevant to the development of local industry. In particular, greater importance should be given to the development of strong linkages between engineering institutions, small-scale industries and the agriculture sector with the principal aim of producing simple, modern tools and equipment required by farmers to increase their productivity and efficiency (Box 2).

Small research and training units should also be formed and strengthened in areas of cutting-edge technologies relevant to industry, such as lasers, fibre optics, composite materials, pharmaceuticals, fine chemicals and biotechnology. These centres should operate as a joint venture between universities and industry and should be run by a common board involving high-level indigenous industrialists and academics. Furthermore, to strengthen the linkages between research institutions and industry, qualified staff and postgraduate students in these institutions should be encouraged to undertake specific development projects in industry.

Protecting Africa's intellectual and biodiversity capital

Harnessing S&T for sustainable development requires the protection of intellectual capital and access to technology, which are governed by a number of complex international agreements. These include the Convention on Biodiversity (1992), which, in Article 8, recognizes explicitly the importance of traditional knowledge and creates a framework for ensuring that local people share in the benefits arising from the appropriation and use of such knowledge and the biological resources of their environment. Plant breeder's rights and farmer's rights are equally recognized in the Convention. These resources are of great importance for Africa's sustainable development and they must receive adequate attention. Plant varieties, which are protected by the International Convention for the Protection of New Varieties of Plants (UPOV) and the International Undertaking on Plant Genetic Resources (IUPGR), constitute unique instruments through which Africa can strengthen its capacity in S&T (UNECA, 2005). In this regard, the decision by the focal points of Ministers of the African Agency of Biotechnology to dissolve this institution in April 2008 is most unfortunate.

The Model Law adopted by the African Union in 2000 for the Protection of the Rights of Local Communities, Farmers and Breeders and for the Regulation of Access to Biological Resources[2] established a framework for national laws to regulate access to genetic resources. Although the Model Law has been severely criticized for putting African countries on the defensive and for being too complex and cumbersome for countries at an early stage of development, it can be a useful resource for repositioning Africa in STI development and for protecting the indigenous knowledge, technological know-how and biological resources of African countries. This is an important policy area for the African Union to explore, in collaboration with other partners, such as the World Intellectual Property Organization, African Regional Intellectual Property Organization[3] and the *Organisation africaine de la propriété intellectuelle.*[4]

Of note is that the African heads of state formally adopted the Pan-African Intellectual Property Organization in January 2007 at the African Union summit in Addis Ababa, Ethiopia. It will serve as a co-ordinating body rather than as an office for the registration of intellectual property. At the time of writing, the Pan-African Intellectual Property Organization had not yet materialised, although it was on the agenda of the AMCOST meeting in Cairo in March 2010.

An urgent need for ICT development

One factor contributing to the isolation of African scientists is the communication barrier caused by the lack of infrastructure in telecommunications and the limited access to ICTs. ICTs are now also one of the most important assets for enterprises wishing to compete in world markets and, therefore, one of the main drivers of inclusion in the 'global village'. ICTs provide the main medium for the transfer of information and knowledge. Most technologically advanced countries are making massive investments in these technologies. Public infrastructure can no longer be conceived only in the traditional terms of roads, railways, power, ports and airports. The availability of fast, affordable and reliable connections to the Internet and development of mobile telephones are some of the new technological infrastructure that African countries need to put in place in order to become competitive and remain so. Investment in these technologies is crucial to give companies a global reach and enable them to conduct efficient business transactions.

2. See: www.grain.org/brl_files/oau-model-law-en.pdf

3. ARIPO is an intergovernmental organization founded in 1976 which counts 16 member states from English-speaking sub-Saharan countries.

4. OAPI has grouped 16 French-, Portuguese and Spanish-speaking sub-Saharan countries since 1977.

Box 2: Songhai: an agricultural centre of excellence

Songhai is an experimental farm founded in Porto Novo in Benin in 1985 by Dominican father Dr Godfrey Nzamujo. The aim of this NGO is to develop sustainable, integrated agriculture to raise the population's standard of living. In addition to practicing animal husbandry, crop-growing and aquaculture, the farm conducts agricultural research and experiments with renewable energies. Songhai also dispenses training and provides the local population with services to make their lives easier. For instance, it manufactures and maintains agricultural machines that are well adapted to local conditions and less costly than imported models. The farm sells its own produce on site to earn revenue and provide the local population with fresh produce.

After Nigerian officials visited the experimental farm, a centre modelled on Songhai was created in Amukpè in the Delta State of Nigeria in 2002.

In 2008, Songhai was declared a regional centre of excellence by the United Nations and, the following year, by the Economic Community of West African States. With the support of the United Nations, a Regional Project for the Development of Agricultural Entrepreneurship was launched in Africa in 2008.

Source: www.songhai.org

Box 3: Science, ICTs and space, an EU–Africa partnership

The European Union–African Union summit in Lisbon in December 2007 launched an EU–Africa partnership in eight different areas. One of these partnerships concerns Science, the Information Society and Space. A number of lighthouse projects are being implemented within this partnership in line with priorities identified by *Africa's Science and Technology Consolidated Plan of Action* (*see page* 297) and by the *African Regional Action Plan for the Knowledge Economy*, adopted at the World Summit on the Information Society in Tunisia in 2005.

Under the science component of the partnership, African research grants are being provided worth €15 million and a Water and Food Security and Better Health in Africa project has been earmarked for €63 million in funding. The African Union Commission has also contributed €1 million for the first year of the Popularization of Science and Technology and Promotion of Public Participation project. The first African Women Scientists award was held on Africa Day on 9 September 2009.

Concerning ICTs, the AfricaConnect project will seek to integrate the African research community at both regional and international levels by improving bandwidth. Meanwhile, the African Internet Exchange System (AXIS) will support the growth of a continental African Internet infrastructure. A third project concerns the African Virtual Campus. With funding from the European Commission, AfDB, Spain and Japan, UNESCO is establishing virtual campuses at universities in 15 West African countries. A 10 000 km-long submarine fibre-optic multipoint cable system is also under construction. Last but not least, a project led by the World Health Organization is lending support to telemedicine in Africa.

As concerns the exploration of inner space, Global Monitoring for Environment and Security (GMES) is a European initiative for the establishment of a European capacity for Earth observation. The GMES and Africa project was launched by the *Maputo Declaration,* signed on 15 October 2006. The initiative aims to develop infrastructure for a more coherent exploitation of Earth observation data, technologies and services in support of the environmental policies put in place in Africa. An *Action Plan* is due to be submitted to the next European–Union–African Union Summit in 2010. It is being prepared by the GMES and Africa Coordination Group, composed of seven members from Europe and seven from Africa. Among the proposed projects, one known as Kopernicus-Africa will focus on the use of remote-sensing satellites for African Global Monitoring for Environmental and Security. A second project will build capacity within the African Union Commission to use the geospatial sciences for a range of applications that include natural resources management, food security and crisis management.

Source: www.africa-eu-partnership.org/documents/documents_en.htm

GMES is an EU Joint Technology Initiative, see page 163

A number of countries have adopted ICT policies in recent years, including Nigeria, South Africa and Uganda. However, Internet connectivity remains extremely low (Figure 4). In Nigeria, just 6.8% of the population had access to Internet in 2007. Nevertheless, this represented a leap from 0.3% in 2002. Progress has been slower in South Africa, where connectivity grew from 6.7% to 8.2% over the same period. Progress has also been slow in Uganda, where just 0.4% of the population had access in 2002 and 2.5% four years later.

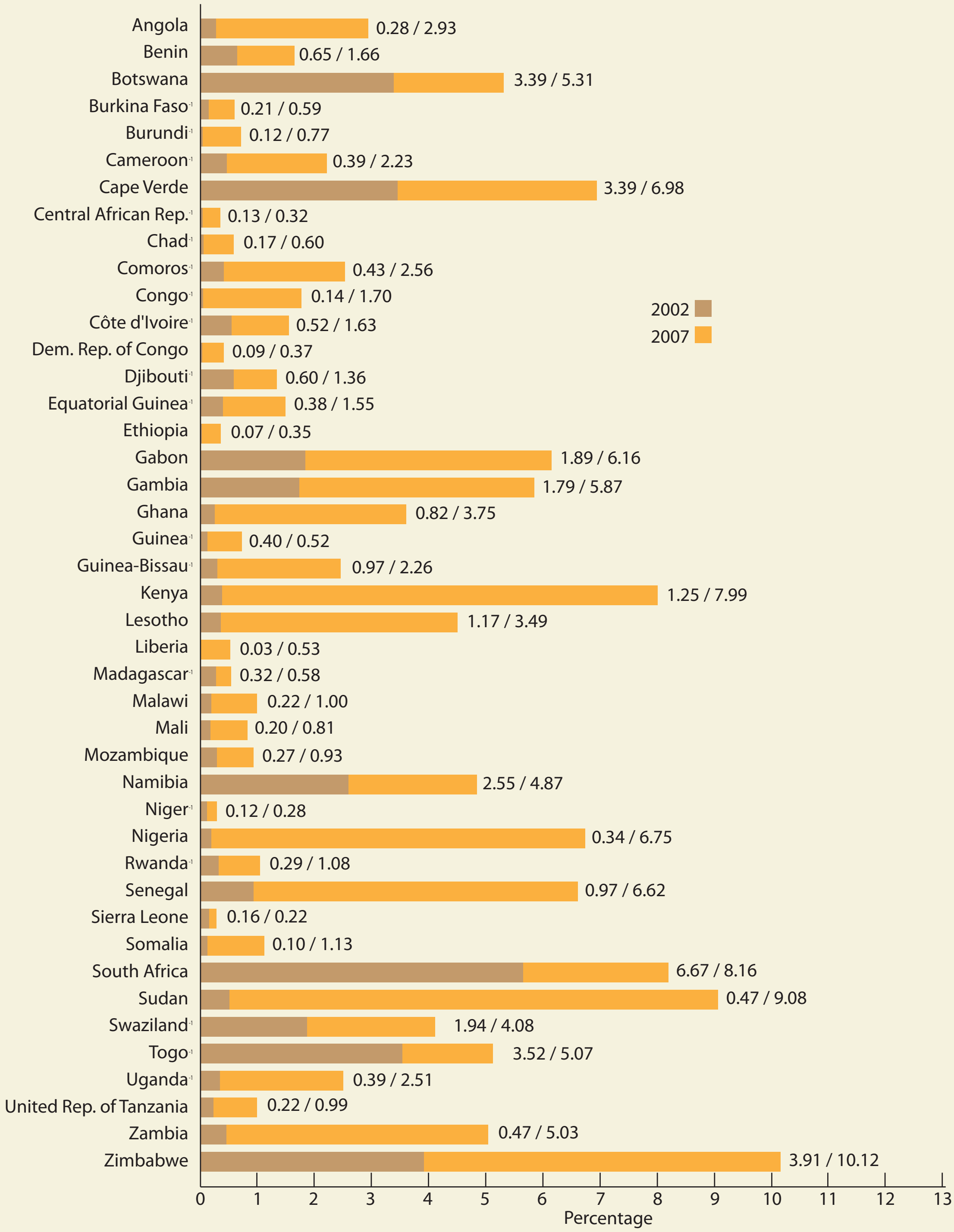
The launch of the Nigerian satellite NigComSat-1 in 2007 should offer Africa better telecommunications in future. There is also a host of international initiatives to help Africa develop its information infrastructure. Among these, perhaps one of the most ambitious is the EU-Africa Partnership (Box 3).

The brain drain syndrome

The continent's growing sustainability problem will never be solved by outside experts, despite their good intentions. How then can sub-Saharan Africa nurture and sustain the home-grown scientific talents it needs for problem-solving scientific research? Indubitably, the most worrying phenomenon for Africa is brain drain, both internal and external.

A statement on *Brain Drain in Africa* submitted by the Network of African Science Academies (Box 4) to the G8+5 Summit in July 2009 indicates that at least one-third of African scientists and technologists live and work in developed countries. Key factors encouraging brain drain include the paltry funding of education, poor incentives for research and innovation, political and

Figure 4: Internet access per 100 population in sub-Saharan Africa, 2002 and 2007
Selected countries



-*n*: data refer to *n* years before reference year

Source: United Nations Statistical Division, Millennium Development Goals Indicators

Sub-Saharan Africa

religious crises, a lack of adequate regulations to protect intellectual property and, most importantly, a poor reward system for researchers, teachers and technologists working in research institutions and universities. These are the factors that have pushed native scientists to migrate to the comfortable zones of the developed world. The overriding issue should not be how to lure African expatriates back home but rather how to transform brain drain into brain gain by improving conditions at home.

