Economic Commission for Africa

Harnessing Technologies for Sustainable Development

ECA Policy Research Report

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Tonnes means metric tons.

Two years separated by a dash (2000–01) indicate a range of calendar years, while two years separated by a slash (2000/01) indicate a fiscal year or, in the context of agriculture, an agricultural year.

Dollar figures are in current U.S. dollars unless otherwise specified. Billion means 1,000 million.

Foreword

The most striking contrasts in the modern world are the vast differences in technological development and human well-being—differences most evident in Africa. Poverty and hunger are widespread. AIDS has cut life expectancy by more than 10 years in some countries. Forests are being depleted at the rate of an acre a second due to unsustainable farming practices. And technological development is woefully deficient. In many cases it is the poor, particularly women and children, who suffer the most. They live in environmentally fragile areas, depend on marginal lands, are exposed to health hazards and natural disasters, have very little coping capacity, and have hardly any assets to fall back upon in times of crisis.

This Report is about how African societies can reverse these alarming trends. Its main message is that harnessing new and emerging technologies is critical for development because—as Nobel prize winner Joseph E. Stiglitz put it—"human development is more than just the accumulation of capital and the reduction in distortions (inefficiencies) in the economy; it is a transformation of society, from traditional ways of doing things and traditional modes of thinking." We have long understood the importance of technology for human development. This Report provides a fresh perspective focusing on the major challenges facing Africa as it seeks a rapid transition to sustainable development.

New technology is often assumed to be information technology because it has enormous and still evolving potential to alleviate poverty and speed development. Indeed, information and communications technology was the theme of ECA's first African Development Forum in 1999. The novelty of this Report is that it focuses on other new and emerging technologies that can deliver new medicines to fight diseases, reduce hunger and food insecurity, and reverse the degradation of the environment. These exciting new technologies range from genetically engineered mosquitoes that have the potential to eradicate malaria to vitamin A-enriched rice that can reduce blindness in children.

Many are touting these new technologies as the missing link that can allow poor countries to catch up to their rich country counterparts. But this Report emphasizes that the new technologies are not a panacea or silver bullet. Spreading the benefits of technology will not happen automatically. It will require critical analysis and planning—by regional and international organizations and governments along with the private sector and civil society—to take full advantage of the technological revolution. This Report is presented in this spirit of continuous inquiry and feedback in framing development thinking. It is addressed to policymakers, practitioners, and others interested in Africa's development.

While focusing on new technologies, the Report recognizes that many low-tech, simple solutions are available for many development challenges. For example, biotechnology can produce AIDS treatments that prolong life, but people need to be trained in safe sexual habits so that the benefits are not inadvertently countered. The Report also emphasizes that new technologies can be of use only if placed in an environment of supportive policies.

The Report recognizes that poor people and poor countries do not have adequate access to technology that can benefit them. They lack the resources, infrastructure, quality of governance, and business environment necessary to attract the foreign investment that can bring technology to their countries. The Report outlines the key considerations and building blocks for a technology-infused development strategy. It includes lessons about what practices and products have been proven to work, about how to scale them up, and about how to encourage new ideas and initiatives.

The Report makes a compelling case for an integrated framework to catalyze the transition of African countries to a sustainable path. It includes several specific recommendations along four critical dimensions: education, innovation, regulation, and delivery.

The sustainable development indices developed by ECA—and reported for the first time in this Report—allow for tracking progress of African countries over the last three decades in the areas of economic transformation, institutional development, and environmental conservation. Apart from assessing performance, these indicators also help in identifying key factors that determine successes and failures in achieving a higher level of sustainability. They show what governments can do to encourage investment in productive assets, how Africa's environment can be conserved without hindering development, and what key areas of action can improve institutional structures.

Within the UN family, ECA's mandate is to advance the socio-economic development of the continent. This Report is an important contribution to fulfilling that mandate, particularly in a year that sees the World Summit on Sustainable Development hosted in Johannesburg, South Africa. It is my hope that the main message of this Report—the need for a technology-infused development strategy—will be a clarion call to action that can lead to a better quality of life for all.

K.Y. Amoako
Executive Secretary
August 2002

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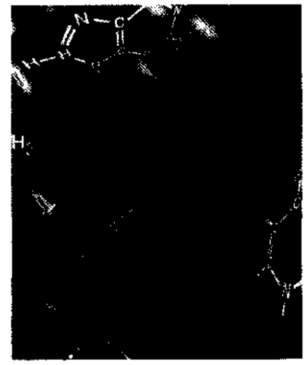
Overview—harnessing technologies for sustainable development



The greatest single problem and danger facing the world of the Third Millennium... is the gap in wealth and health that separates the rich and poor... The only other worry that comes close is environmental deterioration, and the two are intimately connected, indeed are only one.

—David S. Landes, *The Wealth and Poverty of Nations*

Poverty is multidimensional and widely spread in Africa. Incomes and consumption levels are low and volatile. The available productive assets, particularly for the poor, are few and meagre, increasing vulnerability to shocks. Illiteracy, malnutrition, and ill health are prevalent, with mortality and morbidity rates high. All these conditions have led to short life spans. Worsening the situation in recent years are the spread of HIV/AIDS and the resurgence of malaria and tuberculosis.

The pervasiveness of low levels of well-being is caused by, and in turn perpetuates limited productive capacity. Undercapitalized, the production of goods and services in large parts of Africa has yet to benefit significantly from modern technological advances. Average years of schooling are inadequate, while the incidence of illness is high, contributing to low aggregate and agricultural output per worker. The low agricultural productivity is simultaneously a cause and an outcome of the degradation of an already fragile natural environment.

The low and in some cases declining productivity, the deterioration in the natural resource base, and the rapid population growth mean that development is unsustainable in most African countries. Corroborating this is the index of overall sustainability developed by the Economic Commission for Africa. The index jointly measures the economic, environmental, and institutional sustainability of African countries. Combining 27 key economic, environmental, and institutional indicators, it tracks the performance of 38 African countries in 1975–2000. The scores reveal that the number of countries with low sustainability increased (from 16 in 1975–84 to 19 in 1995–2000), while the number of those with high sustainability remained the same (only 3). More telling, within the group of 38 countries the fraction of the population living in the countries with low sustainability rose from one-third in 1975–84 to half in 1995–2000.

So, the continent urgently needs a rapid, sustained, and broad-based economic transformation that is equitable within and across generations—in short, it needs development that is sustainable. The key to achieving the transition to sustainability is realizing and enhancing the capabilities of individuals and their communities. People who are ill, poorly fed, and living in a fragile environment can neither function effectively nor improve their capabilities. Moreover, in part because of rapid population growth, the severity of ill health, food insecurity, and environmental stress is likely to increase in the coming decades. Africa must therefore explore new and radical solutions to these problems.

The development challenge facing Africa is enormous, but it can be overcome. The development of Western Europe and the United States and, more recently, that of East Asian economies (including Japan, the Republic of Korea, and Taiwan, Province of China) corroborates this. Given the right circumstances, advances in and diffusion of technology can pull Africa out of its current state of low development. African countries can emulate the processes and policies that have promoted transitions to sustainability in other regions. Indeed, these processes and policies are better understood today than ever before. In Africa the achievements in Mauritius, for example, and the recent trends in policy reforms and economic growth in large parts of the continent signal the possibilities.

This report maintains that combating ill health (particularly that caused by HIV/AIDS, malaria, and tuberculosis), tackling food insecurity, and reducing environmental stress should be prominent objectives of the endeavour to reduce poverty and achieve sustainable development in Africa. It identifies the epidemiological and agricultural productivity transitions as the current priorities in the continent's striving towards sustainability. Recognizing that modern technology is indispensable to such transitions, the report then focuses on how the "new" technologies—particularly medical and agricultural biotechnology—can contribute.

Sustainability—on the decline

Overall sustainability has been worsening in Africa over the past three decades. This is confirmed by the Economic Commission for Africa's index of overall sustainability, combining economic, environmental, and institutional dimensions. Cluster analysis was used to classify countries into three relatively homogeneous groups characterized as having high, moderate, and low sustainability. Only three countries, accounting for about 6.5% of the continent's population, recorded relatively high overall sustainability throughout the period (table 1).

In the decade after 1975–84 fewer countries achieved moderate overall sustainability, with more falling into the cluster for low overall sustainability. The main explanation is that the significant progress in health and education in 1985–94 was more than offset by a worsening institutional and environmental situation. In that period institutional constraints on chief executives weakened considerably in several African countries—the Democratic Republic of Congo, Ethiopia, Nigeria, and South Africa—while they remained the same in Egypt, Kenya, and Tanzania. In addition, both population density and carbon dioxide emissions increased substantially in several large countries, including Algeria, Egypt, Ethiopia, Morocco, Nigeria, and South Africa.

In the most recent period, 1995–2000, the number of countries with low overall sustainability remained about the same as in the previous one, but the share of the population

Table 1
Overall sustainability clusters for 38 countries, 1975–2000

	High		Moderate		Low	
Period	Number of countries	Population share (percent)	Number of countries	Population share (percent)	Number of countries	Population share (percent)
1975–84	3	7.0	19	58.9	16	34.1
1985–94	3	6.7	15	52.8	20	40.5
1995–2000	3	6.4	16	39.5	19	54.0

Source: *Calculations by Economic Commission for Africa.*

living in such countries rose—an outcome largely explained by the deterioration of economic, institutional, and environmental management in Nigeria during most of 1995–2000. In many other African countries a recovery, though still tentative, has begun. In particular, output per worker and capital per worker rose in Egypt, Ethiopia, Morocco, Tanzania, and Uganda, and civil and political rights improved significantly in many countries.

When the 38 African countries are ranked by their average overall sustainability score for all of 1975–2000, Mauritius, South Africa, Botswana, Zimbabwe, and Tunisia emerge as the top five (figure 1). At the bottom are Burundi, the Democratic Republic of Congo, Guinea, Chad, and Burkina Faso.

There is little surprise in the make-up of the top five. South Africa, with its large and mainly industrialized economy, is quite distinct from other African economies. Indeed, it tops the economic sustainability rankings. But Mauritius and Botswana were the star performers in economic growth for the last three decades. Socio-political stability was also quite good in these countries, with Mauritius and Botswana ranking as the top two in institutional sustainability. Similarly, Tunisia and, until recently, Zimbabwe made reasonable progress in the economic and institutional dimensions.

That Zimbabwe ranks among the top five may be puzzling in light of its recent performance. The reason for this outcome is that until recently the country had been doing rather well, particularly in economic and institutional terms. Thus while Zimbabwe ranks only 12th in overall sustainability and 23rd in institutional sustainability in 1995–2000, it ranks 4th and 6th on these measures in 1985–94.

A blemish on the sustainability record of the top five is their performance in environmental sustainability. Mauritius, Tunisia, and Zimbabwe rank among the bottom five countries in environmental sustainability, and Botswana 30th among the 38 countries. Only South Africa, ranked 19th, does better in this dimension of sustainability. For these top performers, environmental concerns increasingly are becoming binding constraints on further improvement in the overall well-being of their populations. One lesson from this experience is that countries can do well for a while without giving due consideration to environmental factors, but this may not last long.

health services, undermining the productive capacity of a country, furthering social distress, and perpetuating poverty.

As a direct result of HIV/AIDS, the growth of gross domestic product (GDP) in Africa is expected to fall by 0.5–2.6% a year on average (Greener 2002). If malaria had been eliminated years ago, Africa's GDP would be as much as $100 billion greater (Medilinks 2001). And in countries with a high burden of tuberculosis, annual productivity losses due to the disease amount to an estimated 4–7% of GDP (Stop TB Initiative 2002).

The combined socio-economic burden of these diseases has led Sub-Saharan countries towards major crises that threaten to reverse decades of development gains and undermine national security. The damage from these diseases clearly calls for accelerating the epidemiological transition in Africa. Indeed, that is the most important development challenge for many African countries. Meeting it requires a prudent exploitation of techniques and products developed by recent advances in medical biotechnology.

The agricultural productivity transition

A person who has food has many problems. A person who has no food has only one problem.
—Chinese proverb

The agricultural productivity transition involves increasing agricultural production by raising output per unit of land through advances in knowledge and technology rather than by expanding the area cultivated. Historical evidence clearly shows that for most countries this transition is essential for securing access to enough food for a healthy life for all people and at all times.

Agricultural productivity is low in Africa, particularly in Sub-Saharan Africa. In the late 1990s cereal yields in Sub-Saharan Africa were about 40% of the world average—having fallen by 0.7% a year between 1985 and 1995—and milk yields about 16% of the average. Other crops and agricultural products showed similar gaps in yield. With about 70% of all Africans earning their livelihood from agriculture, low and in some cases falling agricultural productivity means serious poverty and food insecurity. Exacerbating the situation are rapid population growth and urbanization.

About a third of Africa's population is undernourished, while a similar share of its children are underweight. Of those who survive their childhood, many will suffer from impaired immune systems, poor cognitive development, and lower productivity throughout their lives. As adults, their ability to ensure good nutrition for their children will be compromised, perpetuating the vicious cycle. Indeed, it is only in South Asia and Sub-Saharan Africa that the number of malnourished people is projected to increase in the current decade.