Uganda figures in the top ten among developing countries for the rate of loss of university-educated citizens: 36% (ATPS, 2007). Medical doctors and researchers are leading this exodus. Uganda's national report on the economy for financial year 2008, released in July 2009, shows that remittances from Ugandans working overseas jumped from US$ 546 million in 2007/2008 to US$ 748 million a year later. Poor pay – even by East African standards – is inciting many Ugandan professionals to leave the country in search of greener pastures. Uganda's health and education sectors have been badly hit as a result. In presenting the national budget for 2010/2011 in June 2010, President Yoweri Kaguta Museveni announced a 30% hike in scientists' salaries, with a budget of 18 billion Ugandan shillings (US$ 8 million) [Nordling 2010*c*].

Uganda also faces internal brain drain. A tracer study carried out in Uganda by UNCHE (2006) targeted 1 000 graduates fresh out of university to determine how long it would take them to find gainful employment. The public sector took on only 32% of graduates, the great majority (53%) finding employment in the private sector. Among degree-holders, graduates in veterinary medicine and social sciences waited longest – more than

Box 4: The Network of African Science Academies

The Network of African Science Academies was established in December 2001. It strives to accelerate the pace at which its member academies implement best practices, in order to equip them to advise their governments on STI policy reform. Currently, the consortium has 16 national members, plus the African Academy of Sciences.

Founded in Nairobi in 1986, the African Academy of Sciences has a dual mission to honour African achievers in S&T and mobilize the African S&T community to promote science-led development in Africa. Fellows of the African Academy of Science work together in a transdisciplinary manner to tackle many of Africa's developmental problems. Through the African Academy of Sciences, they conduct R&D and disseminate the results, organize training and undertake public advocacy.

Table: The 16 national African science academies

Year of creation	
2010	Ethiopian Academy of Sciences
2009	Academy of Science of Mozambique
2008	Sudanese National Academy of Science
2007	Mauritius Academy of Science and Technology
2006	Hassan II Academy of Science and Technology, Morocco
2006	Tanzania Academy of Sciences
2005	Zimbabwe Academy of Sciences
2001	Academy of Science of South Africa
2000	Uganda National Academy of Sciences
1999	National Academy of Science and Technology of Senegal
1990	Cameroon Academy of Sciences
1983	Kenya National Academy of Sciences
1977	Nigerian Academy of Sciences
1959	Ghana Academy of Arts and Sciences
1948	Academy of Scientific Research and Technology, Egypt
1902	National Academy of Arts, Letters and Sciences, Madagascar

Source: authors

For details: www.nasaconline.org

nine months – for a job proposal. The labour market was observed to have an inadequate supply of medical doctors, engineers, information technology specialists and science teachers but was saturated with arts graduates, social workers and those with backgrounds in finance and accounting. An analysis of jobs advertised in the most widely circulated newspapers in Uganda for the period 2002–2004 found a low percentage of science-based opportunities, the majority of jobs advertised being in the service sector.

Uganda is not the only country to have taken energetic steps recently to improve its reward system. In early 2009, the Government of Cameroon used the writing-off of part of its debt to create a permanent fund of 4.2 billion Central African francs (CFA, almost US$ 9.5 million) to boost the salaries of university lecturers and researchers. Senior lecturers saw their monthly salary triple overnight to US$1 600. Within a year, the number of academics receiving the supplementary allowance had swollen from 1 800 to more than 2 500, suggesting that the scheme was already luring scientists back home. One spin-off of the scheme has been a rise in the number of scientific articles produced by state universities (Mvondo, 2010).

In November 2007, Zambia announced the reintroduction of allowances for academic staff at state universities to make salaries more competitive with those of researchers in other African countries. Other incentives to curb brain drain presented by the Ministry of Education include higher grants for academic research, home loans for academic staff and a first in Zambia: funding for the journals published by the University of Zambia and Copperbelt University (Ngandwe, 2007). In 2008, Zambia received a US$ 30 million loan from the African Development Bank (AfDB) to support teaching and research at the University of Zambia and to provide postgraduate fellowships to some 300 students majoring in science and engineering. At the African Union Summit in 2007, President Levy Patrick Mwanawasa proclaimed that building capacity in 'science and technology is the only means to develop the country.'

Another example is Botswana. One of the strongest economies in Africa, Botswana was spending millions of dollars each year to support approximately 7 000 Botswanans studying at universities abroad. In order to staunch the haemorrhage of students leaving the country, Parliament approved plans for the Botswana International University of Science and Technology in January 2006. Construction of the university began in April 2009 on a 250-hectare site in the city of Palapye, 270 km north of Gaborone. A public–private partnership, the university will focus on engineering, mining, geology and basic sciences. Due to open in 2011, it will initially house laboratories and residences for 250 students. A research park is planned for a later stage (Makoni and Scott, 2009).

Borrowing a model from football

If inadequate ICT infrastructure and poor scientific networks and exchanges are a barrier to the circulation of expertise within the continent – not to mention the language barrier between French-, English- and Portuguese-speaking Africans – African scientists and engineers also face a physical barrier, the sheer difficulty in travelling freely around the continent. The question of African countries easing immigration regulations and procedures in order to facilitate the mobility of international experts, and African expatriates in particular, has figured repeatedly on the agenda of African Union summits without ever being resolved.

A workshop organized by the African Technology Policy Studies Network in Nairobi, Kenya, in March 2010 came up with a novel idea for turning brain drain into temporary brain gain. It suggested that African governments should borrow the model of the International Federation of Association Football (FIFA) for African researchers and scientists working abroad. The FIFA model entitles foreign football clubs to release their players to play for their home countries during major events like the African Nations Cup. The 'fifarization' of African scientists and researchers working abroad would entitle them by law to return to their home countries if the occasion presented itself and to request permission to participate occasionally in charting the way forward for their country's development in STI. Once their mission was accomplished, they would return to their home base. In this way, a team of medical professionals working in the USA and Europe, for instance, could travel to their home country in Africa once in a while to share their knowledge and skills. This idea has been enthusiastically received in various STI fora in Africa.

A similar approach to tackling brain drain in Africa has been proposed by the Network of African Science Academies. In their statement submitted to the G8+5 Summit in July 2009, the academies recognize the opportunities offered by the African diaspora and call for new policies to harness their knowledge and expertise to driving scientific and economic progress in Africa, as Nigeria has been doing (*see page* 311). This approach turns the phenomenon long perceived as a one-way flow out of Africa into a two-way interaction through joint projects between Africa's emigrant researchers and home-based scientific communities. Developed countries are asked to contribute by helping to improve Africa's S&T infrastructure, fostering North–South scientific co-operation and by promoting policies that allow scientists greater mobility across borders.

The statement proposes five measures for tackling brain drain:

- Investing in the rebuilding of universities and research centres in Africa to enable African scientists to engage in world-class research without having to emigrate;
- Extending financial support to young African scientists to pursue postgraduate and postdoctoral training at universities in Africa and in developing countries elsewhere;
- Launching regional and international centres of excellence in Africa in areas of study of critical importance to Africa's development, especially with regard to the Millennium Goals. These centres should promote international collaboration in solving global problems relevant to Africa;
- Broadening efforts to encourage Africa's diaspora to participate in initiatives to address critical science-based issues on the continent and to engage African scientists in joint projects. To this end, policies may be devised to encourage short-term visits and collaborative projects involving Africa's scientific diaspora and scientists who have remained in their home countries; expanding North–South scientific exchange; and developing a database of highly qualified Africans in the diaspora.
- Honouring the commitment made by G8+5 countries at the 2005 G8 Summit, based on the recommendations of the Commission for Africa's publication, *Our Common Interest*, which called on its members to provide US$ 5 billion to help rebuild universities and US$ 3 billion to help establish centres of scientific excellence in Africa.

Socializing science

Last but not least, there is a need to domesticate S&T in Africa. All key stakeholders must be involved through national dialogue in the policy formulation and implementation process, so as to transcend policies that tend to be too narrowly focused on a handful of isolated, ill-equipped and underpaid researchers and academicians. This will contribute to moving away from elitist policies and to defining and strengthening the respective role of public institutions, international partners, universities, NGOs, women's organizations, civil society and the private sector (UNECA, 2005). It will also ensure that policies are tailored primarily to meeting the specific needs of end-users and clients. In this regard, the fight against illiteracy should aim to give girls and boys the same chances of being empowered through S&T.

Various means should be employed to promote science popularization and to ensure that information on S&T reaches all the relevant stakeholders, via such media as science centres and museums, radio programmes for farmers, media-training for scientists, public libraries with a focus on S&T, booklets and other printed materials, school science days, inter-school science competitions, public lectures, science fairs, academies and associations, adult education, demonstration centres, national merit awards in science, science quizzes, science newsletters, exhibitions, science clubs, science festivals, etc.

Kenya's National Council for Science and Technology is working with the African Technology Policy Studies Network on a project entitled Science, Ethics and Technological Responsibility in Developing and Emerging Countries (SETDEV) in the context of the European Union's Seventh Framework Programme for Research and Technological Development. The broad objective of this project is to help an emerging economy (India) and a developing country (Kenya) to elaborate their own perspective on the socialization of research. The National Council for Science and Technology is involved in the development of a *Handbook on the Socialization of Science and Technological Research in Kenya*, the findings of which may feed into the implementation plans for the country's *Kenya Vision 2030* (*see page* 306).

A REGIONAL STRATEGY FOR DEVELOPING STI IN AFRICA

Africa's Science and Technology Consolidated Plan of Action

We have seen from the previous section that wide disparities remain in the level of investment in R&D and scientific productivity between South Africa and the rest of sub-Saharan Africa, with only a handful of countries producing a meaningful volume of publications. However, there are also wide disparities in economic terms, with a large share of the African population being excluded from STI dividends. Inequalities in income distribution have destroyed internal demand for manufactured goods, in turn inhibiting the learning process of enterprises. These factors have also had huge repercussions for the brain drain of scientists and other qualified personnel.

One of the most ambitious strategies in recent years for strengthening STI in Africa has been the adoption of *Africa's Science and Technology Consolidated Plan of Action* for 2008–2013 (CPA). The fact that countries are at different stages of developing a national STI policy makes it all the more difficult to establish a common policy for Africa. It has been suggested in many fora that one way to give such a process a kick is to attempt a regional STI policy that will eventually key into the continent-wide action plan. The CPA is a framework for channelling investment into S&T in Africa. It was adopted in 2005 by the continent's science ministers with buy-in from development aid agencies and is overseen by AMCOST. Apart from providing a list of projects, the CPA outlines flagship R&D programmes in four areas: biosciences; water; materials science and manufacturing; and ICTs. Italso co-ordinates science aid and has put a stop to the tradition of donors cherry-picking projects to suit their own agenda (Nordling, 2010*a*).

In January 2007, heads of state and government invited UNESCO to work closely with the African Union and NEPAD secretariat to implement the CPA, in the *Declaration* adopted at the African Union summit in Addis Ababa. Later the same year, UNESCO adopted its own African Science, Technology and Innovation Policy Initiative for 2008–2013 to accompany this process. This initiative involves an assessment of the status of S&T policy formulation in Africa, the provision of technical advice and support for national STI policy reviews, the development of common African STI indicators, the creation of an African STI observatory and the launch of a pilot science park in Africa.

Five years after the CPA's adoption, several donor agencies are disappointed with progress, with some even going so far as to declare it dead (Nordling, 2010*a*). Development experts also say that fewer national-level policy-makers support the CPA than when the plan was first agreed upon. It has been noted that the CPA's proposed mechanism for channelling donor funding, the African Science and Innovation Facility, has not materialized. That notwithstanding, 'the CPA is still the framework for S&T activities on the continent,' observes Aggrey Ambali, advisor on S&T within NEPAD (Nordling, 2010*a*). Considerable progress has effectively been made on several individual programmes within the CPA, particularly in biosciences and water research. In addition, the CPA will have met another of its goals when one of its key elements, the African Science and Technology Indicators Initiative (ASTII), delivers its first set of pan-African R&D statistics in June 2010. Having taken over the reins of AMCOST in March 2010, Egypt should now champion a reintroduction of the original expectations in the CPA.

It has been suggested that three things are needed to revive the CPA: *firstly,* its implementation needs to refocus on results and co-ordination; *secondly,* it needs the African Union and NEPAD to show leadership; and *thirdly,* it needs a political and financial buy-in from African countries.

Another impediment to regional integration is the lack of dialogue, collaboration, co-ordination and harmonization among various initiatives designed to promote S&T across the continent. These initiatives include the African Science Academy Development Initiative (Box 5), UNESCO's African Science, Technology and Innovation Policy Initiative, the Knowledge Management Africa project (Box 6) and NEPAD's Science and Technology programme.

Also hampering regional co-operation and integration is the prevalence of micro-nationalism, which causes rivalry. Each country is keen to house every institution within its own borders rather than creating centres of excellence on the basis of the comparative advantages of each. There are existing international centres in Africa on which new centres could be modelled. The International Centre of

Box 5: The African Science Academy Development Initiative

The African Science Academy Development Initiative (ASADI) is a 10-year endeavour to empower African science academies to act as efficient partners in the policy-development process. Launched in 2004 with funding from the Bill and Melinda Gates Foundation, the initiative is managed by the US National Academies of Science, through the Board on African Science Academy Development at the Institute of Medicine in Washington DC.

ASADI works with African academies of science to develop and implement mechanisms for providing independent, apolitical and evidence-based advice to their national governments. ASADI supports capacity-building at the science academies of Nigeria, South Africa and Uganda. Partnering with these academies via a grants system helps to develop infrastructure, personnel, the relationship between each academy and its national government, as well as rigorous procedures for the provision of policy advice. The grant also provides some support to the academies of Cameroon, Ghana, Kenya, Senegal and to the regional African Academy of Sciences, in particular for strategic planning. It is expected that the initiative will be extended to academies in other African countries.

ASADI has already promoted strong collaboration among African academies, research institutes, universities and other S&T institutions. It is also fostering co-operation between the African academies and the Royal Society of Canada, Royal Society of the United Kingdom and the Royal Netherlands Academy of Science.

In addition to capacity-building, the initiative strives to inform African government policy-making and public discourse on issues related to the amelioration of human health and all development sectors. In this way, it aims to foster a deeper appreciation on the part of African governments of the benefits of decision-making based on evidence and analysis.

Every year, the ASADI Board organizes an international conference on a specific issue of great importance to Africa. This event brings together US and African representatives of science academies, policy-makers and experts on the specific topic under discussion. These meetings place special emphasis on what academies in Africa can do to make an impact on policy pertinent to the relevant issue. In previous years, the conferences have focused on food security, water, health and on achieving the Millennium Development Goals.

Source: authors

Box 6: Knowledge Management Africa

Knowledge Management Africa (KMA) is an African initiative launched by the Development Bank of Southern Africa in February 2005. On the premise that knowledge should be the engine that drives appropriate development solutions for Africa, KMA sets out to improve governance and service delivery in Africa through the creation, sharing, dissemination and utilization of knowledge.

KMA facilitates research by mobilizing resources and by linking basic and applied research on the continent and beyond. It encourages co-operation between universities, research institutes and other specialized institutions, in order to create a pool of African expertise on specific challenges for development.

Every two years, KMA hosts an international conference to create an environment conducive to the creation and sharing of African knowledge among policy-makers, sector professionals, researchers, knowledge management experts, government and civil society leaders, officials from international institutions, business leaders and so on.

The themes of the first three conferences were: Knowledge to Address Africa's Development challenges (Johannesburg, 2005); Knowledge to Remobilize Africa (Nairobi, 2007); and Knowledge to Reposition Africa in the Global Economy (Dakar, 2009). At the latter, it was decided to create the Knowledge Management Africa Foundation to ensure the sustainability and consolidation of the initiative.

The KMA secretariat is located in Midran, South Africa, but there are plans to conduct programmes through sub-regional chapters.

Source: authors

For details: www.kmafrica.com

Insect Physiology and Ecology and the International Institute for Tropical Agriculture, for example, both enjoy stable funding and outstanding scientific leadership and have, over the years, earned international recognition.[5]

African STI Indicators Initiative

In September 2005, AMCOST established an intergovernmental committee comprised of relevant national authorities to develop, adopt and use common indicators to survey Africa's development in S&T. This system of indicators will constitute the mainstay for production of the *African Innovation Outlook*, which will report on developments in STI at the national, regional and continental levels. The indicators can also be used to monitor global technological trends, conduct foresight exercises and determine specific areas for investment. An example is the target of a GERD/GDP ratio of 1% for African countries.

The intergovernmental committee was given the following mandate:

- Consider and agree upon common definitions, indicators and methods for conducting STI surveys. It will also determine the means of integrating STI indicators into the African Peer Review Mechanism[6];
- Identify and designate competent national authorities for the gathering and analysis of STI indicators;
- Design and adopt a work plan for preparing the *African Innovation Outlook*;
- Promote the sharing of experiences and information on national STI surveys;
- Develop, publish and widely disseminate an *African STI Indicators Manual*;
- Consider and agree on the means of establishing and running an STI observatory;
- Participate in international committees and/or processes on STI indicators. This will involve establishing formal ties with the OECD and other regional platforms and programmes for STI indicators;
- Review national surveys and propose common policies for promoting STI.

The committee has been assisted by an expert working group established by NEPAD. In 2010, this working group was preparing a document proposing indicators and guidelines for the conduct of surveys. This document should form the basis for initiating an intergovernmental process to enable African countries to agree upon definitions and methods and, where none exist, to develop these.

Since 2008, sub-regional training seminars and workshops on STI policy-relevant indicators have been co-organized by UNESCO and the African Union for English- and French-speaking Africa. The organizers are also advising on the design of questionnaires, manuals and documentation for national collection of STI data.

Towards an African STI observatory

For indicators to be used effectively, they must be embedded in the policy process. This requires interaction between key stakeholders, including policy-makers and statisticians. This process of interaction allows each group to do what it does best, policy analysis and development on the one hand, survey and questionnaire development on the other. These are quite different skills but they must be brought together if the resources available for indicator production are to be used effectively and efficiently. In both cases, there may be a need for capacity-building, which could be addressed by an African Observatory of Science, Technology and Innovation. In 2010, UNESCO and the African Union were engaged in discussions on the road map for transforming the African STI Initiative into a permanent observatory in Equatorial Guinea, which had volunteered to host the observatory and pledged US$ 3.6 million (Nordling, 2010*b*). As part of the process, UNESCO was preparing a feasibility study for the African Union in 2010. However, South Africa is also a contender for the observatory. In the time that it has been hosting the African STI Indicators Initiative in Midrand, it has gathered R&D and innovation data from 19 African countries. The interim observatory is due to deliver its first set of data in June 2010.

5. In June 2010, the International Centre of Insect Physiology and Ecology developed a collar for cattle which repels tsetse flies. The collar exudes the synthetic equivalent of the odour of animals that tsetse flies avoid. The flies transmit trypanosomiasis, a disease which kills up to three million cattle each year. The European Union has signed a US$ 1.8 million deal with the centre to trial the collars with Maasai pastoralists in East Africa over the next three years (Adhiambo, 2010).

6. This voluntary mechanism was introduced by the African Union in 2005 to help countries improve their governance. Countries develop a self-assessment report and programme of action, which is then submitted to the secretariat in South Africa and later publicly released by the country review team. Countries' progress in implementing their programme of action is reviewed in subsequent years.

The observatory will have a mandate for collecting, storing and disseminating data from the African Union's 53 member states on everything from R&D expenditure to the number of PhD students. It will ensure that STI indicators and methodologies for information-gathering and validation are standardized across the continent. The African equivalent of co-ordinating bodies like Eurostat or the OECD Directorate for Science, Technology and Industry, it will manage expert committees from African countries and oversee the collection of national statistics, in addition to producing manuals and the *African Innovation Outlook*. The observatory will also build capacity through the provision of training, sample survey instruments and case study templates, as well as practical advice on the development of country profiles, indicator reports and the use of indicators in evidence-based policy.

COUNTRY PROFILES

In the following section, we take a closer look at the strategies adopted by 14 African countries in recent years to take up the challenges discussed above. The following list is by no means exhaustive and is merely intended to illustrate some of the approaches being adopted by African countries and the persistent obstacles they face.

Benin

After the change of political regime in Benin in April 2006, the new government redefined strategic orientations for a national development policy that would fully recognize the central role of R&D in the development process. The aim is to improve higher education and the scientific research system within a National Policy for Scientific and Technological Research that takes into consideration the results of a national consultation – or *Etats généraux* – on R&D in 2004. The Benin Minister for Higher Education and Scientific Research has consequently requested UNESCO's support within its African Science, Technology and Innovation Policy Initiative.

Fully aware of the need for credible, accurate data and indicators to underpin any policy, the National Directorate for Scientific and Technical Research (DNRST) launched a study in 2006 to create databases on research conducted in the country. The DNRST also initiated the creation of the Benin Agency for the Enhancement of Research (ABVaR) and a National Fund for Scientific and Technical Research (FNRST), together with the adoption of an ethical code for R&D.

Like many other African countries, Benin devotes very little to R&D, although official figures are not available. The bulk of financial resources allocated to universities and R&D institutions goes to salaries and grants for students, leaving little for research. In addition to budgetary constraints and organizational problems, R&D in Benin faces a third challenge: the strain on existing facilities resulting from the drastic increase in the number of university students. The student body totalled about 60 000 in the 2006 academic year but the number of students is expected to rise to 160 000 by 2015 (Gaillard, 2008).

Burkina Faso

In Burkina Faso, the Ministry of Secondary and Higher Education and Scientific Research (MESSRS) is responsible for S&T policy, with the National Centre for Scientific and Technological Research (CNRST) acting as the ministry's operational arm. The CNRST participates in the elaboration and implementation of the national S&T policy and co-ordinates and assesses research programmes. It also supervises the creation and management of public research institutes, promotes research results and oversees the training and promotion of researchers.

Since the agriculture sector employs more than 90% of the active population and contributes more than 38% of GDP, the bulk of resources for R&D goes to agriculture (Figure 5). Burkina Faso has 11 agricultural research bodies. Of these, the Institute for Environment and Agricultural Research (INERA) employs around 60% of the country's researchers and absorbs about the same share of the research budget for agriculture. Burkina Faso has the highest level of education in Africa in the agriculture sector, with almost half of researchers holding a PhD (Stads and Boro, 2004).

In 2006, Parliament passed an important Law on the Security Regime for Biotechnology in Burkina Faso, followed by a decree in 2007 defining the mission and responsibilities of the relevant agencies, including the Directorate for Studies and Planning (DEP) for the collection, processing and diffusion of statistics, among them those on scientific research. However, the DEP lacked a specific tool for collecting and processing S&T data. To remedy this, a Memorandum of Understanding was signed between MESSRS and the UNESCO Institute for Statistics in 2007 to establish a new scientific information system by 2009.

Cameroon

At the time of independence in 1960, Cameroon inherited an appreciable research infrastructure established during colonial times but only a small pool of trained Cameroonian researchers. The research structure remained essentially agricultural with a focus on plant breeding and crop protection. Gradually, attention turned from subsistence crops towards cash crops for export, such as coffee, cocoa, cotton, rubber and banana. The first institute created by the new state was the *Ecole nationale supérieure d'agronomie*. In 1974, the new Council for Higher Education, Science and Technology was entrusted with the dual tasks of funding R&D and advising the government on policy issues related to higher education and R&D. Thanks to oil revenues and a genuine political will to train scientific elites, Cameroon was among the first African countries to invest consequent amounts in research, with funding levels rising from 1 billion CFA in 1976/1977 to almost 10 billion CFA a decade later. Unfortunately, during this euphoric period, research was carried out within programmes included in the country's five-year development plans, under which each researcher was simply asked to execute programmes defined beforehand by the institute in question. Under such conditions, many researchers participated in programmes without actually publishing anything.

Today, the Ministry of Higher Education, Scientific Research and Innovation (MINRESI) is charged with formulating research policy and programmes in Cameroon. Its main attributions are to initiate, co-ordinate and assess scientific research, as well as to promote science popularization and innovation through the utilization of research results, in permanent relation with all national economic sectors, others ministries and interested organizations. The ministry operates the state research institutes, which include the Institute of Agronomic Research for Development (IRAD), the Geological and Mineral Research Institute (IRGM), the Institute for Medical Research and Medicinal Plant Studies (IMPM), the National Institute for Mapping (INC) and the Centre for Energy Research (NERCE) supported by the International Atomic Energy Agency. Other institutions are attached to various ministries or are of an international character with offices in Cameroon. The latter include the French Institute of Research for Development (IRD), the Centre for International Cooperation in Agronomic Research for Development (CIRAD) and the International Institute for Tropical Agriculture. Moreover, MINRESI launched a Mission for the Promotion of Local Materials (MIPROMALO) in the 1990s, combining technology transfer, R&D and the promotion of entrepreneurship (Box 7).