The growing demands for food and nutrition are not being met in a sustainable manner. Farmers have tried to overcome declining yields by expanding croplands and grazing areas, an environmentally unsustainable option. Given limits on crop area expansion and increased demands on land already in production, physical and chemical soil degradation becomes a greater concern. Africa's tropical forests are fragile, quickly losing productive potential when under stress. Roughly 5 million hectares of forest are lost annually, most to crop area expansion (Paarlberg 2001). This is not a sustainable solution for the continent's agricultural production problems.

Low agricultural productivity, rapid population growth and urbanization, diminishing reserves of unused arable land, extensive and increasing degradation of land (both soil and vegetation), and large deficiencies in food and nutrition—all these call for an accelerated agricultural productivity transition in Africa. They also imply that such a transition is unlikely without substantial changes in the technology of agricultural production. Thus the next phase of yield increases in African agriculture cannot ignore new techniques and products offered by biotechnology.

The new technologies

Modern technologies are indispensable in achieving the epidemiological and agricultural productivity transitions. They bring tremendous hope to those who live in fragile environments, depend on marginal lands, are exposed to health hazards and natural disasters, and have little coping capacity and almost no assets to fall back on in a crisis. But the new technologies are no panacea. They involve potential risks. And their benefits will not spread automatically to the poor and vulnerable. Minimizing the risks and realizing the full benefits of the technological revolution will require critical analysis and careful planning.

Medical (red) biotechnology

Modern biotechnology and genetics are expanding opportunities for developing new drugs and improving the efficacy of existing drugs and treatment. Genomics and its applications (genetic engineering) to health care—"red" biotechnology, in contrast to "green" biotechnology in agriculture and the environment—is creating a wide range of powerful new tools that are changing how common diseases are diagnosed, managed, and treated. These include gene therapy, DNA-based vaccines, and novel vaccine delivery systems. These new technologies are capable of enabling African countries to stem the devastation caused by the three leading causes of death—HIV/AIDS-related infections, malaria, and tuberculosis.

New applications of biotechnology to diagnostic tests are speeding and simplifying the identification of diseases, while advances in pharmacogenics are providing greater understanding of how the body responds to drugs, making it possible to develop more accurate and effective medication. Gene therapy holds promise for directly correcting genetic disorders, providing a cure rather than simply a treatment of symptoms of these disorders. And new genetic engineering techniques are revolutionizing vaccination.

Modern biotechnology is creating the possibility of soon developing vaccines capable of tackling a wider range of diseases, including sexually transmitted diseases, and with greater efficiency. Equally important are technological improvements to the delivery of existing vaccines. New forms of vaccines are being designed to overcome problems of access—scheduling, storage, stability, and cost. These new forms could avoid such requirements as the cold chain that is needed to keep vaccine doses at the correct temperature, which restricts the distribution of the oral polio vaccine.

Four new concepts for delivering vaccines are under development (CVI 1999; Fell 1998):

- *Naked DNA vaccines,* created by genetic coding for key antigenic components of viruses or bacteria.
- *Trojan horses,* produced by introducing genes into organisms that enable them to carry a vaccine into the body.
- *Edible vaccines,* developed by engineering seeds that produce plants capable of forming vaccines in their fruit or leaves and thus of acting as vaccines themselves.
- *Sugar glass vaccines,* kept in crystalline form so that they are easy to transport and store and can be "revived" with just a few drops of water.

With these innovative vaccine technologies, prospects for controlling and eradicating infectious diseases in the coming century are greater than ever.

Indeed, these and other advances in biotechnology offer hope that the three leading causes of death in Africa can be brought under control. A decade ago an HIV diagnosis was akin to a death sentence. Today the means exist to fight HIV/AIDS. Antiretroviral therapy is prolonging life and restoring health for HIV-infected individuals. Several HIV vaccines are showing positive results in advanced stages of clinical trials, including some directed towards the HIV strains prevalent in Africa. A malaria vaccine too may soon be developed, and research to transform the malaria-transmitting mosquito into a harmless insect has reached advanced stages. Beyond these, many other new discoveries in medical biotechnology fuel expectations of finding cures for many of the diseases directly implicated in Africa's poor economic performance. In short, these medical technologies have the potential to reverse the damage by HIV/AIDS, malaria, tuberculosis, and other diseases and put the continent back on the path of the epidemiological transition to sustainability.

Ethical issues in medical technology. Ethical concerns surrounding gene manipulation are so important that many countries, industrial and developing, have set up bioethics committees to determine general principles of research and application and monitor compliance with them.

The concerns are many. The potential impacts of human gene manipulation on research strategy and the enormous power conferred on the scientific community raise questions about rights to information and civil society participation. Major ethical questions also arise about equity and what is considered the common heritage of mankind. In particular, questions are raised about whether the ownership and economic benefits of gene discoveries can be privatized. These questions point to contradictions between the recognized right of intellectual property protection and the recognized universal ownership of genetic material, based on the principle that the DNA structure of human beings is the heritage of all and should be registered as the property of all.

Disequilibrium in research priorities. Worldwide, there is a huge disequilibrium between research devoted to the diseases of the poor and that focusing on the diseases of the rich: less than 10% of global spending on health research is directed to the health problems accounting for 90% of the world's disease burden—the 10/90 disequilibrium (Global Forum for Health Research 1999). As measured by disability-adjusted life years (DALYs), the global burden of communicable diseases, concentrated in low- and middle-income countries, is 13 times the global burden of non-communicable diseases, the main health concern of the developed world. Yet non-communicable diseases receive by far the most research attention, while communicable diseases are neglected. For example, malaria accounted for 2.7% of the global disease burden in 2000, with 90% of cases in Africa, but it accounts for only 0.17% of the $60 billion spent globally on biomedical research each year (CMH 2001; Global Forum for Health Research 2002).

This inequality in research is also reflected in medical products. Of the 1,233 drugs that reached the market between 1975 and 1997, only 13 were for tropical diseases (Global Forum for Health Research 2002).

Inaccessibility of new drugs. Two main factors are preventing Africa from benefiting fully from the new scientific and technological advances in medicine. First, African countries, with annual per capita health spending as low as $10, have difficulty purchasing vaccines and drugs. Thus even though the prices of antiretroviral drugs have dropped substantially, many African countries still cannot afford them. As a result fewer than 1% of Africans infected with HIV/AIDS have access to antiretroviral therapy today (UNICEF and others 2001).

Complicating the problem of the high cost of drugs are the generally weak health systems in Africa. The treatment and care of HIV/AIDS and tuberculosis patients require highly trained doctors and nurses to ensure strict compliance with the complicated drug regimens. But health systems in Africa are often poorly equipped to serve as effective conduits for care. About 95% of Africans infected with HIV/AIDS have no access even to basic health care.

Agricultural (green) biotechnology

The biotechnology or gene revolution is the third green revolution. It offers possibilities for further amplifying the gains from the first two through technologies involving reproductive biology and the manipulation of the genetic material of living organisms. These technologies cover a wide range, including molecular DNA markers, gene transfer, and vegetative reproduction.

Agricultural biotechnology is likely to have a significant impact in several ways:

- Improving the ability to diagnose plant and animal pathogens.
- Quickening the pace of research through new biotechnological techniques.
- Expanding the spectrum of potential products and traits through genetic engineering of plants and animals.
- Transferring genes from wild relatives of a crop as well as from unrelated crops.
- Improving the nutrient content of foods and thus addressing the serious nutritional problems of the poor.

Of particular importance to Africa are the recent advances in biotechnology that promise to produce crop varieties with higher yields, greater resistance to pests and disease, and better nutritional, health, and environmental attributes. The distinctive promise of the gene revolution for Africa is that it can provide a better way to extend productive potential to poor farm communities, pre-packaged in genetically engineered seeds rather than delivered haphazardly in many separate purchased inputs.

The gene revolution also offers the potential for reducing yield variability through improved pest and disease resistance. And it holds out possibilities of higher production on previously unusable lands through crops that can tolerate drought, salinity, and aluminum. Under the right circumstances, modern biotechnology could speed Africa's agricultural productivity transition to sustainability—and expedite reductions in poverty and food insecurity.

Exacerbate income inequality? Whether the potential benefits of genetically modified crops accrue to small farmers is a question of the type of technology and the degree of inequality in a country. Where land tenure reforms are implemented, there is support for small farmers, and other elements of a development-friendly environment are in place, a new technology can benefit all farmers. But where, say, 70% of the land belongs to 5% of the population and agricultural extension and credit services are available only to big landowners, a new technology will widen the income gap between large and small farmers. Thus the social and economic impact of genetic engineering and biotechnology can only be as good as the socio-political soil in which the resulting new varieties are planted.

Some types of biotechnology could deepen poverty in Africa. For example, commercialization of the terminator gene technology, designed to prevent seed reproduction and thus ensure repeated seed purchases, would harm the millions of small farmers who depend on replanting farm-saved seeds. These farmers simply do not have the money to buy new seeds each year. Critics argue that this technology removes one of the foundations of rural agriculture—forcing small farmers into colonial dependence on rapacious multinationals—and raise concerns about the spread of this trait to other plants. Proponents maintain that it is only a concept and that it is not being developed. But it is believed that terminator gene technology is now on the fast track to commercialization (RAFI 2000), though no products are planned for Africa.

Damage human and animal health? There is still no conclusive evidence to show that any of the transgenes found in genetically modified foods are harmful to humans. But one frequent concern is that if foreign genes were present in such foods at excessive levels, they could build up in the consumer's body, increasing the resistance of diseases to several types of antibiotics (Malcolm 1999).

Another potential risk is that people with allergies could suffer reactions after unwittingly consuming genetically modified foods containing allergenic proteins introduced from external sources (Altieri 2000). For example, someone who is allergic to peanuts might suffer a reaction after consuming genetically modified soybeans modified by the insertion of the peanut gene that produces the allergic reaction.

In fact, all the proteins that have been placed into foods through the use of biotechnology and are currently on the market are non-toxic; are sensitive to heat, acid, and enzymatic digestion (and thus rapidly digestible); and have no structural similarities to proteins known to cause allergies. Similarly, current evidence does not support the argument that inserting a new gene can alter the metabolism of plants and animals to produce allergens and toxins (Thompson 2000).

Some of these concerns have also been raised for animal health—concerns much publicized in the North, particularly in Europe. Livestock and poultry consume large amounts of genetically modified corn and soybeans, and some livestock producers have raised the prospect of antibiotic resistance. If genetically modified organisms lead to a buildup of antibiotic resistance, commonly used antibiotics might become ineffective, increasing the cost of maintaining animal health. Concerns have also been expressed about the risk that antibiotic resistance could be passed on to people who consume livestock products. No evidence has emerged to show that consumption of genetically modified feeds has affected animal health. But because such feeds have not been around long enough to carry out effective trials, it would be premature to conclude that the issue has been definitively resolved (Abelson and Hines 1999).

Degrade the environment? Probably the most controversial issues surrounding agricultural biotechnology relate to the long-term impact on the environment. The key issues:

- Whether genetically modified crops lead to genetic uniformity and, as a result, vulnerability to new matching strains of pathogens.
- Whether herbicide-resistant crops reduce agro-biodiversity.
- Whether cultivation of herbicide-resistant plants will result in super weeds by increasing the exchange of genetic information between crops and its spread to weedy relatives nearby.
- Whether *Bacillus thuringiensis* (Bt) crop hybrids destroy non-target insects, as Bt corn was thought to do to monarch butterflies (Losey, Rayor, and Carter 1999).

Only extensive, well-designed, and well-monitored field tests will provide conclusive answers to these questions. But the evidence so far is that the risk of environmental degradation is minimal (McGloughlin 1999). In the past 15 years researchers in the United States have conducted more than 4,000 field tests at 18,000 sites for efficacy, performance, and suitability for release into the environment (USDA/ERS 1999a). These and thousands of similar field tests in other countries have produced no conclusive evidence of danger to the environment.

Nor has biotechnology increased the vulnerability of germ plasm to homogeneous strains of pathogens or led to genetic erosion. For example, more than 1,000 Roundup Ready varieties of soybean are cultivated in the United States alone (USDA/ERS 1999a, b). But more impact assessment studies are needed to expand the empirical evidence, answer unanswered questions, and put the risks and benefits of genetically modified crops and foods into better perspective.

Reduce Africa's comparative advantage in tropical crops? With biotechnology, it will become possible to produce, in the laboratory or in temperate zones, crops that have been grown exclusively in the tropics. This prospect gives rise to concerns that the resulting competitive edge could drive many tropical products off the market. The common example is laboratory production of vanilla aroma, which could threaten the livelihoods of tens of thousands of small farmers in Madagascar, Uganda, and other African countries.

In cocoa production, genetically modified cacao seed varieties could raise yields and lower prices, dislodging smallholder production through plantation-scale farming in the newly industrialized economies of Asia. A similar outcome could occur for vegetable oils. And such countries as Mauritius, which depends on sugarcane for a large share of its export earnings, could find themselves hard-pressed if industrially manufactured low-calorie sweeteners supplant sugarcane.

The challenges—educate, innovate, regulate, deliver

Realizing the expected benefits of both medical and agricultural biotechnology in Africa is challenging in three respects.

First, some of the new technologies may not be readily applicable in Africa. This partly reflects the need for systematic provision of information and training to generate sufficient knowledge about the use of specific technologies. And it partly reflects the high cost of developing technologies and adapting them to a specific location. Effective exploitation of new technologies demands considerable investments in physical and human capital as well as institutions.