The country's seven state-owned universities and four private universities provide the national platform for education and research. There is a strong demand for tertiary education, with university enrollment in S&T fields having increased from 90 000 in 2000 to 150 000 in 2010. However, the government's agenda of achieving education for all might be compromised unless proactive measures are taken urgently to align education expenditure on the growing demand for higher education. Nor can private universities make up the difference, as the high fees they charge keep student rolls low.

Cameroon has several specialized journals: the *Journal of the Cameroon Academy of Sciences,* the *Journal of Health and Disease,* the *Journal of Applied Social Sciences,*

Box 7: Technology transfer in Cameroon

In the 1990s, the Government of Cameroon set up the *Mission de promotion des matériaux locaux* (MIPROMALO) to promote the use of local building materials and thereby reduce the country's trade deficit.

A key mission of this public body, which answers to the Ministry of Higher Education, Scientific Research and Innovation but is financially independent, is to set up technology transfer centres in 10 regions across the country.

MIPROMALO consists of three main programmes: eco-construction and development (solar panels, etc); business creation and development and gender empowerment; and education and new technologies. MIPROMALO facilitates the industrialization of production of local materials in Cameroon and develops public–private partnerships.
It provides the following services:

- Research and development;
- Engineering services;
- Technical assistance;
- Training;
- Laboratory analysis of materials;
- Production materials rental;
- Business incubators.

Source: http://mipromalo.com

Biodiagnostics and Therapy, and a quarterly newsletter published by the organization responsible for the surveillance of endemic diseases in Central Africa (OCEAC), the *Bulletin de l'OCEAC*. The OCEAC secretariat is located in Yaoundé and supported by the World Health Organization. Scientists would be able to access the content of these journals more easily if they were registered in standard bibliometric indexes.

One issue of concern is the low output of Cameroonian scientists. In early 2009, the government showed its willingness to strengthen university research by creating a special fund to triple the salaries of academics from US$ 550 to US$ 1 850 per month and modernize research facilities. This measure has been designed to increase the productivity of researchers and staunch brain drain.

The development of R&D has become one of the government's priorities, with an annual budget of 3 billion CFA and an average budgetary growth rate of approximately 1%. To promote excellence in scientific research and innovation, MINRESI launched a national biennial event in October 2007 tagged *Journées d'excellence de la recherche scientifique et de l'innovation du Cameroun* (Days of Excellence in Scientific Research and Innovation in Cameroon), while working in parallel on a directory of isolated or independent researchers and a scientific *Research Sectoral Strategy Plan*. Major barriers to the development of STI persist, however. These include:

- the lack of a national STI policy;
- a policy vacuum on distance learning;
- poor, expensive communication infrastructure;
- institutional inertia towards innovation that fuels a misuse of funds;
- a scarce, expensive energy supply reliant on fossil fuels and hydropower that would benefit from heavy investment in R&D to develop renewable sources of energy such as biomass, wind and solar energy.

Central African Republic

Statistics on scientists, researchers, engineers and their programmes are fragmentary in the Central African Republic, mostly due to latent political instability and repeated crises. Only the University of Bangui produces a statistical yearbook and then only with long delays, in spite of support from the UNESCO Institute for Statistics. What is certain is that the country lacks a critical mass of researchers and that the research pool is concentrated at the University of Bangui and the Pasteur Institute situated in the capital. The small size of the country's research body precludes the constitution of any associations of scientists or engineers.

Founded in 1970, the University of Bangui is the country's only university. The small pool of researchers is mostly involved in teaching rather than in research, as the budget for research is negligible. Although a High Council for Research was established in 1987, it is not operational.

To improve the situation, the government issued a Decree on the Organization and Functioning of the Ministry of Education, Literacy, Higher Education and Research in June 2005. This was followed in May 2006 by a special Decree on the Creation and Organization of the Researchers' Profession. In December of the same year, the ministry was again the subject of a decree modifying its statutes. The Decree on the Organization and Functioning of the Ministry of Education, Literacy, Higher Education and Research also fixed the minister's duties. In 2010, the ministry was implementing an important project funded by the French cooperation agency in support of higher education. Known as SUPC@, this project includes a number of R&D components.

In response to the government's request, UNESCO is currently providing support for the adoption of a national STI policy under its African Science, Technology and Innovation Policy Initiative. To that end, a consultant visited the country in July 2008 and July 2009. Moreover, a national forum was organized in March 2010 to ensure shared ownership of the new policy by all relevant stakeholder groups in the elaboration of a national STI policy: the research community, public and private entrepreneurs, civil society, funding agencies and so on.

Republic of Congo

Like Angola, Equatorial Guinea and Nigeria, among others, the Republic of Congo's industrial sector is largely dependent on oil. Oil has supplanted forestry as the mainstay of the economy, providing a major share of government revenues and exports. The country was seriously handicapped by two civil wars in the 1990s and, more recently, by the fall in global oil prices in 2008. As a result, it is currently experiencing a severe economic crisis that is jeopardizing the country's R&D programmes.

Although agriculture contributes only about 6% of GDP and 1% of exports, it is vital for the national economy, as it employs 40% of the workforce (Figure 5). This makes agricultural R&D a national priority. However, although the total number of agricultural researchers in Congo has gradually increased in recent years, expenditure on agricultural R&D has fallen by more than half over the same period. The country's 11 agricultural research centres, which fall under the Directorate-General for Scientific and Technological Research, account for about two-thirds of expenditure on agricultural R&D. The large number of these relatively small agricultural research agencies, however, coupled with their overlapping mandates, weakens the co-ordination and efficacy of agricultural research in Congo.

In 2004, the Congolese government requested UNESCO's assistance in strengthening national capacities in S&T to revitalize the science system after all the lost years of the Congolese civil war. UNESCO has since accompanied this ongoing effort to reform the country's science system step by step, with financial support from the Government of Japan. In the project's first stage, a *General Report* was prepared in 2004 to assess the state of S&T in Congo, in close collaboration with national stakeholders from the public and private sectors. The *General Report* (UNESCO, 2010*b*) found that:

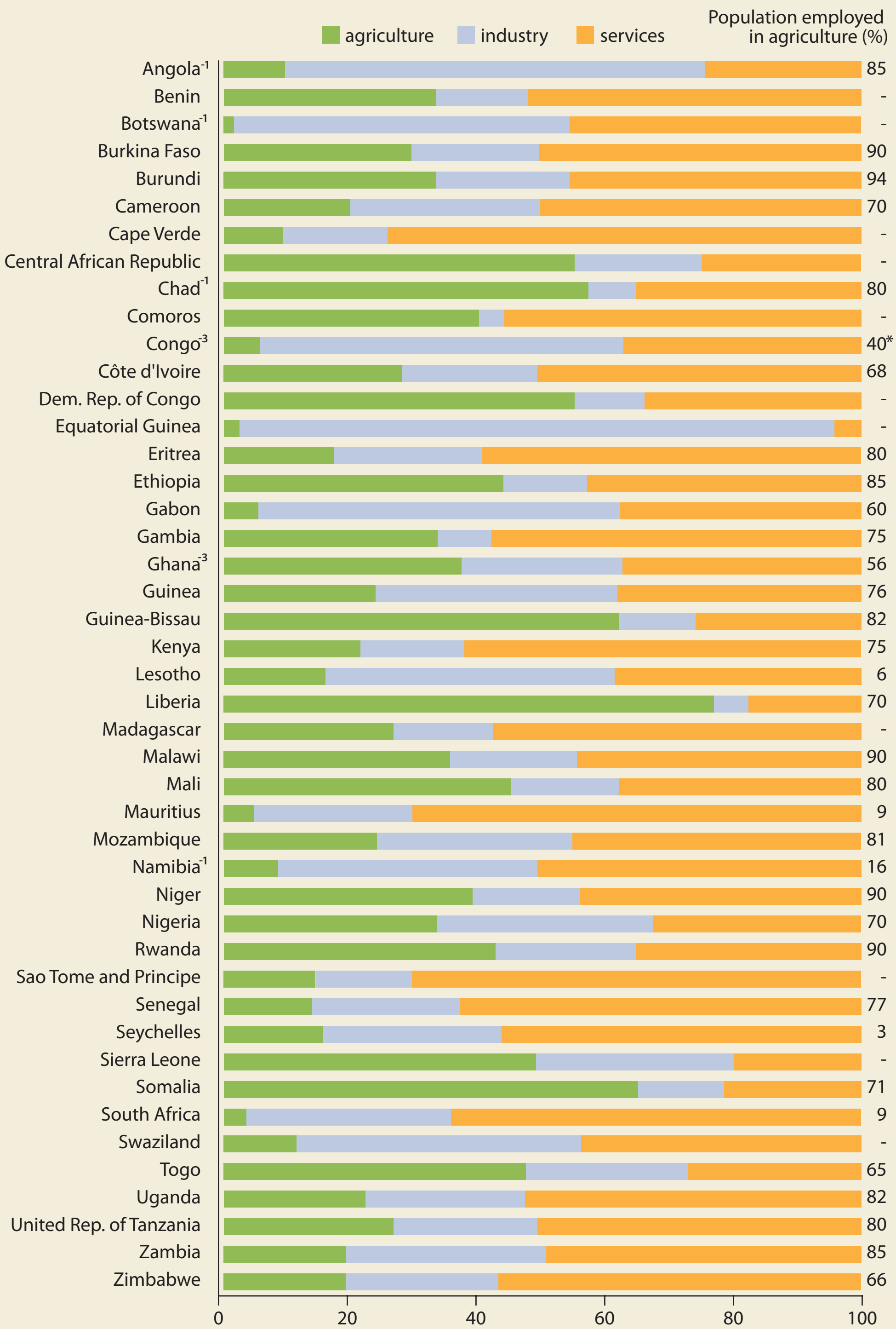
- the science governance system was dysfunctional. Some governance structures existed only in theory and, at 0.13% of GDP, public research funding was well below the stated target of 1%;
- research institutes, universities and industry remained isolated from one another and the entire system suffered from a lack of networking and intersectoral co-operation;
- the scientific community had no common representative structure, such as an academy or professional associations;
- research institutions suffered from a severe shortage of facilities, equipment, logistics and administrative and technical personnel;
- public research was placed under the auspices of the Ministry of Scientific Research and Technological Innovation but remained isolated from other sectors, such as agriculture or industry;
- since the end of the civil war, Congolese scientists had enjoyed little interaction and only rare exchanges with foreign scientists, including limited involvement in regional and international co-operation;
- the capacity of science policy-makers and managers was very low.

Once feedback had been received from officials on the diagnosis made in the *General Report*, a series of recommendations were made on the formulation, organization and implementation of an S&T policy. These were then the object of extensive consultations before being forwarded to the government in early 2006. The 'diagnosis' was validated and enriched by nearly 60 Congolese officials from various stakeholder groups at a National Policy Forum for Scientific Research and Technological Innovation organized in Brazzaville in May 2007. A series of seminars and training sessions on such themes as the governance of S&T and innovation policies followed in Brazzaville (UNESCO, 2010*b*).

Since 2005, the project has resulted in (UNESCO, 2010*b*):

- the creation of a full-fledged ministry responsible for scientific research and technological innovation in January 2005 to deal with an area that had previously come under the responsibility of the Ministry for Higher Education;
- the establishment of a Directorate for Technological Innovation within the new ministry;
- the development of specific statutes for research workers which were in the final stages of adoption in 2010, under consideration by the Supreme Court;
- a reform of the research infrastructure which was still under way in 2010, in order to group the large number of research units within three major institutes, those for agricultural sciences, health sciences and exact and life sciences;
- reconstruction of several research facilities and the allocation of greater resources to strategic areas, such as the National Agency for the Enhancement of Research (*Agence nationale de valorisation de la recherche*);

Figure 5: Composition of GDP in sub-Saharan Africa by economic sector, 2009 (%)



-n: data refer to *n* years before reference year

*provided by authors

Source: estimates from CIA (2010) *World Factbook*

- the establishment of a postgraduate school at the Marien Ngouabi University, supported by the university's Centre for Information Technology (*Campus numérique de l'Université Marien Ngouabi*);

- the elaboration and approval in April 2009 of a science policy document and an action plan for research and innovation covering 2010–2013. The action plan reiterates the 1% target for the GERD/GDP ratio. Specific research priorities have been defined, such as human and animal health; food security; and environment and biodiversity. These are in keeping with the major objectives of the country's development policy;

- the inclusion of a chapter on S&T in President Denis Sassou-Nguesso's Vision document for Congolese society, covering 2009–2016, entitled *Le Chemin d'Avenir*.