Second, biotechnology is not without potential risks, relating mainly to biosafety (risks to human health and safety and to the environment). Regulatory diligence is required, although available evidence suggests that such risks are minimal.

Third, the potential of biotechnology can be realized only if its innovations reach the ultimate beneficiaries. Delivering these innovations to poor and vulnerable individuals and communities (farmers, people suffering from HIV/AIDS, communities at high risk of malaria and tuberculosis infection) is thus as important as generating them.

In short, the successful use of new technologies depends on efforts to educate, innovate, regulate, and deliver—a course of action with mutually reinforcing components that should be embedded in the broad development strategy of each country.

Educate

Individuals—farmers, consumers, policy-makers, and scientists—are the agents and the beneficiaries of technological innovations. So, enhancing the capacity of these stakeholders to generate and adopt the new technologies is essential. There are two key parts to this:

systematic provision of information, and expanded training and education (formal and informal as well as general and specialized).

First, knowledge has to be systematically generated and disseminated about the technologies and about their appropriateness to African communities where they are going to be used. Information needs to be provided to all stakeholders about the benefits and risks of the technological innovations. Equally important, knowledge should be furnished about the needs, endowments, and constraints of target communities, particularly to policy-makers and research and development specialists. Such systematic generation and provision of knowledge is particularly essential for the new innovations in medical and agricultural biotechnology, given the impassioned debates about the biosafety, food safety, and other risks.

Information contributes to the successful adoption of these technologies in a number of ways. It helps potential users (such as poor farmers, consumers, and patients) and policy-makers to set priorities for research and development, particularly for the choice of crops and desirable traits, disease targets and treatments, and product delivery systems. It also helps researchers and product developers tailor their efforts to the needs of their target population (poor farmers, for example) in a way that reflects local endowments and constraints. The benefits from effective participation of stakeholders and context-specific innovations cannot be overemphasized.

Second, the stock of human capital in Africa needs to be further expanded and deepened. Human capital makes two critical contributions. It is a major determinant of the continent's capacity to absorb the knowledge associated with new technologies. And it is an essential input into the creation of new knowledge and technologies appropriate to the region. So, general education needs to be expanded to boost the analytical and adaptive capacity essential to the adoption of technologies. Advanced or specialized training is also indispensable, to build the expertise required for developing, regulating, and delivering biotechnology products. Education investments and curricula should reflect these demands.

Innovate

Research and development efforts in medical and agricultural biotechnology have been concentrated in industrial countries, with most conducted or funded by private companies motivated primarily by profits. As a result most biotechnology products are intended for use in industrial countries and controlled by a few multinational corporations. The evolving system of intellectual property rights complicates the situation by extending protection to certain types of innovations (such as the isolation of a gene, protected by a patent) while ignoring others, particularly indigenous knowledge and biodiversity. These circumstances call for technological and institutional innovations if Africa is to reap the benefits of biotechnology.

African countries need to direct their research and development efforts towards filling the gaps created by biases in multinational-led research and development, making advances in biotechnology relevant to African countries and their poor citizens. One urgent concern is HIV research and vaccine development focused on the strains of the virus prevalent in Africa. Much attention should also go to research on staple foods in African settings, local resource-intensive technologies, and crop and animal traits relevant to poor farmers.

It is important that the research and development efforts in Africa strike the right balance between fundamental research and product development. The capacity for fundamental research needs to be built gradually. Initially, however, resource constraints suggest that African countries are likely to benefit more from innovative adoptions of fundamental research technologies developed elsewhere. An important avenue is to combine discoveries in biotechnology with more conventional techniques and indigenous knowledge. For example, genes corresponding to desirable traits could be inserted into local varieties to further enrich them while preserving their good qualities. Appropriately exploited, such innovations could boost the productivity of poor farmers at reasonable cost.

Institutional innovations are also necessary. High transaction costs, considerable initial and fixed costs, imperfect information, and enforcement problems mean that thin markets and market failures are common in most African countries. Policy failures were also common until recently. To realize the potential benefits of biotechnology, these countries therefore need to initiate innovative institutional changes:

- *Ensure that biotechnology policies are African-owned.* The future of biotechnology lies in public awareness and acceptance: good technology alone is not enough. Diverse stakeholders should be involved in the formulation of national biotechnology policies, strategies, and plans. Continuous networking and monitoring by civil society groups are fundamental. And the participation of African research centres in the production process is vital to ensure that the final outputs are appropriate for Africa.
- *Develop intellectual property rights regimes.* Legislation should be enacted as needed to establish intellectual property regimes compatible with international agreements and national circumstances. This would encourage the expansion of private sector research and development capacity and ensure the protection of indigenous knowledge and local biodiversity while also benefiting users.
- *Expand public sector biotechnology research.* Market failures and institutional weaknesses mean that the public sector will continue to play the main role in research and development in Africa for the foreseeable future. So, it is critical to formulate a public sector strategy for biotechnology research, setting priorities and identifying areas and mechanisms for partnerships. Public investment in biotechnology research needs to be expanded and redirected accordingly.
- *Build innovative partnerships.* Public-private partnerships need to be developed, building on complementarities. Regional and international partnerships should be strengthened, and new ones formed. In agriculture, it is essential to build collaboration and support among national agricultural research systems in Africa and between these systems and public and private research establishments in industrial countries. In medicine, partnerships among pharmaceutical companies, governments, and international

Box 1

Best practice in research and development cooperation—for an HIV-1A vaccine

The clinical trial in Kenya to test a vaccine candidate for HIV-1A, one of the most common strains of the virus in East Africa, is an encouraging example of how research and development partnerships can work:

- *Funding*. The International AIDS Vaccine Initiative (IAVI) is funding the trial.
- *Collaboration*. The research is part of the larger initiative to develop a simple, effective, and affordable HIV vaccine, the basis of the unparalleled partnership among IAVI, the University of Oxford, and the University of Nairobi in Kenya.
- *Research approach*. The research approach was inspired by the seemingly natural immunity to the HIV virus witnessed in prostitutes in Nairobi slums. Researchers have designed a vaccine to simulate the natural immune response of these women.

Source: *IAVI 2002.*

organizations have proved vital in speeding the production and distribution of drugs and vaccines. Cooperative arrangements—such as the Consultative Group on International Agricultural Research and the International AIDS Vaccine Initiative—could play a key role in facilitating such collaboration and support (box 1). Also useful would be to explore the potential benefits and feasibility of regional or subregional common research areas, designed along the lines of common markets. These could facilitate technology transfer, help coordinate research and development priorities, secure and disburse funding, and organize the monitoring and evaluation of research and development through trials, peer review, and journals. A European Research Area is being established in the European Union to reduce the fragmentation of research activities and to improve efficiency in the use of financial and intellectual resources. The logic of establishing such areas in Africa is much more compelling.

Regulate

Government regulation of the diffusion of biotechnology is necessary for two reasons. It is required to safeguard against the risks associated with some innovations in biotechnology, including threats to biosafety and consumer safety. And it is required to enforce intellectual property rights.

In designing regulatory procedures, African governments should set coherent guidelines outlining where the responsibility for the introduction of new biotechnology products begins and ends. And they should ensure that risk assessment has a built-in system of checks and balances to safeguard the independence of test results—so that the potential risk of new products is not assessed by those wanting to release the products on the market. In some cases it may be advantageous to build regional regulatory arrangements that address common regulatory problems, leveraging scarce institutional and human resources through economies of scale.

Although the need for regulation applies generally, the extent and forms of regulation are likely to vary across countries. A key consideration is the institutional capacity and stock of human capital at a country's disposal. A country with limited resources for regulation may prefer to promote less risky biotechnology products, though the rewards may be smaller. In determining what forms of regulation to adopt, each African country needs to weigh the urgency of achieving its development goals and its capacity to regulate against the potential risks of biotechnology.

Deliver

The successful application of emerging technologies requires building effective delivery systems and creating and strengthening the complementary infrastructure. The aim should be low-cost delivery not only of biotechnology products (such as improved seeds, drugs, and vaccines) but also of complementary inputs (such as pesticides, fertilizers, irrigation water, improved management practices, and relevant and up-to-date information and advice). There are three priorities.

First, innovations in biotechnology must be made affordable to potential adopters and users. The research and development costs of biotechnology products are considerable, and the prohibitively high prices of those now available partly reflects that. As a result many of these products are beyond the reach of those who need them most—such as poor farmers and HIV/AIDS patients. Well-designed government support schemes are needed to increase access for these groups. Current arrangements involving drug companies, international agencies, and individual countries should be strengthened to further extend access. And similar arrangements should be initiated to promote access to agricultural biotechnology.

One proposal that warrants international dialogue involves establishing an innovation purchase fund that would buy patents for innovations from private innovators (Kremer 2000). These innovations would be put into the public domain, thus ensuring adequate diffusion. The fund could be designed to be pro-poor, to have priorities specific to regions or country groups, to cover biotechnological and other relevant innovations, and to promote innovations other than those already patented.

Second, potential adopters and users of biotechnology products must have the incentives to adopt them. This is particularly important for agricultural biotechnology products. Such incentives, reflecting returns from adoption or use, are determined largely by market and institutional structures and physical infrastructure. So, investments aimed at developing incentives are essential. These might include an effective agricultural extension service and a well-equipped health infrastructure—or efficient transport, communications, and electricity networks to facilitate the delivery of the biotechnology products as well as access to factor and product markets. Efficient credit schemes for the poor (including micro-finance) are also critical. Equally important are investments to build institutions that ensure the rule of law and improve contract enforcement. All these investments are essential to provide potential adopters and users the opportunity to realize the potential benefits of innovations and thus the incentive to adopt them. They would also encourage the private sector to provide goods and services to poorer areas.

Third, because the resource requirements of building effective delivery systems are substantial, cooperation between the public and private sectors is essential, and generous assistance from Africa's development partners indispensable.

The need for collective action

An important message emerging from the report is the need for regional approaches and strategic partnerships to complement national measures. The report shows that achieving sustainable development will require the production of regional and global public goods—services or resources whose benefits are shared among the countries in a region or more broadly.[1] Regional approaches can effectively deliver regional public goods. Strategic international partnerships can help deliver global public goods.

Regional and global public goods include the knowledge, the regimes, and the standards and rules required to address cross-border problems such as infectious disease control and use of genetically modified crops; the institutions that monitor and enforce the rules and regimes; and the benefits that arise and are shared indiscriminately among countries. To ensure the provision of these goods in sufficient quantity, international collective action will be critical, because no individual country has an incentive to pay for such things as the prevention of contagious diseases, the preservation of biodiversity, or research to develop new crops, vaccines, or drugs to treat tropical diseases.

Regional and global public goods arise when individual countries take actions leading to beneficial cross-border spillovers. One example is a public health policy that improves domestic health while reducing the transmission of pathogens and disease across borders. The production of regional public goods typically requires cross-border collective action engaging all or most members of the spillover group.

Many of the failures to tackle the underprovision of regional public goods result from a lack of collective action, high coordination costs, or lack of trust and political will. Regional approaches can stiffen the political will and avoid costly policy reversals. They can also minimize the transaction costs of sharing information. Cooperation among neighbouring countries is often simpler because the countries know one another better and find it easier to share information.

Optimal provision of regional and global public goods demands an open, consultative process of bargaining, to ensure that all countries and regions receive the benefits. A regional approach can be an efficient means of coordinating action, setting priorities, reviewing progress, mobilizing resources, allocating funds, and monitoring contribution levels.

The provision of regional public goods will require new and innovative financing at the regional level. Development assistance remains anchored in country-based projects and programmes. Greater flexibility will be needed to finance regional programmes for providing regional public goods.

Around $16 billion is allocated annually to international resource transfers for global public goods in health, environment, and knowledge creation. Roughly $11 billion of this goes to support national infrastructure for public goods provision—such as basic health care systems and environmental management—leaving only a small share for regional and global public goods. Thus much more needs to be done at the regional level. Regional agencies, in collaboration with other development partners, can play an important role in the provision of regional public goods through their ability to convene and their capacity to generate and transfer knowledge.

* * *

Modern medical and agricultural biotechnology can contribute much to increased food security and better health in African countries by speeding the agricultural productivity and epidemiological transitions in these countries. For that to happen, it is critical that biotechnology be viewed as one part of a comprehensive, sustainable poverty reduction strategy, not as a technological "quick fix" for Africa's hunger and poverty problems. It is also essential that the necessary innovations and investments be made in institutions. And particularly critical is building national and regional consensus to invest in the future. Indeed, the greatest risk for Africa is to do nothing, allowing the biotechnology revolution to pass it by.

Note

1. International public goods fall into two categories, regional and global public goods, with the difference being the more limited geographic reach of regional public goods. The benefits of pure regional public goods are "non-rival" (one country's consumption does not subtract from the amount available to other countries) and "non-excludable" (no country in the region can be excluded from benefiting, except at prohibitive cost). In reality, most regional public goods are significantly, but not wholly, non-rival and non-excludable. Rather than being "pure," they are "mixed," meaning that they bestow a combination of national and transnational benefits.