The first project phase wound up in 2010. For the second phase, UNESCO is suggesting to the Congolese government that it undertake the following projects:

- review of research institutions;
- the development of an STI financing system;
- the strengthening of human resources in science policy;
- the launch of a sub-regional parliamentary forum on the role of STI in socio-economic development;
- the setting-up of university teaching and research programmes on STI ;
- a study on how to develop science and innovation in the private sector;
- promotion of innovation and technological entre-preneurship, taking into account the informal sector;
- the establishment of an intellectual property protection system;
- a review of participation in regional and international scientific activities.

UNESCO has also recommended that the budgeting process be adjusted to allow for a multi-year budgetary programming cycle with a long-term vision, accompanied by greater flexibility in the use of funds. It proposes that the Directorate General for Scientific and Technological Research fulfil the essential role of co-ordination and supervision, in close partnership with the Ministry of Finance. UNESCO is also urging the scientific community to organize itself into fully representative bodies, such as one or more academies or associations. The scientific community is currently too fragmented to play the role of partner in a permanent process of interaction with the state authorities and civil society (UNESCO, 2010*b*).

Côte d'Ivoire

Côte d'Ivoire was a paragon of stability and economic growth in West Africa from the time of independence in 1960 until 2002 when a severe political crisis degenerated into civil war. This situation practically partitioned the country and completely jeopardized economic growth, paralysing scientific progress in the process. As a result, Côte d'Ivoire produced 129 publications in 2000 but only 111 in 2002. By 2008, productivity had recovered to 171 but the growth rate was well below that of Uganda, a country with comparable output in 2000. International collaboration was likewise affected. Côte d'Ivoire's scientists co-authored 103 articles in 2000 and 84 in 2002, a number that had risen to 115 by 2008.

One consequence of the political crisis has been the extreme difficulty in collecting and processing statistical data, since the second *National Strategy Document for Statistics Development* (2001–2005) was never adopted by the government and its successor for 2007–2010 was still being finalized in 2010.

Cote d'Ivoire is the world's largest producer and exporter of cocoa beans and a key exporter of coffee and palm oil. Despite government attempts to diversify the economy to reduce its vulnerability to international prices and climatic conditions, the country remains heavily dependent on agriculture (CIA, 2010). The National Centre for Agronomic Research (CNRA) employs two-thirds of the country's researchers and absorbs three-quarters of R&D expenditure.

CNRA has benefited from significant funding from the World Bank within two successive National Agricultural Services Support Projects for 1994–1997 and 1998–2010. CNRA has also attracted funding from the African Development Bank, United Nations Development Programme and the co-operation agencies of France and Belgium. It has established bilateral co-operation with the private sector via contracts with the African Sugar Company (SUCAF), the Ivorian Company for Textile Development (CIDT) and the Ivorian Cotton Company (ICCI), among others.

Democratic Republic of Congo (Kinshasa)
Endowed with rich agricultural soils, dense forests, abundant water and large reserves of minerals, this large country with enormous potential was devastated by almost uninterrupted civil war, rebellions and armed conflict between the time of independence in 1960 and the government signing of peace agreements with various rebel groups in March 2009. As a result of this prolonged political instability, the country's economy is in ruins: GDP amounted to just PPP US$ 20 billion in 2008. Scientific productivity is negligible, with just 30 publications registered in Thomson Reuters' Science Citation Index in 2008, although the language barrier may explain, in part, this poor performance.

The Democratic Republic of Congo has a small research infrastructure. Of the country's 25 public research centres and institutes, 18 fall under the Ministry of Scientific and Technological Research and seven under other ministries. There are also 19 institutions of tertiary education and 13 research centres and institutes in the higher education sector. The main private R&D institutions are the Luozi Pharmaceutical Research Centre (CRPL), Pan-African Research Development Institute (IRDA), African Centre for Industrial Research (CARI) and the Congolese Centre for Strategic Studies and Research specializing in international relations.

In May 2005, the country organized the *Etats généraux* for scientific research. This national forum brought together different stakeholder groups to draft a strategic plan for S&T and gave orientations for the future, including for the periodic assessment of the research system.

In 2008, the Democratic Republic of Congo requested UNESCO's assistance in developing a national S&T policy. This process is being conducted by the Ministry of Scientific and Technological Research, together with the National Scientific Council (CSN).

Gabon
Gabon is among the richest countries in Africa, thanks mainly to exports of petroleum, manganese, uranium and wood. Some 85% of the country is covered by dense forest. With its natural resources deteriorating, however, more importance is now being given to agriculture, although Gabon's agricultural R&D capacity remains one of the weakest on the continent. Three agricultural research institutes account for more than three-quarters of the country's total R&D staff and expenditure.

The Ministry of Higher Education, Research and Technological Innovation is entrusted with the mission of planning, promoting and assessing R&D programmes, as well as capacity-building. The ministry has signed an agreement with the French Cooperation Mission to develop a Research Directory Scheme in Gabon. This could boost scientific production, which is globally very low: in 2008, Gabonese scientists authored just 76 of the papers recorded in the Science Citation Index.

Besides the National Council for Higher Education and Scientific Research (CONAREST) and the three national universities – Omar Bongo University, the Science and Technology University of Masuku and the University of Health Sciences – Gabon's main research institutions are the National Centre for Scientific and Technological Research (CENAREST), the Centre for Specialized University Research (CERESU), the International Medical Research Centre of Franceville (CIRMF) and the Schweitzer Foundation Medical Research Laboratory.

Research programmes are mostly conducted within teams participating in international or sub-regional collaborative networks, such as with Europe (28.6%), North America (8.6%), the Economic and Monetary Community of Central Africa (17.1 %) and the Economic Community of West African States (12.4 %). In 2007, just 57 scientific articles resulted from international collaboration in S&T. However, 22% of researchers have never published within international networks and, more worrisome still, 14% of researchers have never published at all in the course of their career.

Kenya
Kenya is the regional hub for trade and finance in East Africa. Kenya's economy suffered in early 2008, after post-election violence affected tourism and investor confidence. This situation, coupled with the drop in exports and remittances as a result of the global recession, has caused annual GDP growth to slip from 7% in 2007 to barely 2% in 2008 and 2009 (CIA, 2010).

Against this backdrop, the Kenyan president decided to establish a new science ministry in 2008 by merging the Ministry of Science and Technology with the Department of Higher Education. The resultant Ministry of Higher Education, Science and Technology plans to strengthen the linkages between higher education and research. The Kenyan Parliament has since approved a national policy for biotechnology devised by the ministry (Box 8).

The government announced a *Kenya Vision 2030* in June 2008. This document calls for a series of five-year plans for the country's economic development. The first plan covers 2008–2012 and identifies six key sectors for investment with 20 flagship projects. These sectors are: tourism, agriculture, manufacturing, trade, information technology and financial services.

Concerned at the impact of climate change on the environment, the government allocated US$ 721 million to conservation in 2010 and announced plans to establish a regional carbon emissions trading scheme. The government is hopeful that such a scheme will attract funding to Kenya and add regional carbon trading hub to Kenya's established role as a regional hub for trade and finance. Most of the US$ 721 million allocated to conservation – a rise of more than 50% over the previous year's budget – will go to the environment, water and sanitation sectors (Mboya, 2010).

Mali

A landlocked country, Mali has suffered droughts, rebellions, coups and a brief border war with Burkina Faso in recent years. Endowed with a democratically elected civilian government since 1992, Mali still faces sporadic fighting with nomadic Tuareg tribes in the north. The country is saddled with a chronic foreign trade deficit and an economy largely dependent on cotton production. The low level of resources allocated to STI has spawned a small pool of ageing researchers who often lack motivation.

Since 2000, the national budget has allocated an annual grant of approximately €1 200 000 (*circa* US$ 1.8 million) to studies and research. In addition, a special budget for investment of 600 million CFA (about US$ 1.2 million) was allocated each year from 2005 to 2007 for the rehabilitation and equipping of laboratories in universities and secondary schools.

As elsewhere in Africa, agricultural research predominates in Mali. It is thus hardly surprising that it is one of the priorities of Mali's *Strategic Plan* for 2010–2019. Mali differs from many other African countries, however, in that it has adopted a policy of centralizing research. There is one main agricultural R&D agency, the Rural Economy Institute, which groups roughly 85% of the country's agricultural researchers and expenditure.

In addition to government contributions, the Rural Economy Institute is largely dependent on funding from the National Agricultural Research Project and the Support Programme for Agricultural Services and Associations of Producers (PASAOP), drawn predominantly from World Bank loans and funding from the Netherlands through the Rural Economy Institute Support Project (PAPIER). PASAOP ended in December 2009 but has been replaced by another programme supporting agricultural productivity in Mali (PAPAM).

Private-sector involvement in funding agricultural research on cotton, rice and other crops is limited to the Malian Company for Textile Development and the Niger Office. However, research institutions generate some income of their own through the commercialization of research products or services.

Despite a research environment lacking in everything from infrastructure and equipment to a well-trained, motivated young labour force, Malian research has managed to innovate, in particular in the agriculture and health sectors. Scientists have developed new varieties of maize, millet, rice and cowpea that are drought- and pest-resistant, as well as new techniques to increase yields. They have also developed traditional medicines and vaccines.

Scientific authorship remains low, however. Just 88 scientific articles from Mali were recorded in the Science Citation Index in 2008, although this was up from 30 in 2000. There was a similar level of productivity in international collaboration in 2008, with Malian scientists co-authoring 81 articles.

Today, there is a perceptible political will to support STI. The government has set up 18 national research institutes co-ordinated by the National Centre for Scientific and Technological Research (CNRST). Established in March 2004 under the Ministry of Higher Education and Scientific Research, CNRST manages the budget line for Studies and Research. This budget line leapt from 9 million CFA in 2000 to 60 million CFA in 2009.

In Mali, agricultural research is co-ordinated by the National Committee for Agricultural Research (CNRA). Health research, on the other hand, is the purview of the National Institute for Public Health Research (INRSP).

The University of Bamako was founded in January 2006 to take over from the University of Mali. It counts five faculties and two institutes. Other institutions employed in R&D and training are the: Central Veterinary Laboratory;

Box 8: Africa invests in biotech

Just three months after discovering Cuba's drug manufacturing capacity during a visit to the country, so the story goes, former South African President Thabo Mbeki announced South Africa's first National Biotechnology Strategy in 2001. Several regional and one national biotechnology innovation centres followed, the role of which was to recruit venture capitalists and distribute federal funds to start-ups. In just a few years, South Africa's biotech strategy has doubled the number of biotech companies to more than 80 and created more than 1 000 research jobs. Biotech products in development nearly doubled from 900 in 2003 to more than 1 500 in 2007 and the industry reported over US$ 100 million in revenue in 2006.

This novel approach has become the hallmark of biotech R&D in Africa. Rather than relying on big pharmaceutical companies for investment, a growing number of African governments are funding biotech themselves via support for start-ups, partnerships with foundations and United Nations agencies, and R&D collaborations between universities and private laboratories. The Wellcome Trust's African Institutions initiative is investing US$ 50 million in training researchers in neglected tropical diseases and in sponsoring collaboration between 50 scientific institutions in 18 African countries and private companies.

The World Health Organization is also pouring US$ 30 million annually into research and bringing biotech products to the market within the African Network for Drugs and Diagnosis Innovation that it has helped to establish.

In 2004, the Kenyan government decided to invest US$ 12 million to build a 'biosafety greenhouse' to allow containment of genetically modified (GM) crops, in a project funded jointly by the government and the Swiss Syngenta Foundation. Kenya thereby became the second sub-Saharan country after South Africa to be equipped to conduct GM experiments that conform to international biosafety standards. The greenhouse has been built within the Insect-Resistant Maize for Africa project. The greenhouse was developed jointly by the Kenya Agricultural Research Institute and the International Center for Maize and Wheat Research (CIMMYT), which also trained scientists to manage the facility at its centre in Mexico.

In 2007, the Kenya Wildlife Service concluded a five-year biotech research partnership with the Danish company Novozymes to use enzymes with potential industrial applications in biofuels and medicine, in particular. In return for authorizing Novozymes to exploit rich microbial biodiversity commercially within areas under its control, the Kenya Wildlife Service is collaborating with Novozymes in enzyme R&D and patenting.

Novozymes is also assisting with transfer technology to Kenya and is training Kenyan students to turn plants, animals, insects and micro-organisms into marketable goods. The company has agreed to build a special laboratory at the Kenya Wildlife Service headquarters in Nairobi. Kenya passed a biosafety bill in 2009.

Burkino Faso passed its own biosafety bill in 2006. Two years later, Uganda's Cabinet approved the country's first national biotechnology and biosafety policy. Uganda is currently using a US$30 million loan from the World Bank to improve the cassava plant.

Nigeria established a National Biotechnology Development Agency (NABDA) in 2001 as an institutional framework for implementing the National Biotechnology Policy. At a roundtable organized by NABDA in April 2008 on the introduction of GM crops into Nigeria, participants 'noted the undue delay in the processing of the Nigerian biosafety bill' and urged 'the [relevant ministers] to fast-track the process to obtain National Assembly approval without further delay.' NABDA has designated six zonal biotechnology centres of excellence for the conduct of R&D corresponding to specific biotechnology problems within each zone. The biosafety bill has been before parliament since 2009.

Source: Bagley (2010); Chege (2004); Zablon (2007) ; Odhiambo (2007)

See: www.nabda.gov.ng

Rural Economy Institute mentioned above; Traditional Medicine Research Centre (CRMT); National Agency for Telemedicine and Medical Computing (ANTIM) and; Rural Polytechnic Institute/ Institute for Training and Applied Research of Katibougou (IPR/IFRA).

The Ministry of Industry holds a National Invention and Innovation Exhibition every two years, through the National Directorate for industry (DNI) and the Malian Centre for Industrial Property (CEMAPI).

A wide range of laws and decrees have been adopted in recent years to improve the legal framework for S&T. Of note are those establishing a Statute for Researchers (2000) and new institutions, or fixing the functioning modalities of existing institutions. One product of this legislative onslaught is the National Agency for Information and Communication Technologies (AGETIC) dating from January 2005. One of the first tasks for AGETIC was to conduct a study, in June 2005, for the establishment of a National Policy on Information and Communication Technologies, with support from UNECA, the European Commission and the United Nations Development Programme.

In 2010, Mali was in the process of formulating a national STI policy with a strong focus on innovation, with UNECA support.

Nigeria

With the return to democracy in 1999 after 15 years of military rule, the role of STI in driving development started to feature prominently in Nigeria's economic reform agenda. In 2001, President Obasanjo appointed an International Honorary Presidential Advisory Council on Science and Technology to advise him on:

- effective ways of developing S&T for the benefit of Nigerians, by enhancing capacities in such critical areas as biotechnologies, ICTs, space science and technology, energy, nanotechnology and mathematics;
- effective ways of promoting S&T as an instrument for co-operation and integration in Africa;
- effective capacity-building programmes for implementation by the Federal Ministry of Science and Technology, including recourse to the expertise of Nigerians in the diaspora, and partnerships with international bodies.

The Council met twice a year for nearly seven years and made several important recommendations in the areas described above.

Under the presidency of Olusegan Obasanjo (1999–2007), the National Economic Empowerment and Development Strategy (NEEDS) was adopted to provide a framework for poverty reduction and wealth creation over the period 2003–2007. It identified STI as a cross-cutting issue, the promotion of which was vital to achieving economic objectives. This was followed by a *Seven-point Agenda* and *Nigeria Vision 20: 2020*, which represents the country's current economic development policy platform. The *Nigeria Vision 20: 2020* embraces areas identified by 12 committees set up by the Federal Ministry of Science and Technology at the turn of the century. It spans:

- biotechnology;
- nanotechnology;
- institutional linkages;
- capacity-building;
- renewable energy;
- venture capital;
- space research;
- industry-targeted research by small and medium-sized enterprises;
- knowledge-intensive new and advanced materials;
- STI information management;
- information and communication technologies;
- intellectual property rights;
- traditional medicine and indigenous knowledge.

The target of the *Nigeria Vision 20: 2020* is for Nigeria to join the 20 most powerful economies in the world by 2020. This target is based on the assumption that the country will achieve a consistent 12.5% growth rate in GDP per capita over the next decade. There are nine strategic targets:

- Carry out a technology foresight programme by the end of 2010;
- Invest a percentage of GDP in R&D that is comparable to the percentage invested by the 20 leading developed economies of the world;
- Establish three technology information centres and three R&D laboratories to foster the development of small and medium-sized enterprises;
- Increase the number of scientists, engineers and technicians and provide them with incentives to remain in Nigeria;

- Support programmes designed by professional S&T bodies to build STI capacity;
- Develop an STI information management system for the acquisition, storage and dissemination of research results;
- Attain progressively 30% of local technology content by 2013, 50% by 2016 and 75% by 2020;
- Develop new and advanced materials as an alternative to the use of petroleum products;
- Establish a National Science Foundation.

In October 2004, UNESCO set up an International Advisory Board for the reform of the Nigerian science system, at the government's request. One aim of the reform process was to diversity Nigeria's economy, which had become extremely dependent on fluctuating global oil prices. The board recommended (UNESCO, 2006):

- establishing a US$ 5 billion Endowment Fund in Nigeria which would be supplemented by donors;

- creating a National Science Foundation. This would be an independent funding body for competitive research and projects and programmes in innovation. Its main functions would be the provision of grants to research bodies, universities, enterprises and individuals on a competitive basis; the equipping and capitalization of research groups; and the establishment of research universities;

- creating technology-based 'good business' zones in each state where, for instance, businesses could obtain a license within 30 days and benefit from reduced capital costs;

- providing six Nigerian universities with targeted funding and technical assistance to enable them to rank among the 200 top universities in the world by 2020.

These four recommendations have since been approved by the government. Moreover, the proposal to create the National Science Foundation has been incorporated in the Economic Transformation Blue Print for the *Nigeria Vision 20:20,* as we have seen. In 2010, the government approved a special intervention fund of US$210 million over three years to develop centres of excellence at six universities, as well as US$ 66 million for upgrading selected polytechnics and colleges of education. Nigeria has 104 approved universities, 27 of which are federal, 36 state and 41 private universities.

Box 9: African Institutes of Science and Technology

The African University of Science and Technology in Abuja (AUST), Nigeria, was established in 2007 by the Nelson Mandela Institution, a charity incorporated in the USA, as the first in a Pan-African Network of Institutes of Science and Technology and centres of excellence across the continent.

AUST started its first academic year in June 2008. Two years later, the university was offering five MSc degree programmes in pure and applied mathematics; computer science; applied physics; materials science and; petroleum engineering. The university intends to develop its own PhD programme in the coming years and to establish strong partnerships with overseas universities to allow PhD students to do part of their research abroad.

The AUST in Arusha, Tanzania, has six start-up postgraduate programmes. These are in materials science and engineering; biosciences and bioengineering; mathematics and computational science and engineering; water and environment engineering; energy science and engineering (both renewable and non-renewable energy); and humanities and business studies. The latter includes management and entrepreneurship; innovation management and competitiveness; and law and IPRs.

Each AUST intends to become a world-class research-oriented institution. In Abuja, the AUST has developed extensive links with the African scientific diaspora and partnerships with the African Institute of Mathematical Sciences in Capetown (South Africa), with the Indian Institute of Technology Bombay (India) and with an AUST affiliate centre, the International Institute for Water and Environmental Engineering in Ouagadougou (Burkina Faso). The AUST in Abuja is also expected to collaborate with the Nigerians in the Diaspora Commission established by Parliament in 2010 to identify Nigerian specialists living abroad and encourage their participation in Nigerian policy and project formulation. Sponsors of the AUST in Abuja include UNESCO's Abdus Salam International Centre for Theoretical Physics, the African Development Bank Group and the Nigerian National Petroleum Corporation.

Source: authors; see http://aust.edu.ng/; www.nm-aist.ac.tz/index.htm

In 2010, Parliament approved the establishment of the Nigerians in the Diaspora Commission, the aim of which is to identify Nigerian specialists living abroad and encourage their participation in Nigerian policy and project formulation. The African University of Science and Technology in Abuja is expected to collaborate with the Commission on implementing this project (Box 9).

Priorities for industrial development in Nigeria

Nigeria has about 66 R&D institutes covering various sectors of the economy. R&D in many of these institutes has produced a host of nationally patented inventions but the vast majority remain on the shelf rather than being turned into innovative products and processes. In line with the government's NEEDS strategy and ensuing reforms, the federal government approved funding for the development of the Abuja Technology Village in 2007 and established a project team. This project draws on similar initiatives worldwide which cluster local and multinational companies, as well as residential areas. These include Silicon Valley in the USA, Dubai Internet City, the International Technology Park in India and Cyberjaya in Malaysia. The main clusters of the Abuja Technology Village are: minerals technology, biotechnology, energy technology and ICTs.

The National Biotechnology Development Agency was established in 2001 as an institutional framework for implementing the National Biotechnology Policy adopted the same year. The agency has a mandate to co-ordinate, promote and regulate all biotechnology activities in the country with a view to making available this cutting-edge technology for the promotion of a healthy environment, ensuring national food security and providing affordable health care delivery and poverty alleviation. Its development has been hampered, however, by the delay in the adoption of a biosafety act to provide a framework for the introduction and development of GM crops in Nigeria. See Box 8 for details.

The state of information technology (IT) in Nigeria left much to be desired at the turn of the century. Technology and industrial policy regimes had been marked by the indiscriminate importation of technology in which transfer agreements contained unfair clauses. These clauses included monopoly pricing; restrictive business practices; export restrictions; high royalty rates; tie-in clauses with equipment, raw materials, components and so on; a lack of training and management programmes; and poor opportunities for local R&D.

The elaboration of Nigeria's National Information Technology Policy in 2001 sought to reduce Nigeria's dependence on imported technology and promote the country's global integration to facilitate economic development. The policy went through a consultative process that brought together the country's major IT stakeholders[8]. Nigeria created a National Information Technology Development Agency in 2001 specifically to implement the IT policy. Six years later, Internet access had jumped from just 0.3% in 2002 to 6.8%. One area that merits investment in Nigeria is software development.

In July 2006, the federal government launched the Computer for All Nigerians Initiative (CANI). This public–private collaboration is sponsored by the Federal Ministry of Science and Technology, Microsoft and Intel. The computers are made with Intel processors and are assembled locally by International Business Machines, Hewlett Packard and four Nigerian companies: Omatek, Zinox, Brian and Beta Computers. The scheme makes desktop computers and laptops available to employers at a 30% discount off the market price. It also offers affordable 24-month bank loans for the purchase of personal computers (PCs). The loans are guaranteed by the employer, with instalments being deducted directly from the employee's salary. Employers are being encouraged to subsidize the package by about 20% to reduce the cost of a PC to half the market price.

In 2003, Nigeria became the third country after South Africa and Egypt to have a presence in space, after the launch of a low-orbit remote-sensing micro-satellite, NigeriaSat-1, with the assistance of the Russian Federation. NigeriaSat-1 monitors the environment and provides information for infrastructure development. This prowess enabled Nigeria to join the Disaster Monitoring Constellation grouping Algeria, China, the UK and Viet Nam. NigComSat-1 followed in 2007, in collaboration with the China Great Wall Industry Corporation, to offer Africa better telecommunications.

In April 2010, the Nigerian Oil and Gas Industry Content Development Act (Local Content Act) received presidential assent. Now in force, the new law seeks to

8. These included the Computer Association of Nigeria, now known as the Nigeria Computer Society, the National Information Technology Professionals Association and the Association of Licensed Telecommunication Companies in Nigeria (ALTCON), as well as all Nigerians in the diaspora.

increase indigenous participation in the oil and gas industry by prescribing minimum thresholds for the use of local services and materials and by promoting the employment of Nigerian staff. The Local Content Act derives from the Nigerian Content Policy, which seeks to promote active participation by Nigerians in the petroleum sector without compromising standards. The policy also focuses on promoting value addition in Nigeria through the utilization of local raw materials, products and services in order to stimulate the growth of endogenous capacity.

Rwanda

Rwanda's new development strategy, as elaborated in reports like *Vision 2020* and the *National Investment Strategy*, shows the country's determination to adopt S&T as a fundamental tool to achieve economic development. Key government measures to promote STI include improvements to the country's S&T infrastructure through public investment and South–South co-operation, the promotion of a knowledge economy through information technology and the application of science, as well as the development of a small number of world-class institutions of higher education, including the National University of Rwanda and the Kigali Institute of Science, Technology and Management.

At the African Union Summit in January 2007, Rwandan President Paul Kagame announced that his country had boosted expenditure on S&T from less than 0.5% of GDP a few years ago to 1.6%. He also said his country would increase investment in R&D to 3% of GDP by 2012. That would make Rwanda's GERD/GDP ratio higher than that of most developed countries. A country teetering on collapse less than a decade ago and still living in the shadow of genocide has embarked on a path that could lead to science-based sustainable development.

In 2008, the government evoked the possibility of establishing an endowment fund for innovation which would also serve to build R&D capacity in Rwanda's centres of excellence. A first for Rwanda, the fund would be a public–private partnership, with research teams being entitled to apply for funding collectively, a move which would facilitate the composition of multidisciplinary research teams. At present, each researcher has to apply for funding from individual ministries. However, at the time of writing in early 2010, no specific amount had been confirmed for the fund and the project was still under consideration (Niyonshuti, 2010).