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Chapter 1

Sustaining Natural Assets and Reducing Human Vulnerability

The poor rarely speak of income, but focus instead on managing assets—physical, human, social and environmental—as a way to cope with their vulnerability.

The poor live at the whim and mercy of nature.

—Narayan and others 2000

Some key facts

- Poverty in Africa is exacerbated by precarious livelihoods and deteriorating agro-climatic conditions, with the rural poor suffering the most.
- Africa's population, growing by 2.5% a year, will exceed 1.2 billion people by 2025—with disastrous consequences.
- Africa has a much higher disease burden than any other region, with 30% of the burden due to environment-related diseases such as malaria, diarrhea, and respiratory infections.
- Land degradation is a major source of household food insecurity, income risk, and vulnerability.
- More than half of Africa's soils are acidic and low in nutrients.
- Though Africa generates only 2–3% of the world's carbon dioxide emissions from industrial and energy sources, it is highly susceptible to the effects of climate change: droughts, cyclones, floods, and bushfires.
- Africa has a large, diverse stock of biodiversity, including more than 1,000 mammal species, 1,500 bird species, and 50,000 plant species. The continent contains 5 of the world's 25 biodiversity hotspots—including the Guinean hotspot, the world's most diverse in terms of mammal species. East Africa, meanwhile, contains 63% of Africa's endemic bird species, 55% of mammals, 49% of reptiles, and 40% of amphibians.
- Nearly 80% of Africa's logging activities and 17% of agriculture clearing occur in frontier forests.
- Significant climate changes over the next 50–100 years will likely make it impossible for many wild organisms to survive in their natural ranges.

Households and societies manage a diverse portfolio of assets: physical, human, social, intellectual, and natural. Although Africa benefits from—and depends on—extensive natural assets, they are at enormous risk. The reason is that natural assets such as forests, fisheries, and water tend to be common property goods for which markets cannot provide basic coordinating functions—revealing true values, balancing interests over time, and providing efficient outcomes. As a result natural assets are difficult to manage sustainably, leading to the loss of tropical forests, degradation of soils, overexploitation of fisheries, destruction of coral reefs, and deterioration of surface water and groundwater.

Two functions of natural assets are especially crucial to the health and livelihoods of poor Africans—particularly in rural areas, where 70% of the region's people live. The first is a sink function, with air and water absorbing human-generated pollution. The second is a production function, supporting livelihoods through output from forests, fisheries, and mines. Moreover, these two functions are interlinked: human health—which suffers in the face of widespread pollution—affects productive capabilities, and a lack of output (such as food) affects health.

Achieving sustainable development in Africa will require maintaining natural assets and reducing human vulnerability

Human vulnerability is defined as the lack of key assets, exposing societies to increased risk of poverty. The fewer assets a society has, the more vulnerable it is. Thus degradation of natural assets can exacerbate poverty and increase vulnerability. In rural Africa seasonal fluctuations in food and water supplies are one of the main causes of vulnerability. In addition, many poor Africans live in environmentally fragile areas such as arid or tropical lands with low soil fertility. Lacking other options, growing numbers of poor people have also moved to steep hillsides and low-lying coastal areas. These fragile sites are increasingly caught in a downward spiral of poverty and resource degradation.

The urban poor are also vulnerable to degradation of natural assets and to extreme weather events. During 1970–95 the number of poor urban Africans increased by 5.2% a year (Fay and Opal 2001)—with disastrous consequences. In some parts of Benin poor people live in "water up to their ankles for three months a year and must contend with diarrheal diseases and respiratory tract infections, impassable streets, reduced opportunities for petty trades and constant housing repairs" (Narayan and others 2000, p. 47). In Senegal the urban poor live in what have been called "floating neighborhoods," with crowded, unsanitary housing in peri-urban areas.

The main message of this chapter is that achieving sustainable development in Africa will require maintaining natural assets and reducing human vulnerability. The chapter lays the groundwork for those that follow by defining three key elements of a strategy to make the transition to sustainable development:

- Using more robust, timely indicators of sustainable development to monitor, diagnose, and manage problems at the local and regional levels (chapter 2).
- Increasing agricultural productivity and reducing food insecurity by exploiting recent advances in biotechnology (chapter 3).
- Improving health, with particular attention to diseases that worsen poverty—HIV/AIDS, malaria, and tuberculosis—by exploiting recent advances in science and gene technology (chapter 4).

These elements are not an exhaustive list. Sustainable development requires an approach spanning multiple sectors, including water, energy, health, agriculture, and biodiversity. But no attempt is made here to offer detailed multi-sector recommendations. Instead, vital but often overlooked issues—such as reliable statistical systems and indicators—are highlighted as a basis for action. In addition, important missing elements—such as new technologies for health and food production—are identified.

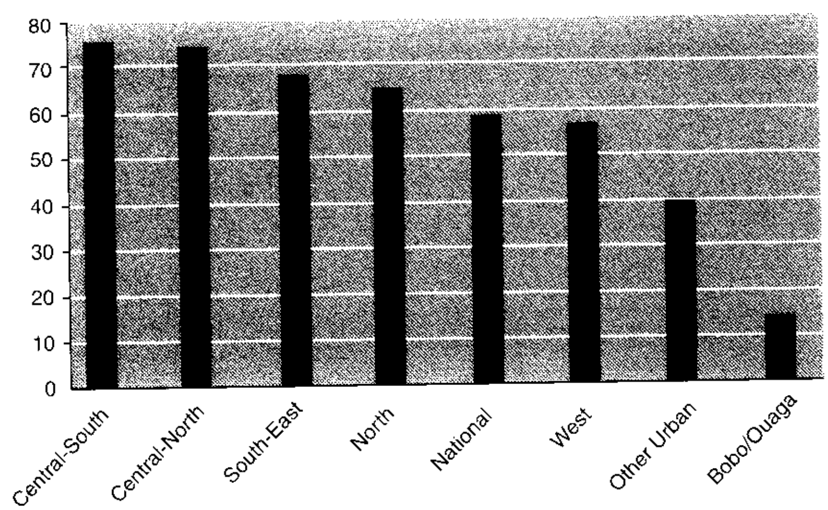
Agro-climatic conditions are highly correlated with poverty and vulnerability

Vulnerability occurs when people or societies lack key assets and are exposed to greater risk of poverty

Vulnerability occurs when people or societies lack key assets and are exposed to greater risk of poverty. Poor people tend to have not only low incomes, but also low and unstable natural resource bases. As a result poor people's livelihoods are more likely to be disrupted by prolonged drought, major crop failures, or devastating livestock diseases. Thus agro-climatic conditions and geographic factors, such as rainfall and soil type, are critical in determining vulnerability and poverty.

Large differences in living standards between areas in the same country are correlated with unequal distributions of natural assets, differences in agro-climatic conditions, or differences in geographic conditions, such as remoteness from markets and transport routes (Bigman and Fofack 2000). These findings are intuitive because households in remote areas, living on fragile lands, would be expected to have fewer opportunities and face greater risks and vulnerability than households in better-endowed areas. The findings are also consistent with the fact that poverty is more severe in rural than in urban Africa. These

Figure 1.1
Poverty in Burkina Faso by region, 1994 (headcount, percent)



Source: *Adapted from Bigman and others 2000.*

analytical underpinnings make it possible to develop a strategy for sustainable development based on sustaining natural assets and reducing human vulnerability. The following examples show the clear relationship between poverty and agro-climatic conditions in various African countries.

Burkina Faso

Burkina Faso has relatively high population densities, few natural resources, and fragile soils. About 90% of the population is engaged in subsistence agriculture, which is highly vulnerable to variations in rainfall. Poverty varies enormously by region, ranging from 14% in the capital to 75% in central and southern regions (figure 1.1). Poverty is high in the south-central, north-central, and south-east regions due to scarcity of natural resources such as water and fertile land, as well as severe population pressures (see Burkina Faso Ministry of Economy and Finance 2000). Poverty is much lower in regions close to the capital and those with better agro-climatic conditions—particularly in the west, which is hilly and wet.

Ghana

In 1998/99 the poverty headcount ratio for Ghana's rural savannah was 70%, while for Accra (the capital) it was just 4% (table 1.1). The vast differences in poverty across regions owe much to variations in agro-climatic conditions. High poverty in rural savannah and rural coastal regions is partly the result of dry climates. Southern and eastern areas, and especially rural forests, have lower poverty partly due to more favourable agro-climatic conditions, including high plateaus and mountains with better rainfall. In addition, parts of these areas are drained by the Volta river.

In 1998/99 the poverty headcount ratio for Ghana's rural savannah was 70%, while for Accra it was just 4%

Table 1.1
Poverty in Ghana by agro-climatic region, 1998/99 (percent)

Agro-climatic region	Headcount ratio
Rural savannah	70
Rural coast	45
Urban savannah	43
National average	39
Rural forest	38
Urban coast	24
Urban forest	18
Accra	4

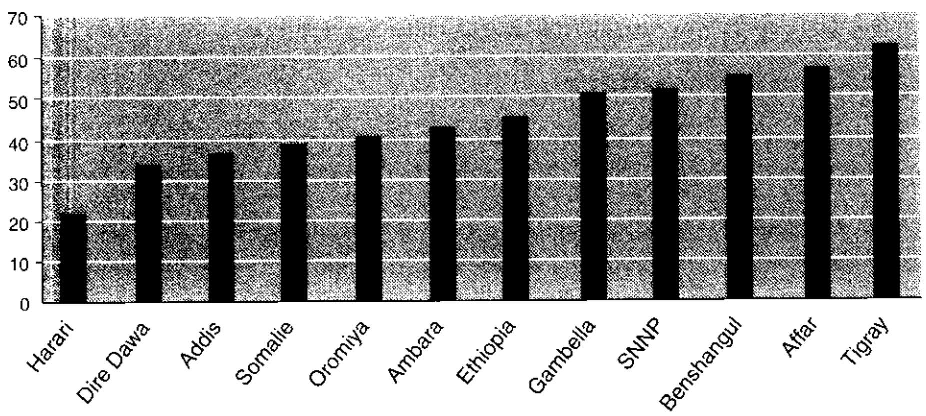
Source: *Christiaensen, Demery, and Paternostro 2002.*

Ethiopia

In 1999/2000 the poverty headcount in Ethiopia ranged from 26% in Harari—a prosperous region that produces many export crops—to 61% in Tigray—a drought-prone region dominated by settlements on fragile land (figure 1.2). Other poor regions, such as Affar and Benshangul, rely on pastoral livelihood systems and are exposed to frequent hardships in the form of livestock disease and other environmental hazards.

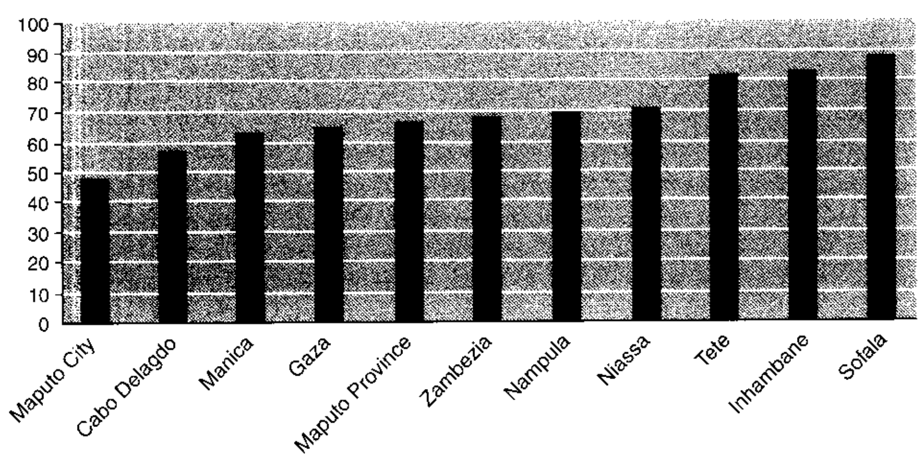
In Mozambique the provinces of Sofala, Inhambane, and Tete had poverty headcounts above 80% in 1996/97, while the city of Maputo had a headcount of about 48%

Figure 1.2
Poverty in Ethiopia by region, 1999/2000 (headcount, percent)



Source: *Ethiopia Ministry of Finance and Economic Development 2002.*

Figure 1.3
Poverty in Mozambique by province, 1996/97 (headcount, percent)



Source: *Datt and others 2000.*

Mozambique

In Mozambique the provinces of Sofala, Inhambane, and Tete had poverty headcounts above 80% in 1996/97, while the city of Maputo had a headcount of about 48% (figure 1.3). Agro-climatic conditions in the poor provinces make them more prone to vulnerability and risk. Most of Sofala is covered by deciduous forests and mangrove swamps. Similarly, Inhambane has a climate that varies from humid tropical on the coast to dry tropical on the mainland—a pattern not especially conducive to rural livelihoods.

Income fluctuations are a significant cause of transitory and persistent poverty

By contrast, the province of Cabo Dolgado is abundant in water resources, being drained by five major rivers. Most households in this province survive on farming and some fishing. And despite a prolonged war, poverty in the province is the second lowest in Mozambique—mainly due to favourable agro-climatic conditions.

Uganda and elsewhere

The distribution of poverty in Uganda is also closely related to agro-climatic conditions. Poverty is higher in the relatively dry north than in the more fertile south and west.