Senegal

In Senegal, agriculture earns around 14% of GDP and employs three-quarters of the labour force (Figure 5). As in many other African countries, it occupies the lion's share of research activities. In all, nine institutes conduct agricultural research, the two core ones being the Senegalese Institute for Agricultural Research (ISRA) and the Institute of Food Technology (ITA), which employ 70% and 5% of Senegalese researchers respectively.

Given the importance of agriculture, the government has deployed a lot of energy in funding and re-organizing agricultural research over the past decade. In 1999, it created the National Fund for Agricultural and Agro-Food Research (FNRAA) to serve as a mechanism for channelling competitive funding during the first phase of the World Bank's PASAOP programme offering support to farmers' organizations. This fund has since become an instrument for harmonizing and promoting institutional collaboration in agricultural R&D and related sectors. FNRAA has been the major initiator of the National Research System for Agriculture, Forestry and Animal Husbandry (SNRASP) launched in June 2009. This system has considerably strengthened co-operation among major institutions operating in this sector. SNRASP derived from a decree issued in November 2008, which itself emanated from the Orientation Law adopted in June 2004 to implement a 20-year vision for the agriculture sector. SNRASP aims to rationalize agricultural R&D and foster inter-institutional collaboration, as well as the setting-up of an efficient S&T information network for agriculture and related sectors.

The Ministry of Scientific Research adopted a *Strategic Research Plan* for 2006–2010 in June 2006. However, this plan has not been implemented as expected, mostly due to frequent cabinet reshuffles. The ministry merged with the Ministry of Higher Education in October 2009 to form the Ministry of Scientific Research and Higher Education. In 2010, the ministry was putting together a formal STI policy with UNESCO's assistance.

Founded in 1999, the National Academy of Science and Technology of Senegal is an independent body that provides evidence-based advice to the government and alerts public opinion to S&T issues. The academy is divided into four sections: agricultural sciences; health sciences; science and technology; and economic and social sciences.

The academy has clocked up a number of achievements. For example, it has adopted a draft programme for the development of science teaching in Senegal called the National Indicative Programme. In parallel, it has reviewed innovative experiences and trends at home and abroad as a preamble to elaborating a science education policy. Following a fact-finding mission to Saint-Louis, members of the academy staged a special scientific session on the theme of Floods and Management: the Case of Saint-Louis, which resulted in the submission of a paper on a Flood Control and Urban Management Strategy to the Ministry of Hydraulics and Water Resources. The academy has also organized a number of intercontinental conferences in recent years, in partnership with the African Regional Centre for Technology and within both the African Science Academy Development Initiative (Box 5) and the Knowledge Management Africa Initiative (Box 6).

In May 2008, the National Agency for Applied Scientific Research came into being. It operates directly under the presidency with its own agenda. One of its main programmes is the development of a science park supported by the United Nations Department of Economic and Social Affairs (UNDESA), which is supporting a similar park in Ghana. The park in Senegal will focus on four areas: ICTs; biotechnologies; the garment industry and; aquaculture. The agency also organized a sub-regional exhibtion on research and innovation in March 2010.

South Africa

Just two years after the election of the country's first democratic government, a White Paper on Science and Technology was published in 1996. Entitled *Preparing for the 21st Century*, it pinpointed a number of systemic failures (OECD, 1999):

- a fragmented and inadequately co-ordinated science system;
- the erosion of innovative capacity;
- poor knowledge and technology flows from the science base into industry;
- poor networking both within the region and in the global context;
- low investment in R&D;
- imbalances created by past policies and actions;
- a lack of competitivity within the global environment.

The White Paper made a number of policy recommendations for developing South Africa's national innovation system, including: the re-allocation of government spending according to new priorities to promote innovative solutions for the disadvantaged, in particular; the introduction of processes to challenge government research institutions to derive more support from competitive sources of funding; the promotion of the diffusion of the results of R&D to make R&D expenditure more efficient; and the introduction of longer-term perspectives in planning and budgeting for R&D (OECD, 1999).

Six common themes emerged from the White Paper's review of policy documents (OECD, 1999):

- Promoting competitiveness and job creation;
- Enhancing the quality of life;
- Developing human resources;
- Working towards environmental sustainability;
- Promoting an information society;
- Producing a greater volume of knowledge-embedded products and services.

In 2002, the government adopted the National Research and Development Strategy. This document has since formed the basis for the development of South Africa's national innovation system. To promote South Africa's competitiveness, the strategy identified key technology missions and science platforms. The former include biotechnology, nanotechnology and ICTs, and the latter Antarctic research, marine biology, astronomy and palaeosciences.

The National Research and Development Strategy recognized the need to develop synergies among the public and private components of the science system to create wealth, improve the quality of life, develop human resources and build R&D capacity. It also fixed the objective of attaining a GERD/GDP ratio of 1%. One of the measures implemented by the government to realize this goal is the R&D Tax incentive Programme launched in 2008 (*see page* 315).

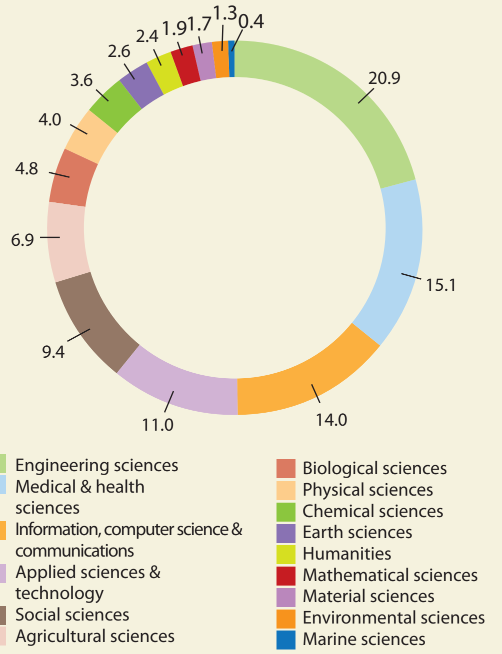
Another objective of the National Research and Development Strategy was to scale up the number of skilled researchers and technologists by adopting a dual upstream (existing R&D personnel) and downstream (school learners) approach. Upstream, the government has since put in place a South African Research Chairs Initiative, a Centres of Excellence Programme and a

Postdoctoral Fellowship Programme. Downstream, it has introduced Bursary Initiatives, Youth into Science and the Science and Engineering and Technology Awareness programmes.

Since the National Research and Development Strategy was adopted, statistics gathering and analysis have been reinforced and new indicators have been introduced to assess how well the national innovation system is performing. The role of the National Advisory Council on Innovation (NACI) is to provide a diagnosis and propose ways of improving the national innovation system.

NACI is comprised of 22 members. Established by law in 1997, the council advises the Minister of Science and Technology and, through the minister, the Cabinet, on the role and contribution of science, mathematics, innovation and technology in promoting national objectives. NACI also identifies R&D priorities. The council groups the full spectrum of sectors and organizations involved in the South African national innovation system and is supported by a professional secretariat based within the Department of Science and Technology in Pretoria, as well as by three specialized advisory committees: Science, Engineering and Technology for Women; the National Biotechnology Advisory Committee and; the Indicators Reference Group.

Figure 6: Breakdown of government expenditure on R&D in South Africa by field of research, 2006 (%)



Source: DST (2009) National Survey of Research and Experimental Development

Trends in R&D investment in South Africa

South Africa has managed to increase GERD from 0.7% at the time the National Research and Development Strategy was adopted to 0.9% in 2006. The business sector funded 44.8% of GERD in 2006 and performed 57.7%. Investment is not evenly spread around the country, however, as just three out of nine provinces concentrate four-fifths of the total. A *National Survey of Research and Experimental Development* undertaken in 2006 and 2007 by the Department of Science and Technology (DST, 2009) revealed that more than half (51%) of the country's R&D expenditure in the private and public sectors was concentrated in the Gauteng Province. The Western Cape (20.4%) and KwaZulu-Natal (11.0%) Provinces ranked second and third respectively.

South Africa's R&D effort can be broken down into 15 broad fields. In 2006, the lion's share of government funding went to the engineering sciences (Figure 6). There may be a correlation between this high level of funding and the numerous breakthroughs in engineering by South Africa in recent years, one example being the Southern African Large Telescope (Box 10). Other fields receiving a large allocation are medical and health sciences and information, computer science and communications.

Towards a knowledge economy in South Africa

In July 2007, the DST adopted a ten-year innovation plan (2008–2018). *Innovation towards a Knowledge-based Economy* builds on the foundations laid by the National Research and Development Strategy adopted in 2002. The purpose of the ten-year plan is to help drive South Africa's transformation towards a knowledge economy, one in which the production and dissemination of knowledge lead to economic benefits and enrich all fields of human endeavour. The plan is underpinned by five grand challenges:

- *The 'Farmer to Pharma' value chain to strengthen the bio-economy*: over the next decade, the goal is for South Africa to become a world leader in biotechnology and pharmaceuticals, based on the nation's indigenous resources and expanding knowledge base (Box 8);

Box 10: The largest telescope in the Southern Hemisphere

The Southern African Large Telescope (SALT) is the largest single optical telescope in the Southern Hemisphere (*see photo, page* 278) with a hexagonal mirror array 11 m across. It is located in the semi-desertic region of Karoo in South Africa.

SALT is a facility of the South African Astronomical Observatory established in 1972 and run by South Africa's National Research Foundation. Inaugurated in November 2005, SALT has been funded by a consortium of partners from South Africa, the USA, Germany, Poland, India, the UK and New Zealand.

The telescope will be able to record distant stars, galaxies and quasars a billion times too faint to be seen with the naked eye, as faint as a candle flame at the distance of the Moon.

In 2010, the South African Astronomical Observatory won a bid to host the International Astronomical Union's Office for Astronomy Development, which will play a key role in taking astronomy to the developing world by co-ordinating and managing all educational activities.

South African astronomy celebrated another milestone in 2010 when the first four telescopes of the KAT-7 demonstrator radio telescope were linked together as an integrated system to produce Africa's first interferometric image of an astronomical object. Interferometry refers to a technique by which radio signals collected at the same time by a system of networked radio telescopes are processed into a single high-resolution image. This milestone augurs well for the African bid to host what will be the world's largest radio telescope, the Square Kilometre Array, because it demonstrates that Africans have the technical expertise to build such a complex working instrument.

Source: www.salt.ac.za; www.saao.ac.za/; SouthAfrica.Info (2010*a*; 2010*b*)

- *Space science and technology*: South Africa should become a key contributor to global space science and technology, with the founding of the National Space Agency in 2009, a growing satellite industry and a range of innovations in space sciences, Earth observation, communications, navigation and engineering;
- *Energy security*: South Africa must meet its medium-term requirements in terms of energy supply while innovating for the long term in clean-coal technologies, nuclear energy, renewable energy and the promise of the hydrogen economy;
- *Global climate change science*: South Africa's geographical position enables it to play a leading role in climate change science;
- *Human and social dynamics*: as a leading voice among developing countries, South Africa should contribute to a greater global understanding of shifting social dynamics and the role of science in stimulating growth and development.

The government launched an R&D Tax incentive Programme in 2008 to help reach the target stated in the National Research and Development Strategy of a 1% GERD/GDP ratio. The aim of the programme is to encourage businesses to invest in R&D and innovation (NACI, 2009). It encourages private companies to acquire capital assets, labour and technology for R&D in the manner they consider most productive then to claim the tax incentive. The incentive includes a tax deduction of 150% in respect of actual expenditure incurred for eligible activities and provides for an accelerated depreciation of assets used for R&D over three years at the rate of 50:30:20.

The government has also introduced a scheme allowing it to assess the impact of the R&D Tax Incentive Programme on the economy and society. The Income Tax Act requires the DST to report on the aggregate expenditure on R&D activities and direct benefits of such activities in terms of economic growth, employment and other government objectives.

In 1999, the DST set up an Innovation Fund. It invests in late-stage R&D, intellectual property protection and the commercialization of novel technologies. Among the selection criteria, applicants are expected to form a consortium and to propose a programme for diffusing their new technology to small, medium-sized and micro-enterprises. From 2010 onwards, applications for funding will be administered by the newly created Technology Innovation Agency.

Among other measures to foster university–industry linkages, science councils themselves are now entitled to engage in high-tech spin-offs, either via their own R&D or via the commercialization of research results acquired from universities. The Department of Trade has also introduced the Technology for Human Resources in Industry Programme. Administered by the National Research Foundation, it matches the funding provided by university–industry research projects (OECD, 1999).