Large variations in poverty—with similar links to agro-climatic conditions, remoteness, or both—have also been found in many other countries. In Africa poverty is much more heterogeneous within than across countries.

Shocks to natural assets speed transitions into poverty

Income fluctuations are a significant cause of transitory and persistent poverty (Dercon 2001). In Ethiopia harvest failure—largely due to drought, flood, pests, or disease—has been a major shock for most rural households since 1980, in some cases reducing consumption by one-fifth (figure 1.4; Dercon 2001; Kebede and Shimeles 2002).

The rural poor tend to be more vulnerable because of their limited ability to substitute assets to mitigate shocks. A recent survey in Ethiopia found that just 2% of rural households produced enough crops to last them more than a year, and only 45% produced enough to last them more than six months (Ethiopia Central Statistical Authority 2001). Some farmers may understate crop production in an effort to secure food aid or other benefits. But it is more likely that most rural farmers are malnourished and suffer from illnesses, resulting in insufficient crop production and persistent food insecurity and poverty.

Zimbabwe's 1995 drought clearly illustrates the severity of income losses associated with shocks such as harvest failures. Changes in the rural income distribution between 1990 and 1995 would have been much smaller had rainfall in 1995 remained at its 1990 level. The drought caused extensive income losses and so increased poverty. But the drought was not the only reason the income distribution changed: other changes resulted from individual and household characteristics.

Physical ecology exacerbates the burden of disease

Africa has a much higher disease burden than any other region, with 30% of the burden due to environment-related diseases such as malaria, diarrhoea, and respiratory infections (table 1.2).[1] Africa suffers a high disease burden for several related reasons: its physical ecology supports high infectious disease transmission, poor nutrition results from low agricultural productivity, and there are feedbacks through poverty (illiteracy, lack of access to medical care, lack of access to sanitation).

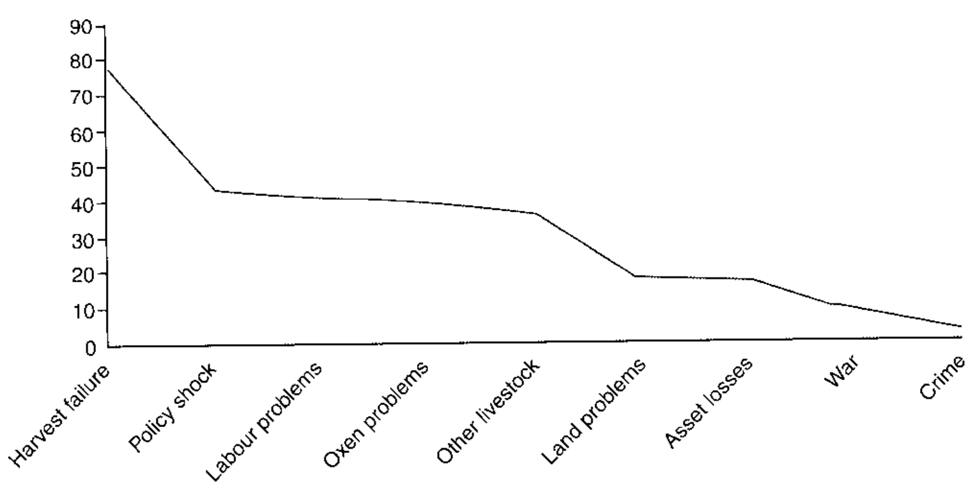
The rural poor tend to be more vulnerable because of their limited ability to substitute assets to mitigate shocks

Physical ecology appears to be by far the most important reason for Africa's disease burden. Consider malaria, where an ambient temperature of 18 degrees Celsius is required for successful transmission between the vector (the mosquito) and the human host. The year-round warm temperatures in Sub-Saharan Africa support year-round transmission and much higher infection rates.

Population pressure is increasing

Africa's population, growing by 2.5% a year, will exceed 1.2 billion people by 2025 (UN 2001). But there will be considerable differences by region. Growth will be slightly faster in Central Africa (3.0%), West Africa (2.9%), and East Africa (2.6%) but slower in North Africa (2.1%) and Southern Africa (1.0%). The explosive growth in population is putting pressure on the continent's natural resources.

Figure 1.4
Shocks to rural households in Ethiopia, 1980–2000 (percentage reporting hardships)



Source: *Dercon 2001.*

Population densities in Africa are highly variable—and low relative to other tropical regions. The continent's average population density jumped from 7 inhabitants per square kilometre in 1950 to 24 in 1995, and is projected to reach 46 in 2050. By comparison, population densities are 152 in the Caribbean, 127 in South Asia, 121 in East Asia, and 107 in South-East Asia. But Africa's average disguises significant variations, with areas of both very low and very high population densities. The highest are in East Africa's island states, where densities range from 160 per square kilometre in the Seychelles to 570 in Mauritius. Some of the lowest population densities are found in the Horn of Africa: Somalia (14), Djibouti (27), and Eritrea (30).

Africa has a much higher disease burden than any other region

The demographic transition is stalled

The demographic transition—from high fertility and mortality to low fertility and mortality—is essential for sustainable development because it slows population growth, increases investments in individual children, and expands the working-age population. Slower population growth also places less strain on a society's natural resources.

Box 1.1

Southern Africa's food security crisis—and its links to drought and disease

Southern Africa is facing a regional food security crisis due to adverse climate conditions for two consecutive growing seasons, mismanagement of grain reserves, and questionable government policies, particularly in Zimbabwe. A drought extends across much of the region, with Lesotho, Malawi, Mozambique, Swaziland, and Zimbabwe among the most affected countries. The World Food Program estimates that in 2002 Zimbabwe's maize production will be about 0.5 million tonnes—nearly two-thirds less than in 2001. Production will meet just one-quarter of Zimbabwe's maize consumption requirements. The current crisis may be worse than the 1995–96 drought, which affected 6 million people.

The Southern Africa Development Community estimates that across the region, the maize deficit will total 3.2 million tones in 2002. Zimbabwe has traditionally exported food, supplying food-deficit countries in the region such as Malawi and Zambia. Thus Zimbabwe's significant shortfalls in agricultural production are affecting food prices, availability, and accessibility throughout Southern Africa.

High rates of HIV/AIDS in much of the region leave large portions of the population increasingly susceptible to the health problems associated with food shortages, including malnutrition. People suffering from both malnutrition and HIV/AIDS also become more susceptible to endemic diseases such as malaria and cholera. In Malawi 45, 000 children are suffering from severe malnutrition, and the United Nations Children's Fund expects the situation to deteriorate further during the lean season, between January and March 2003.

Source*: Economic Commission for Africa from official sources.*

Table 1.2
Burdens of disease from major environmental risks
(percentage of disability-adjusted life years lost in each group)

Environmental risk	Africa	India	China	Asia and Pacific	Latin America	Least developed countries
[illegible]	[illegible]	[illegible]	5	2	3	2
Malaria	9	0.5	0	1.5	0	3
[illegible]	1	1	1.5	1.5	2	1
Indoor air pollution	5.5	6	9.5	4	0.5	5
[illegible]	[illegible]	13	4.5	10	7	9
Total	29.5	20.5	20.5	19	12.5	21

Source: *Lvovsky and others 2000; Lvovsky 2001.*

Africa's population, growing by 2.5% a year, will exceed 1.2 billion people by 2025

Africa's high burden of disease has slowed its demographic transition. Among other reasons, households will tend to compensate for high child mortality by maintaining high fertility (Sachs 2001). Projections show a slow decline in fertility, from 6.1 children per woman in 1995 to 4.9 in 2025, accompanied by a slow and uneven decline in mortality. Average life expectancy at birth is expected to increase from 50 years in 1995–2000 to 58 years in 2025, and in 2025 could reach 80 years in Reunion, 77 in Mauritius, and 74 in South Africa. But life expectancy will not rise much above 55 years in countries with poor health services or those hit hard by HIV/AIDS. In several countries HIV/AIDS has already reduced life expectancy by more than 10 years.

Land degradation is accelerating, with dire consequences for food security

Nearly 500 million hectares in Africa are moderately or severely degraded. Land degradation is linked to poverty and population pressures, people's attitudes and values, weak land management and tenure systems, and drought—which result in overgrazing, unsustainable agricultural activities, overexploitation of land (such as trees used for fuelwood), and deforestation (box 1.1). About 50% of land degradation is caused by overgrazing, 24% by crop production, 14% by clearance of vegetation for agriculture, and 13% by overexploitation. Degradation has increased desertification, decreased land productivity, and caused losses of arable land. Degraded land produces less food, reduces the availability of biomass fuel, makes ecosystems less resilient, and increases malnourishment and susceptibility to disease in local populations. Nearly 40% of Africans live on fragile lands—the highest share in the world (table 1.3).

Where land is abundant, rapid population growth does not lead to degradation because farmers shift their cultivation patterns, leaving cropped land fallow to replenish lost nutrients. But land is scarce in many African countries, and rapid population growth without intensive cultivation results in degradation (ECA 1999b). Population pressures are also reducing arable land per capita, which fell from 0.60 hectare in 1961 to 0.27 hectare in 1993.

Poor farmers cannot undertake intensive agriculture requiring significant inputs or investments in soil improvements. Their only alternative is to mine soils until they become completely degraded (see below). Poverty also makes rural people dependent on fuelwood for energy. Because there is no afforestation to mitigate overexploitation, degradation results.

Land is scarce in many African countries, and rapid population growth without intensive cultivation results in degradation

Land degradation is also closely linked to land tenure systems. If people do not have title to land, they have no incentive to invest in long-term improvements—especially on rented land. On rangelands, traditional methods of managing grazing have become less effective. Free-range grazing has led to overgrazing, especially in arid and semi-arid areas, leading to deteriorated land cover. Finally people's attitudes are very important in land management. Because rural people tend to be poor and unaware of conservation methods, their attitudes and approaches may lead to land degradation.

Soil degradation

Soil degradation is the most serious consequence of land degradation. Among regions, the most degraded soil is in Asia (37% of all soil) and Africa (26%). In Africa the main type of soil degradation is water erosion (53%), followed by wind erosion (31%), chemical

Table 1.3

Populations living on fragile lands by region, 2000

Region/country group	Total population (millions)	Population on fragile lands: Number (millions)	Population on fragile lands: Share of total population (percent)
Sub-Saharan Africa	658	258	39.3
Middle East and North Africa	293	110	37.6
East Asia and Pacific	1,857	469	25.3
South Asia	1,355	330	24.4
Latin America and the Caribbean	515	68	13.1
Europe and Central Asia	475	58	12.1
OECD[a]	850	94	11.1
Other	27	2	6.9
Total	6,030	1,389	24.7
Total less OECD	5,180	1,295	26.9

a. Includes Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Italy, Japan, Luxembourg, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, Switzerland, the United Kingdom, and the United States.

Source: *Economic Commission for Africa from official sources.*

degradation (11%), and physical degradation (5%; table 1.4). The main causes are overgrazing (59%), crop production (18%), overexploitation (17%), and deforestation (7%; UNEP 1997).

North and East Africa have experienced significant soil losses. In Ethiopia and Uganda soil erosion accounts for more than 80% of the costs of environmental degradation, estimated at 1–4% of GDP. Each year Ethiopia loses 1.9 billion tonnes of topsoil from its highlands, while Burundi loses 80–150 tonnes a hectare—and Rwanda, 557 tonnes a hectare (CT&E 2000; CEDARE 2000). South Africa could be losing as much as 400 million tonnes of soil each year, while in Malawi soil losses range from 0–50 tonnes a hectare each year.

Each year Ethiopia loses 1.9 billion tonnes of topsoil from its highlands, while Burundi loses 80–150 tonnes a hectare

Soil erosion caused by water or wind and is mainly associated with annual crops such as maize and millet. Water erosion occurs throughout Africa but is especially pronounced in the Mediterranean and arid North Africa, humid and subhumid West Africa, subhumid and mountainous East Africa, and subhumid and semi-arid Southern Africa. In addition, cultivation of annual crops causes water erosion on arable land in every subregion. By 1991 water erosion had affected 170 million hectares in Africa (see table 1.4). Overgrazing, deforestation, and cultivation of hill slopes are the main causes.

Wind erosion is prevalent in the Mediterranean and arid North Africa, Sudano-Sahelian Africa, and subhumid and semi-arid Southern Africa, and is especially common on arid grazing lands. Wind erosion has affected 98 million hectares in Africa, and can be caused by human activity or prolonged drought (see table 1.4). Controlling erosion is difficult without using narrow grass strips, terracing, or mulch from crop residue.

Chemical degradation is expressed through nutrient loss (83%), salinization (11%), and acidification (5%). It is mainly caused by poor irrigation practices, shortening of fallow cycles, and inappropriate fertilizer use. Chemical degradation affects 4% of Africa's drylands and 51 million hectares across the continent (ECA 1999b).

Physical degradation causes the structure of soil to deteriorate, making it more compact and harder to use because it drains poorly and is less permeable to rain. Such soil also develops hardpans and surface crusting. Some 17 million hectares of African land have been affected by physical degradation (ECA 1999b).

Effects on productivity and food security

Land degradation significantly reduces soil productivity and food security. If erosion's effects on soil productivity and plant nutrients are not addressed, soil eventually becomes unsuitable for crop production. Soil fertility is already a major problem: 56% of Africa's soils are acidic and low in nutrients (Moran 1987). Between 1970 and 1999 African soils lost a considerable amount of their natural nutrients, including nitrogen, phosphorus, and potassium. This loss is equivalent to an estimated 1.4 tonnes of urea fertilizer per hectare (in terms of nitrogen loss), 375 kilograms of triple super phosphate per hectare (in terms of

Table 1.4
Types of soil degradation by region, 1991 (millions of hectares)

Region	Water erosion	Wind erosion	Chemical degradation	Physical degradation	Total
Africa	170	98	36	17	321
[redacted]					
Australasia	3	—	1	2	6
[redacted]					
North and Central America	90	37	7	5	139
[redacted]					
Total	748	280	147	39	1,214

***Note:** Data refer to moderately and severely degraded soil.*
***Source:** FAO 1995.*

"Land degradation significantly reduces soil productivity and food security"

phosphorus loss), and 896 kilograms of potassium chloride per hectare (in terms of potassium loss; ECA 1999b).

Soil erosion can also increase flooding, pollute water supplies with sediment, and reduce hydroelectric power supplies through siltation of dams. Since 1950 erosion has reduced the productivity of Africa's cropland by 25%. Moreover, over the past century erosion has caused irreversible losses in soil productivity on at least 20% of land in large parts of Algeria, Ethiopia, Ghana, Kenya, Lesotho, Morocco, Nigeria, South Africa, Swaziland, Tunisia, and Uganda. In 1989 erosion reduced crop yields by 2–40% across Africa, with a mean of 8%. Annual soil losses in Mali, for example, range from 1 tonne a hectare in the north to 31 tonnes a hectare in the south—lowering annual yields by 2–10% (ECA 1999b). Thus land and soil degradation are significant hindrances to Africa's agricultural productivity, food production, and food security.

Deforestation threatens livelihoods

Deforestation—degradation of the wildlife, biomass, and gene pools in forest ecosystems—is one of the most pressing environmental problems in many Sub-Saharan nations. A leading cause is high demand for fuelwood, charcoal, and other wood-derived fuels (collectively known as woodfuels). Population growth is a driving force behind deforestation because it increases land clearing for agriculture and demand for woodfuel. The rising number of rural poor people depend on fuelwood and charcoal for cooking and heating. Charcoal, often in the form of briquettes, is also an important fuel for fast-growing urban poor populations. Market and policy failures also accelerate deforestation, mainly because a lack of property rights encourages overexploitation of woodland resources.

During 1990–2000 deforestation in Sub-Saharan Africa averaged 0.8% a year—the highest rate among all the world's regions. The costs of deforestation are being felt in the form of climate changes, droughts, flash floods, landslides, and soil erosion. There are powerful reasons to avoid destroying wilderness and the resulting extinction of species. The strongest argument for conserving biodiversity is to protect the ecosystems on which humanity depends. Species diversity is essential to the functioning of ecosystems and the biosphere as a whole. Each species is unique, and its functions are not necessarily substitutable. Diverse ecosystems protect soils, watersheds, local rainfall, and reserves of genetic resources for agricultural, industrial, and medicinal purposes. From a global perspective, forests play a decisive role in mitigating the effects of climate change. To regenerate, forests must be used sensibly.

Deforestation is one of the most pressing environmental problems in many Sub-Saharan nations

Despite low greenhouse gas emissions, the threat of climate change looms

Africa contributes very little to global climate change, with low carbon dioxide emissions from fossil fuel use and industrial production in both absolute and per capita terms. Africa accounts for 2–3% of the world's carbon dioxide emissions from energy and industrial sources, and 7% if emissions from land use (forests) are taken into account. Per capita carbon dioxide emissions from all sources are 1 tonne a year (Darwin and others 1995). Moreover, five countries generate most of Africa's carbon dioxide emissions from fossil fuel use and cement production. South Africa is by far the largest emitter, responsible for 39% of the continent's total. Another 42% comes from Algeria, Egypt, Libya, and Nigeria combined. Only Libya (1.98 tonnes) and South Africa (1.88 tonnes) have per capita carbon dioxide emissions higher than the global average of 1.13 tonnes a year.

Studies in 1990–96 found that Ghana, Kenya, Mali, and Zimbabwe are greenhouse gas sinks (ENDA 1997). Although agriculture (in Ghana and Kenya) and the energy sector (in Mali and Zimbabwe) are major emitters, forests are able to absorb far more gases than all other sectors emit.

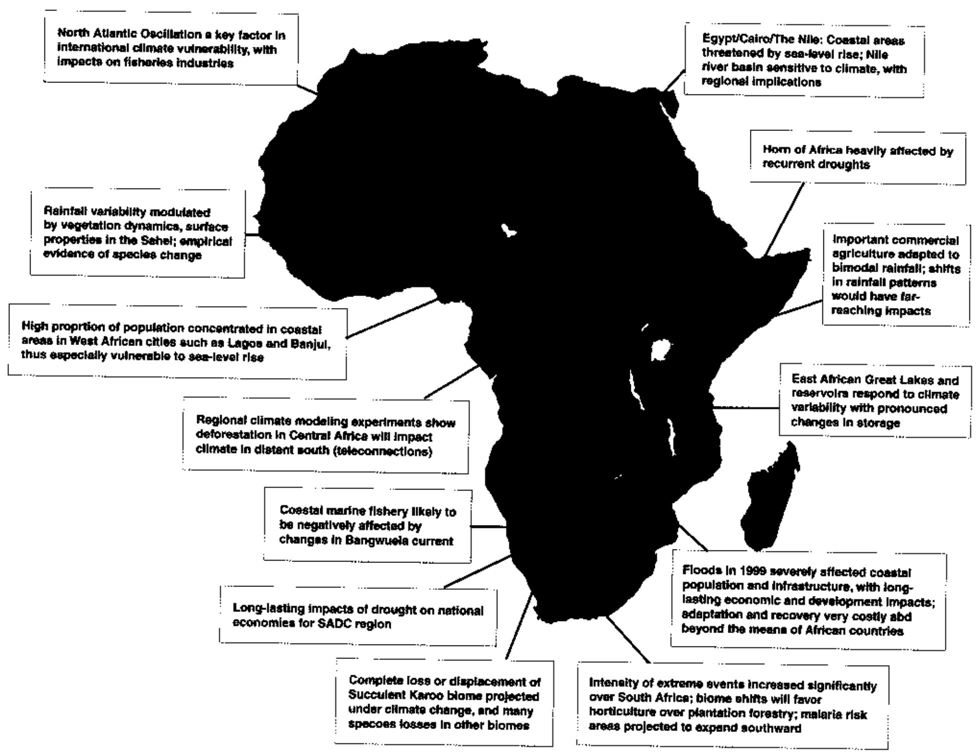
Still, Africa is susceptible to the effects of climate change because limited resources hinder its ability to mitigate the effects of weather and climate extremes (map 1.1). Climate-related disasters and diseases are on the rise. Droughts, cyclones, floods, and bushfires have brought misery (starvation, homelessness, death) to millions of people, especially in the Horn of Africa and Southern Africa (box 1.2). African societies have also suffered from reduced crop yields, decreased water availability, greater exposure to vector and water-borne diseases, and increased flooding. Malaria, cholera, and lower respiratory tract infections are increasing. These diseases result from a range of factors, including climate change, deteriorating water and air quality, and poor disposal of solid waste in urban areas.

Climate change will also likely decrease stream flow and groundwater recharge in many water-stressed countries in Southern Africa and around the Mediterranean. If temperatures were to increase by just a few degrees Celsius, food prices would rise, the incomes of vulnerable populations would fall, the number of people at risk of hunger would increase, and food security could worsen. Natural systems such as corals, mangroves, forests, and natural grasslands are at risk from climate change.

Climate change will likely decrease stream flow and groundwater recharge in many water-stressed countries in Southern Africa and around the Mediterranean

All African regions will likely suffer the effects of climate change, but small island states and low-lying coastal areas are particularly vulnerable. Coastal settlements in Egypt, the Gulf of Guinea, Senegal, and along the East and Southern African coast could be hurt by rising sea levels resulting from flooding and coastal erosion. Moreover, global warming may cause widespread extinctions of plants and animals in Africa—increasing poverty by undermining rural livelihoods and reducing tourism (PANA 2001).

Map 1.1
Africa's vulnerability to climate change



Source: *IPCC 2001.*

Box 1.2
Cyclones and storms increase vulnerability

In early 1994 the south-western Indian Ocean generated five tropical cyclones, causing immense hardships in Madagascar and several other Southern African countries. Cyclones Daisy (mid-January) and Geralda (early February) traversed southern and central Madagascar. Geralda, dubbed the "cyclone of the century" because of the devastation it caused, dropped 400 millimetres of rain and involved winds of 300 kilometres an hour—killing more than 200 people and leaving 500,000 homeless.

In March cyclone Nadia, with sustained winds of 185 kilometres an hour, claimed a dozen lives as it crossed northern Madagascar. Nadia then entered northern Mozambique, where it claimed more than 200 lives and left more than 1 million people homeless. Together the five cyclones in early 1994 produced 25–55% more rain than normal in January to March throughout much of central and southern Madagascar. In addition, in November 1994 some Egyptian harbours were closed and convoys in the Suez Canal delayed due to a series of storms across the Middle East.

In 2000 Madagascar, Mozambique, and other parts of Southern Africa were hit by another series of devastating cyclones. Between February and April these storms—including Eline, Gloria, and Hudah—caused severe flooding and claimed many lives. In Zimbabwe power and phone lines were cut, crops and village granaries washed away, and the Limpopo river reached its highest level in 15 years (http://www.mg.co.za/mg/news/2000feb2).

Africa has a large, diverse stock of biodiversity, including more than 1,000 mammal species, 1,500 bird species, and 50,000 plant species

Africa's rich biodiversity faces threats

Africa has a large, diverse stock of biodiversity, including more than 1,000 mammal species, 1,500 bird species, and 50,000 plant species. The continent contains 5 of the world's 25 biodiversity hotspots—including the Guinean hotspot, the world's most diverse in terms of mammal species. East Africa, meanwhile, contains 63% of Africa's endemic bird species, 55% of mammals, 49% of reptiles, and 40% of amphibians.

Tropical savannahs are Africa's most extensive ecosystem type and home to some of the world's most concentrated populations of large mammals. Mountains, highlands, and wetlands also have rich and unique biodiversity. With 300 endemic species of higher vertebrates (mammals, birds, and amphibians), Madagascar has more than any other African country and ranks sixth in the world. The Democratic Republic of Congo is the richest African country in terms of plant species, followed by Tanzania and Madagascar.

Yet many of Africa's biodiversity resources are endangered or at risk of extinction (box 1.3). All African countries are home to endangered species, with the highest numbers in Tanzania (43 mammal, 33 bird, and 236 plant species) and Madagascar (50 mammal, 27 bird, and 162 plant species). The Democratic Republic of Congo and Côte d'Ivoire also contain large numbers of endangered and vulnerable species. In addition, most of the continent's indigenous tropical forests are threatened, shrinking by nearly 1% a year.

Most of the damage to Africa's biodiversity is caused by human activities—including logging, agriculture, overhunting, pollution, excessive vegetation removal, introduction of alien species, and expansion of human settlements—and climatic variations (box 1.4). About 79% of Africa's logging occurs in frontier forest, as does 17% of agriculture and 12% of energy and other infrastructure development. In addition, significant climate changes over the next 50–100 years will likely make it impossible for many wild organisms to survive in their natural ranges.

Biodiversity provides the basis for many people's livelihoods and for local and national economic growth

Biodiversity provides the basis for many people's livelihoods and for local and national economic growth. It is also an invaluable global heritage. Direct benefits of biodiversity include the provision of food, medicine, and energy. Indirect benefits include the provision of essential life support services such as mitigating pollution, protecting watersheds, combating soil erosion, and recycling carbon, oxygen, and nitrogen. In addition, biodiversity is essential for food security: all major food crops and livestock depend on new genetic material from the wild to remain productive and healthy. Biodiversity also provides recreational opportunities and aesthetic values.

Biodiversity is also important for human health. About 120 pure chemical substances used by pharmaceutical companies around the world are extracted from some 90 species of higher plants. Yet many of the world's natural resources are being used faster than they can replace themselves.

Water resources are inadequate...

Africa's water resources are inadequate given the continent's vast size, high evaporation rates, and rapidly growing population. Moreover, the distribution of water resources varies enormously by region and season. Africa's annual water flow averages more than 4 trillion cubic metres and includes the world's longest river (the Nile) and its second largest in terms of basin and flow (the Congo). But the wet equatorial zone (mainly central and south-western countries) produces 95% of this flow; arid and semi-arid zones produce just 5% (Lake and Soure 1997).

Across Africa, rainfall averages 670 millimetres a year. The highest rainfall occurs in island states (1,700 millimetres), Central Africa (1,430 millimetres), and the Gulf of Guinea (1,407 millimetres). But in North Africa annual rainfall averages just 71 millimetres (ECA 2001).