In 2008, South Africa exported most of its high technology to Germany, followed by France, Nigeria and Zambia. Most of its high-tech imports came from China, followed by the USA, Germany and Sweden (NACI, 2009).

Internet remains unaffordable for many South Africans, a factor which hampers the development of a knowledge economy. Just 8.2% of the population had access to Internet in 2007. In a speech before Parliament in April 2010, the Minister of Communications stated that 'for the past five years, the cost of communicating and doing business in South Africa has been impeded by exorbitant charges.' He said that 'consultation towards developing a comprehensive ICT policy framework has begun'. He also announced that the Department of Communications had developed an ICT Small and Medium Enterprise Strategy for the establishment of ICT business incubation centres in the Limpopo, Mpumalanga and KwaZulu provinces (Minister of Communications, 2010).

South Africa is active in pan-African collaboration. It chairs the Southern African Development Community (SADC) S&T group, which recently drafted a 10-year plan for the SADC. South Africa also supports three NEPAD flagship projects: the African Institute for Mathematical Sciences, the African Laser Centre and the Southern African Network for Biosciences. South Africa also participates in the NEPAD/Southern African Regional Universities Association roundtable discussions on implementation of the CPA and on engineering capacity-building for manufacturing. It has also offered to host the African Observatory of Science, Technology and Innovation (*see page* 299).

Uganda

Manufacturing, construction and mining are Uganda's main industries. The industrial sector accounts for about 25% of GDP and is estimated to have grown by 7.0% in 2007, up from 6.4% a year earlier. The discovery of commercially viable oil deposits has prompted hopes that Uganda will soon become a net oil exporter.

It has been argued that it is not the level of innovation of a country that is paramount but rather its ability to adopt, adapt and absorb technologies. However, many industries in Uganda are operating below capacity because 1) they have imported obsolete technology or for lack of regular maintenance of machinery, 2) some technologies are unsuited to local conditions or even 3) because some technologies have been imported without the technical know-how to use them, rendering them useless – especially when they break down. A further bottleneck stems from the fact that a number of bodies mandated to oversee technology transfer, assessment and forecasting have not been given the means to carry out their mission. These include the Uganda Investment Authority, the Uganda Registration Services Bureau, the Uganda Industrial Research Institute and the Uganda National Council for Science and Technology.

The National Industrialization Policy of 2008 aims to create a business-friendly environment for private sector-led, environmentally sustainable industrialization to help industries improve their productivity and the quality of their products through innovation. It contains provisions for developing domestic resource-based industries such as the petroleum, cement, fertilizer and agro-processing industries (leather goods, dairy products, garments, etc.), as well as such knowledge-based industries as ICTs, call centres and pharmaceuticals. Strategies include encouraging foreign direct investment in industry and industry-related services, the creation of a framework to support public–private partnerships for the production of higher value-added goods and services for domestic consumption and export, a wider tax base and greater integration with agriculture to produce value-added niche products.

In 2008 the Atomic Energy Act established the Atomic Energy Council. The act also provided a framework for the promotion and development of nuclear energy for use in power generation and other peaceful purposes.

Uganda's Information and Communication Technology Policy dates back to 2003. Although Internet access has since grown to 2.5% (2006), Internet infrastructure remains largely confined to the cities, with rural locations depending primarily on VSAT applications. Phase One of the National Backbone Infrastructure (NBI) initiative ended in 2008 after covering Kampala with 900 km of high-capacity fibre optic cables. Phase Two covered an additional 1 500 km in 2009. As a result, the core telecommunications infrastructure network in and around Kampala is relatively well developed, with some fibre optic infrastructure and microwave links. New ICT enterprises and training facilities have proliferated in the form of handset sellers and airtime vendors that include Midcom and Simba Telecom. ICT-related courses like telecommunications engineering are also now being offered at universities that include the Makerere University IT Centre and the ICT incubation park of the Uganda Investment Authority.

Although GERD remains low in Uganda at around 0.3–0.4% of GDP, all of government expenditure on R&D is used for civil purposes, unlike many other countries where it also encompasses defence spending (UNCST, 2007; 2009).

In Uganda, there is little that would qualify as R&D according to the strict definition in the *Frascati Manual* but the government is investing in a wide range of R&D-based programmes. These include programmes to support R&D performed in the higher education sector, with funding from the Millennium Science Initiative and the Swedish International Development Agency. The government also funds R&D programmes executed by government departments and agencies which include the Uganda Industrial Research Institute, the National Agricultural Research Organisation and the Joint Clinical Research Centre.

The government is also funding projects administered by the National Council for Science and Technology and Makerere University to help businesses develop R&D. The 2010–2011 budget announced in June 2010 brings a breath of fresh air to the university. It foresees an extra US$ 2.2 million for Makerere University and US$ 1.8 million to nurture a venture capital fund for start-up companies launched by university graduates. Ugandan scientists are also to receive a 30% rise in salary, the Uganda Industrial Research Institute an extra US$ 540 000 and Enterprise Uganda, a fund supporting entrepreneurship, a further US$ 450 000 (Nordling, 2010*c*).

In 2006, Uganda received a US$ 25 million loan from the World Bank to support S&T within the country, including the creation of centres of scientific excellence that will serve not only Uganda but the entire region. The grant was given, in part, because of Uganda's efforts to build its own S&T capacities, particularly in the fields of agricultural science and public health, including via the Uganda National Health Research Organization Act (2006).

The National Agricultural Research Policy was released in 2003 in line with the principles of the *Plan for Modernization of Agriculture*, in order to guide the generation and dissemination of research and improved technologies for agricultural development and promote the uptake thereof. The policy includes guidelines for the formulation and prioritization of agricultural research programmes. Priority areas for R&D are:

- technology development and multiplication, including the importation, adaptation and adoption of high-yielding disease- and pest-resistant planting and storing materials;
- socio-economic research, including participatory needs assessment, technology adoption and impact studies, policy research and analysis, cost-benefit studies and gender-responsive technologies;
- research on agriculture-related aspects of poverty and food security;
- application of information technologies in developing decision support systems, such as crop modelling;
- farm power and post-harvest technologies, including animal traction, solar and wind energy and biogas;
- storage and preservation of perishable commodities and agro-processing;
- land and water resources management, including soil fertility, land degradation, production systems (for crop, livestock, aquaculture, agro-forestry), water harvesting techniques and irrigation;
- sustainable natural resource utilization, including capture fisheries, biodiversity conservation and environmental-friendly technologies.
- integration of indigenous knowledge into modern and improved technologies, including disease and pest control, food preservation and the improvement of food palatability.

In 2008, Uganda's cabinet approved the country's first National Biotechnology and Biosafety Policy. The policy provides objectives and guidelines for the promotion and regulation of biotechnology use in the country (Box 8).

The National Council for Science and Technology submitted a comprehensive national STI policy to the Cabinet for approval and implementation in July 2006. The broad objectives of this policy are to:

- increase public awareness and appreciation of STI;
- increase investment in STI;
- support R&D;
- strengthen the national system for technology transfer and intellectual property management;
- improve the information management system;
- build and maintain STI human capital and infrastructure;
- strengthen systems for ensuring safety, ethics and high standards in STI;
- strengthen the framework for STI co-ordination.

The national STI policy came a year after the government introduced measures to improve scientific literacy and attract more young people to scientific careers. Under the Science Education Policy adopted in 2005, classes in biology, chemistry and physics have become compulsory for all secondary school pupils. First-year university students are also obliged to take some science courses towards their degree. The policy allocates nearly three-quarters of government scholarships to students studying towards a science degree at university and other institutions of tertiary education.

CONCLUSION

While it appears that the majority of African leaders are convinced that only through science-driven development can their nations overcome poverty and achieve the Millennium Development Goals, there is an urgent need for single-minded political leadership to translate this conviction into an articulated plan of action and for a strong government commitment to implement it. There are seven levels of action that require the attention of governments:

Firstly, it is essential that a national science policy based on the technological and industrial needs of society be appropriately designed in collaboration with the local scientific leadership. For a country to have a clear and effective science policy, it is imperative that an efficient science policy organ be formed involving knowledgeable and capable science managers and advisors with sufficient responsibility and power to enable it to design and execute the national science plan and co-ordinate all the country's S&T activities. The number of African countries with science policy organs has, fortunately, substantially increased in recent years, particularly at the ministerial level. There are currently over 40 ministries responsible for national S&T policies in the region. Nevertheless, a number of critical problems have to be resolved before these bodies can render the services expected of them. These problems are largely caused by a shortage of funds and inefficiency in the management and organization of S&T.

Secondly, it is essential that the science policy be fully integrated into the nation's development plan. This will ensure that the S&T knowledge generated by various research institutions is linked to the country's socio-economic and industrial needs. Furthermore, ensuring a close relationship between the national development plan and the national S&T policy will expand industrial involvement and that of the productive sectors in R&D, on the one hand, and promote mission-oriented R&D in support of economic sectors, on the other. This is well-illustrated by the case of the Republic of Korea where concerted action by the government and private sector has helped the country to achieve remarkable progress in S&T and industrial development (*see page* 415).

Thirdly, the government must ensure that adequate, stable funding is provided for the implementation of the national S&T policy. As indicated earlier, without a firm commitment by the majority of African governments to raising the level of R&D funding from its current level of less than 0.3% of GDP to at least 1%, no science policy will be effective in generating and sustaining endogenous research. The average proportion of GDP allocated to R&D in Africa is about one-tenth the proportion in industrialized countries. This is in stark contrast to the large percentage of GDP spent on the military.

Fourthly, to counteract brain drain and ensure a critical mass of highly qualified experts in S&T, a number of world-class research and training institutions in critical areas such as food security, energy supply, tropical diseases, soil erosion, water quality, deforestation and desertification must be established and sustained on the continent. In addition, African states and donor organizations need to act collectively to establish high-level research and training centres in key areas of frontier science and technology, such as molecular biology, biotechnology, informatics, nanotechnology and new materials. The African Academy of Science, which groups eminent scientists from all over Africa and has facilitated the establishment of a Network of Academies of Science on the continent, can play a key role in developing regional programmes in S&T. Both the Academy of Science and the network deserve strong support from African governments.

Fifthly, every African country should strive to produce at least 1 000 scientists per million population by 2025. To facilitate this trend, African governments and donor organizations should fund a major scholarship programme to enable African students to pursue postgraduate education at high-level scientific institutions on the continent and in other scientifically advanced developing countries. Such a programme could be implemented in collaboration with the Academy of Sciences for the Developing World. Special attention should be paid to the discovery and development of talent. Special programmes, such as the Olympiads aimed at identifying students with exceptional scientific abilities, should be supported at the national, sub-regional and regional levels. Gifted students selected through these programmes should be nurtured in an environment conducive to accelerating the development of their talent. This can be achieved through the establishment of national or regional elite schools and colleges for gifted students, as has been done in Central Asia (*see page* 240), or through the design of intensive, challenging additional school and university courses in basic sciences and mathematics.

Sixthly, there is an urgent need to restructure the systems of secondary and higher education to make science more interesting and attractive to the young. This means devising a more hands-on approach to scientific study in the classroom, emphasizing learning by doing rather than the rote memorization that has historically characterised scientific learning, especially in biology. *La main à la pâte* initiative launched by the French Academy of Sciences a few years ago has become a much emulated strategy for educational reform in science.

Last but not least, African countries must support programmes to increase scientific literacy among both children and adults. As science gains prominence among African countries, it is important to create and support institutions for lifelong learning that enable people to understand what science-based development means for them and the role that science can play in poverty alleviation and sustainable growth. Of the 2 400 science centres and science museums worldwide, just 23 are in Africa, where they are concentrated in five countries: Egypt, Tunisia, Botswana, Mauritius and, most notably, South Africa, which hosts 17 such centres. There is an urgent need to establish at least one science centre or museum in every African country.

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African Peer Review Mechanism: www.aprm.org.za

African Ministerial Council on Science and Technology: www.nepadst.org

African Regional Intellectual Property Organization: www.aripo.org

African Technology Policy Studies Network (Kenya): www.atpsnet.org

Africa's Science and Technology Consolidated Plan of Action: www.nepadst.org

Council for Scientific and Industrial Research (Ghana): www.csir.org.gh

Innovation Fund (South Africa): www.innovationfund.ac.za

National Advisory Council on Innovation (South Africa): www.naci.org.za

National Biotechnology Development Agency (Nigeria): www.nabda.gov.ng

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Organisation africaine de la protection intellectuelle: www.oapi.wipo.net

Parliamentary Monitoring Group (South Africa): www.pmg.org.za

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