The unequal distribution of water resources is even more striking when measured in per capita terms, ranging from 136,000 cubic metres in Gabon to less than 200 cubic metres in Libya (Lake and Soure 1997). Internal renewable resources are generally low, averaging 20% of rainfall for the continent but ranging from 6% in Sudano-Sahelian countries to 34% in island states (ECA 2001). Due to the intensity of rains, very little recharges underground aquifers; most is lost as surface runoff (box 1.5). In Kenya only 6% of annual rainfall is available for use—and in Ethiopia, just 3%. If current trends continue, by 2025 an estimated 25 African countries will suffer from water stress or water scarcity (map 1.2).

Africa also has 17 rivers with catchment areas larger than 100,000 square kilometres. The continent's eight largest international river basins are shared by 4 to 10 countries

Box 1.3

Threats to biodiversity in the Zambezi Basin

Many factors threaten the biodiversity of the Zambezi Basin, including pollution, fires, alien species, dams and other hydrology structures, and land clearance and overexploitation. Though they vary across the basin, many areas suffer from more than one of these problems.

The effects of pollution are often felt after long, continuous discharges of waste. Sources include local industries, mining compounds, and pesticides and fertilizers in runoff from agricultural land. Within the basin, pollution of Lake Chivero (near Harare, Zimbabwe) caused fish deaths in 1995, and mining projects have contaminated tributaries such as the Kafue in Zambia.

The Barotse Floodplains and many other parts of the basin are subject to regular fires. Vegetation in these areas has adapted to suit these conditions.

Introduction of alien species has had mixed effects on the basin's biodiversity. Pine trees have invaded the grasslands of Nyanga (Zimbabwe) and Mt. Mlanje (Malawi). In addition, the Nile tilapia fish was introduced in the waters of the Middle Zambezi, and the Kariba weed (Salvinia molesta) in the Chobe system. The water hyacinth weed now occurs in most tributaries of the Zambezi, reducing the biodiversity of indigenous species. By contrast, introduction of the kapenta fish (Limnothrissa miodon) in Lake Kariba in the 1960s has had more positive than negative effects because it was introduced in a newly created habitat.

Dam construction has the most significant effects on wetland biodiversity because it results in the formation of new habitats and the destruction or modification of old ones. The hydrology of the Zambezi river system was modified by the construction of the Kariba, Cahora, and Itezhi-Tezhi dams.

Human settlements have sprung up in formerly uninhabited areas. As settlements expand—reflecting population growth and other factors—more land is acquired and cleared for agriculture, urbanization, and other human development initiatives. Large settlements include the copperbelt towns of Zambia and the large urban settlements of Harare, Lusaka, Lilongwe, and many other cities in the basin. Land cleared for farms and plantations often replaces a rich diversity with a monoculture of plants.

Human development often also leads to overexploitation of certain species. Examples of overexploitation include overgrazing in various parts of the basin, overfishing in Lake Malawi, destruction of large mammals such as elephants, rhinoceroses, and antelope over wide areas, and harvesting of valuable timbre such as mukwa, African ebony, and Zambezi teak.

Source: *SARDC 2000.*

Africa's water resources are inadequate given the continent's vast size, high evaporation rates, and rapidly growing population

(figure 1.5). In addition, Africa has more than 160 lakes larger than 27 square kilometres, most of which are in the equatorial zone and the subhumid East Africa highlands within the Rift Valley (ECA 2001).

Groundwater accounts for 15% of Africa's water resources, with the main aquifers located in the arid zones of the northern Sahara, the Kalahari, and the Nubia, Sahel, and Chad basins (Lake and Soure 1997). Groundwater is a source of drinking water for more than three-quarters of Africans and is particularly important in North African countries such as Algeria, Libya, Morocco, and Tunisia, as well as in some Southern African countries (ECA 2001).

Box 1.4

The most serious threats to Africa's frontier forests

Frontier forests are the world's remaining large, intact natural forest ecosystems. But in Africa frontier forests face many threats:

- Logging, which can "rewrite" the structure and composition of forests. In Central Africa more than 90% of logging occurs in primary forest—one of the highest levels in the world. The roads built by logging companies open up forests to hunters, would-be farmers, and other profit-seekers. About 79% of Africa's logging takes place in frontier forest, compared with 72% for the world as a whole.
- Overhunting, introduction of harmful species, isolation of small islands of frontier forest through the development of surrounding lands, changes in natural fire patterns, and plantation establishment. A third of Africa's threatened forest frontier is at risk due to runaway poaching to meet urban demand for bush-meat. Overhunting removes key species that help maintain forest ecosystems and can upset other natural processes that shape forests—for example, by changing how seeds are distributed and herbivores are kept in check. Altogether, 41% of these activities in Africa occur in frontier forests. (world, 13%)
- Agricultural clearing, energy development, and excessive vegetation removal are the other main threats to frontier forests in Africa. About 17% of agriculture clearing happens in frontier forest (world, 20%), 12% of energy development, mining, and new infrastructure (world, 38%), and 8% of excessive vegetation removal (world, 14%).

Source: *WRI 2001.*

Africa has 17 rivers with catchment areas larger than 100,000 square kilometres

...and their quantity and quality are suffering

Human activities pose growing threats to the quantity and quality of Africa's scarce water resources.

Wetland degradation

Wetlands are a key component of freshwater ecosystems and have enormous economic and ecological importance. Wetlands provide a wide array of goods and service, including flood control, nutrient cycling and retention, carbon storage, water filtering and storage, aquifer recharge, shoreline protection and erosion control, and a range of foods and materials such as fish, shellfish, timbre, and fibre. Wetlands also provide habitats for many species, from waterfowl and fish to invertebrates and plants (www.wri.org/wr2000/freshwater).

Yet wetlands around the world have undergone massive conversion—with considerable social, economic, and ecological consequences and costs. Wetland changes include conversion to agricultural land and construction of dams that curtail the wetlands' seasonal replenishment. Examples include a large-scale irrigation scheme developed in the Hadjia-Jama'are river basin in north-eastern Nigeria and a dam constructed and rice irrigation scheme developed in the Waza-Logone floodplain in northern Cameroon (www.wri.org/wr2000/freshwater). In Southern Africa many wetlands and floodplains

Box 1.5

Rainwater harvesting: standing the test of droughts

Rainwater harvesting has attracted considerable attention in recent years. A wide range of techniques—tanks, farm ponds, gully detentions—are used, with some systems based on updates of technologies devised thousands of years ago. Where needed, public spending on rainwater harvesting can be justified by the fact that, in scattered settlements, such schemes are often cheaper than piped water.

Macro-catchment systems concentrate water from large areas, storing it in small reservoirs for agriculture. Cisterns (large underground tanks) are an example of macro-catchment. Another type, common in semi-arid North Africa, involves creating mountain lakes to supplement irrigation of crops much lower down.

At the other extreme is micro-catchment, which follows the same principles as macro-catchment. Contour ridges are created on slopes to concentrate water where it is needed, often to improve shrubs and grasses for livestock. In the semi-arid Sahel contour ridges have been used for sorghum and millet crops. In wet years the catchment may also be planted with drought-resistant legumes such as cowpeas and tepary beans.

Satellite and other aerial photography and geographic information systems are increasingly used to help determine suitable sites for water harvesting. Once a site has been identified, field work assesses factors such as run-off to project the amount of water that can be expected. Rainwater harvesting generally does not involve "best practice." Instead of searching for the best technology, efforts should focus on finding technology that can be adapted to local conditions.

For instance, in Niger and most of the semi-arid Sahel, natural rain-filled pools are the first source of water used by pastoralists after rain has fallen. There is scope for deepening some of these pools, for complementing them with human-made pools, and for better managing their use by pastoral communities. Rain-filled drinking points for livestock could help sustain pastoral lifestyles.

Source: *IWMI 2001; SIWI 2001.*

Groundwater accounts for 15% of Africa's water resources

could disappear as a result of large-scale irrigation schemes and other water management activities—as with Botswana's Okavango Delta, a globally important wetland area. If implemented, proposed water projects in the area could be ecologically damaging and put the delta at risk from drainage and water extraction (www.wri.org/wr2000/freshwater).

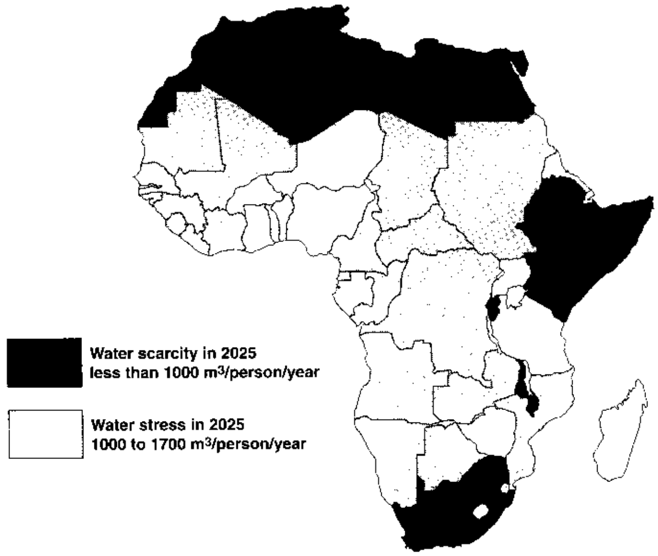
Water pollution

Africa's water bodies are being degraded by overextraction, poor waste management, and agricultural and industrial discharges (box 1.6). Pollution limits the regeneration of freshwater ecosystems and complicates water treatment for domestic use (Lake and Soure 1997). Agricultural and industrial pollution releases chemicals, pesticides, and fertilizers into water bodies, compromising their quality. In some water bodies, such as Lake Malawi/Nyasa, such contamination has killed fish (www.sadcwscu.org.ls/).

Saltwater intrusion also undermines water quality. This issue is especially pressing on the Mediterranean coast and on oceanic island states (such as Comoros) that are highly dependent on groundwater resources. Nutrient enrichment or eutrophication of water bodies resulting from pollution of phosphates and sulphate-rich materials can lead to

Map 1.2
Projected water scarcity and water stress in Africa, 2025

Africa's water bodies are being degraded by overextraction, poor waste management, and agricultural and industrial discharges



Source: *UNEP 2000.*

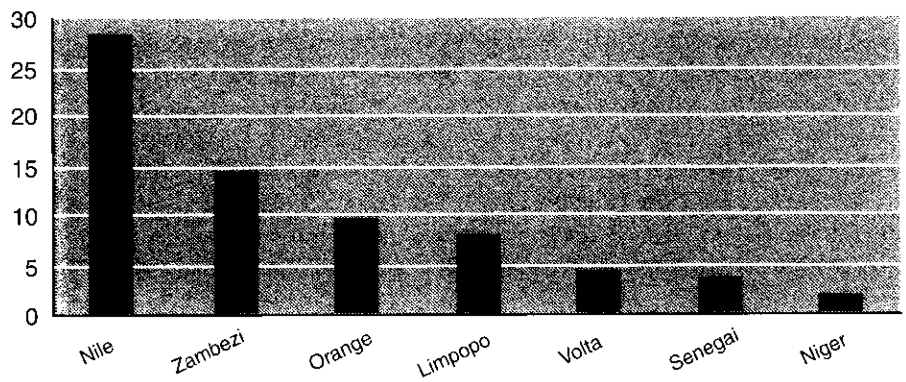
the blooming of aquatic weeds, particularly water hyacinth. Such weeds have caused serious damage to many water bodies, including Lake Victoria, the Nile, and Lake Chivero (ECA 2001).

Another serious concern is overgrazing and deforestation that result in severe soil loss and sediment flows into water bodies. Desertification and erosion threaten much of Africa, shortening the useful lives of reservoirs, lakes, and ponds. In some Sahelian countries rainfall has been declining by about 10 millimetres a year. If this trend continues, and predictions of global climate change come true, some African aquifers may become unusable. In Kenya sedimentation is cutting the lifespan of dams, reducing their storage capacity, and impairing downstream water supplies. In West Africa siltation has caused the Ibohamane and Mouela reservoirs (on the Niger river) to lose half their capacity over the past 15 years (Lake and Soure 1997).

Urban sprawl continues unabated, increasing vulnerability

Urban areas contain 38% of Africa's 767 million people and generate 60% of its GDP. But municipalities in Sub-Saharan Africa receive only a small portion of GDP in revenue—averaging $14 per resident—creating challenges for municipal governance (UN-HABITAT 2001c).

Figure 1.5
Africa's main international river basins (percentage of total)



Many West African countries have few secondary cities, so urban populations are concentrated in one or a few large cities

Note: *The Congo basin is shared by Angola, Burundi, Cameroon, Central Africa Republic, Democratic Republic of Congo, Republic of Congo, Rwanda, Tanzania, and Zambia. The Nile basin is shared by Burundi, Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Uganda, and Tanzania. The Zambezi basin is shared by Angola, Botswana, Malawi, Mozambique, Namibia, Tanzania, Zambia, and Zimbabwe. The Orange basin is shared by Botswana, Lesotho, Namibia, and South Africa. The Limpopo basin is shared by Botswana, Mozambique, South Africa, and Zimbabwe. The Volta basin is shared by Benin, Burkina Faso, Côte d'Ivoire, Ghana, Mali, and Togo. The Senegal basin is shared by Guinea, Mali, Mauritania, and Senegal. The Niger basin is shared by Benin, Burkina Faso, Cameroon, Chad, Côte d'Ivoire, Guinea, Mali, Niger, and Nigeria.*
Source: *Economic Commission for Africa from official sources.*

The pattern of urbanization in West Africa differs from that in East Africa. Many West African countries have few secondary cities, so urban populations are concentrated in one or a few large cities. In East Africa urban populations are distributed more evenly over secondary and tertiary cities, although primary cities are experiencing rapid growth. By 2015 Lagos (Nigeria) is expected to have more than 20 million inhabitants, and 70 African cities will have populations of more than 1 million. Rural-urban migration is one of the main contributors to urbanization in both West and East Africa. In Southern Africa natural population growth has been a key cause of urbanization for some time.

Rapid population growth in African cities (more than 3.5% a year) has been accompanied by mounting development pressures, with high demands for housing and infrastructure. Economic growth has failed to keep up with rapid population growth and its concentration in urban areas, leading to deterioration in human settlements and increased discharge of unprocessed waste into the environment—resulting in severe health problems. A growing portion of Africa's urban population is being forced into unplanned settlements on the outskirts of large cities or into more crowded and deteriorating housing in high-density areas. With physical infrastructure failing, a shrinking share of urban populations has access to good health services, regular garbage disposal, and clean, piped water. As a result most urban residents saw their quality of life worsen in the 1990s.

Box 1.6

The Nile Basin Initiative: regional cooperation on renewable resources

Stretching nearly 6,700 kilometres and draining more than 3 million square kilometres, the Nile is the world's longest river. The Nile is a transboundary river shared by 10 African countries (Burundi, Democratic Republic of Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania, and Uganda). The river's transboundary nature poses complex challenges, especially in terms of sharing benefits. Yet if properly planned and managed, the river promises sound returns for "win-win" development efforts that could enhance food production, energy availability, navigation, industrial development, environmental conservation, and related activities in the region. Some 160 million people live within the boundaries of the river basin, which covers a catchment area equal to 10% of Africa's landmass.

Among the main challenges facing the Nile basin are poverty (4 riparian countries are among the 10 poorest in the world), instability (with conflict in the Great Lakes, Sudan, and the Horn of Africa), rapid population growth (population in the area is expected to double by 2025), and severe environmental degradation (especially in the East Africa highlands).

The river's potential led the Council of Ministers of Water Resources in the Nile to launch the Nile Basin Initiative in 1999. The initiative includes all riparian states and provides an agreed, basin-wide framework to fight poverty and promote socio-economic development through the equitable use and sharing of benefits from the river's common water resources. A strategic action programme, involving both basin-wide and sub-basin investments, includes projects to promote collaborative action, share experience and information, and build capacity. In addition, riparian countries have identified other mutually beneficial investments at the sub-basin level.

A host of multilateral agencies and bilateral donors—the International Monetary Fund, World Bank, United Nations Development Programme, European Union, Canadian International Development Agency, France, Italy, Japan, Netherlands, Nordic countries, Switzerland, United Kingdom, and United States—have shown keen interest in the initiative, and by October 2001had provided $122 million in funding.

Source: *Nile Basin Initiative 2001.*

Economic growth has failed to keep up with rapid population growth and its concentration in urban areas

The rapid urban expansion of recent decades has also increased pressure on the urban environment and on surrounding areas and their natural resources—creating immense and growing air and water pollution, land degradation, traffic congestion, and noise pollution (box 1.7). In some countries as little as 2% of sewage is treated, while 30–50% of urban solid waste is left uncollected (University of Ghana 1995). For example, in the Accra (Ghana) metropolitan area only 11% of the population benefits from household waste collection; the rest use communal disposal sites or bury or burn their waste (University of Ghana 1995). Throughout Africa, dirty streets—with large heaps of uncollected, rotting garbage—are a common feature of cities. With weak infrastructure and poor services, urban agglomerations pose constant health hazards.

Box 1.7

Pollution in Cairo and Lagos—Africa's megacities

Megacities are urban agglomerations containing 10 million or more people. Among the world's 20 largest megacities are Cairo, Egypt (with annual population growth of 2.5%), and Lagos, Nigeria (1.7%). In both cities car ownership is less common than in industrial countries—yet air quality is as bad or even worse.

Cairo, home to about one in four Egyptians, is Africa's most populous city—and one of the world's 20 most air-polluted megacities. Most of Cairo's air pollution is generated by industrial activity and motor vehicles. The city may have the world's highest concentrations of airborne lead particulates, which can impair liver and kidney functions, raise blood pressure, lower children's (measured) intelligence, and cause other neurological damage. Eliminating lead from gasoline is a priority not only because of the harm that lead causes but also because doing so helps lower emissions of other pollutants. For example, catalytic converters can cut pollutant emissions by up to 90%—but they can only be installed on motor vehicles that use unleaded gasoline.

In Lagos large oil companies are destroying the Niger Delta with gas flaring and oil spills. Other major sources of air pollution include frequent traffic jams and a large number of motor vehicles with high pollutant emissions. Diesel-fuelled vehicles emit black exhaust consisting of soot, while gasoline-fuelled vehicles emit blue exhaust containing unburned oil. As a result local populations are exposed to high airborne concentrations of aromatic hydrocarbons, carbon monoxide, and particulates. Another problem is the "harmattan wind"—parching, dusty wind along the West African coast between February and December.

Air pollution in megacities is a function of many factors, including rates of industrialization, population growth, and socio-economic development. Most urban centres pose risks to public health not only because of environmental hazards but also because of heavy congestion, widespread water contamination, and weak or nonexistent sanitation and disposal systems. Cairo and Lagos urgently need better air quality data, emission inventories, and epidemiological data because without them it is difficult to properly assess their pollution problems. Still, the Egyptian and Nigerian governments recognize the importance of reducing urban air pollution and are taking steps to do so. These include:

- Implementing public education programmes to raise awareness of the health benefits of eliminating lead from gasoline and to address public misconceptions about the feasibility of using unleaded gasoline in cars without catalytic converters.
- Developing an intensive infrastructure to increase supplies of natural gas, which is far less polluting than traditional fuels.
- Encouraging technological diversity in power generation.
- Using a variety of economic instruments to encourage lower emissions from motor vehicles.

Source: *Economic Commission for Africa from official sources.*

The way forward—better data and new technology for agriculture and health

The two areas require urgent attention—low agricultural productivity and poor health

Sustainable development is Africa's top priority. This chapter has described some of the challenges facing the continent, including the links between poverty, vulnerability, and agro-climatic conditions, the high burden of infectious disease, severe land degradation and deforestation, biodiversity depletion, and water quantity and quality. These considerable challenges point to two areas requiring urgent attention—low agricultural productivity and poor health.

Although agriculture accounts for 30% of Africa's GDP, 40% of exports, and 70% of employment, agricultural productivity is extremely low. The average cereal yield in Africa is about 1,220 kilograms a hectare, compared with 37,288 kilograms in industrial countries—a 30-fold difference. Several ecological factors explain much of Africa's low agricultural productivity, including fragile soils, high biodiversity (which provides a perfect breeding ground for crop-devastating pests and diseases), extreme hydrological variability (droughts, floods, rainfall variations, evapo-transpiration), and poor water control caused by excessive precipitation (soil leaching, waterlogged fields). Steps required to increase agricultural productivity and reduce food insecurity are discussed in chapter 3.

The burden of disease is much higher in Africa than in any other region. There are several related reasons: the continent's physical ecology supports high infectious disease transmission, poor nutrition results from lower agricultural productivity, and poverty generates multiple feedbacks (illiteracy, lack of access to medical care and sanitation, and so on). Hence more attention should be paid to the killer diseases and epidemics that claim the lives of so many Africans. Urgent action is especially important for diseases that accentuate poverty—HIV/AIDS, malaria, and tuberculosis; see chapter 4.

Finally, better statistical information is needed, including more robust and timely indicators of sustainable development to monitor, diagnose, and manage problems at the local and regional levels. Tracking progress towards sustainable development is critical to the formulation and execution of effective policies; see chapter 2.

Note

1. Work done under the Global Burden of Diseases Initiative uses a standardized measure of health outcomes, disability adjusted life years (DALYs), across various causes of illness and death, providing a way to quantify the losses due to environmental risks (Murray and Lopez 1996).

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Chapter 2

Tracking Progress towards Sustainable Development

Treat the Earth well. It is not inherited from your parents, it is borrowed from your children.

–Kenyan proverb

Some key facts

- An indicator of overall sustainability—encompassing economic, environmental, and institutional dimensions—shows that African economies are less sustainable today than they were 25 years ago. At the end of 2000 more than half the population of the 38 countries assessed lived in economies with low overall sustainability.
- For the last three decades Mauritius, South Africa, and Botswana were Sub-Saharan Africa's star performers in economic growth, socio-political stability, and institutional sustainability. Burundi, the Democratic Republic of Congo, and Guinea had the worst performance in these areas.
- Until recently Zimbabwe ranked among the top five African countries in overall sustainability, with particularly high scores in economic and institutional sustainability.
- Economic sustainability in Africa initially improved in the period 1975–2000. But reversals in social and economic gains led to a downward trend in 1995–2000.
- South Africa, Gabon, and Algeria rank highest in economic sustainability, while Burkina Faso, Guinea, and Mali rank lowest.
- Environmental sustainability in Africa recovered slightly after the mid-1990s as growth in the population and in carbon dioxide emissions slowed.
- Gabon, Burkina Faso, and Guinea top the rankings in environmental sustainability, while Mauritius, Tunisia, and Kenya come in last.
- Overall, African countries made good progress in institutional sustainability over the last 25 years, with sharp improvements towards the end of the period.
- Mauritius, Botswana, and South Africa scored highest in institutional sustainability, while Burundi, the Democratic Republic of Congo, and Rwanda turned in the poorest performance.

In the past three decades African countries have made genuine progress in economic and social transformation. The incidence of infectious and parasitic diseases has been reduced enough so that today fewer infants and children die, people live longer, and birth rates are lower. Literacy rates are higher, and more children attend school. More recently, in the second half of the 1990s, per capita income rose and some countries introduced significant economic, political, and institutional reforms.

But the Africa-wide averages mask large disparities. A substantial share of the population still lives in poverty, the stock of capital is small and productivity low, and institutional weaknesses are widespread. Infrastructure is inadequate, and lack of access to rich country markets impedes economic growth. More ominously, the human capital base has eroded as the HIV/AIDS pandemic, the re-emergence of tuberculosis, and the spread of virulent malaria have reversed health gains.

The continent needs rapid, sustained, and broad-based economic transformation that is equitable within and across generations

Chapter 1 took a close look at conditions on the ground in Africa. It concluded that the continent needs rapid, sustained, and broad-based economic transformation that is equitable within and across generations—in short, sustainable development. This chapter takes a different, though complementary, approach to assessing conditions on the ground, using indices that capture country achievements in economic transformation, institutional development, and environmental conservation. These indices, and the indicators on which they are based, provide valuable information about prospects for sustainable development.

Based on 27 key economic, environmental, and institutional indicators, the indices of sustainability cover 38 countries, accounting for 90% of the continent's population, over the period 1975–2000. Economic, institutional, and environmental sustainability are measured by three separate indices, and these indices are combined in an index of overall sustainability. Together, the indices address these questions: What is the state of economic, institutional, and environmental sustainability in the countries and in the region? What are the main obstacles to achieving sustainable development? And what are the critical areas for policy intervention?

The 38 countries are ranked by their scores on the overall sustainability index for the full sample period. More revealing, though, is breaking the sample period into three intervals: 1975–84, 1985–94, and 1995–2000. This shows that African economies are less sustainable today than they were 25 years ago. Compared with 1975–84, in 1985–94 more countries showed low overall sustainability. The main explanation is that the significant progress in health and education was more than offset by a worsening institutional and environmental situation. In 1995–2000 the number of countries with low overall sustainability remained about the same, but the share of the population living in such countries grew—an outcome largely explained by the deterioration of economic, institutional, and environmental conditions in Nigeria. In many other African countries a recovery began during this period, though it remained tentative. Output per worker and capital per worker rose in many countries, and civil and political rights improved significantly in many parts of Africa. Nonetheless, at the end of 2000 more than half the population of the 38 countries lived in economies with low overall sustainability.

When the 38 countries are ranked by their average overall sustainability index scores over the full period, Mauritius, South Africa, and Botswana emerge as the top three, and Burundi, the Democratic Republic of Congo, and Guinea as the bottom three. There is little surprise in the set of top three countries. With its large and mainly industrialized economy, South Africa is quite distinct from other African economies. But Mauritius and Botswana were the star performers in economic growth in Sub-Saharan Africa for the past three decades. The bottom three countries are also broadly consistent with expectations.

These countries have been misgoverned for decades and embroiled in civil wars. In addition to causing human suffering, these wars have destroyed the countries' productive bases.

The sustainability indices not only measure performance. They also point to priority areas for policy intervention. The two key areas are health and agricultural productivity, both crucial to sustainable development.

Ill health, eroding the human capital base, constrains sustainable development in Africa. The combined socio-economic burden of HIV/AIDS, malaria, and tuberculosis has reversed the development gains achieved by some countries over the past three decades. These reversals have made combating these diseases the most important development challenge for many African countries. The continent urgently needs policies to bring about an epidemiological transition—from lives shortened by infectious and parasitic diseases to longer and healthier lives.

Sustainable development is structural change leading to enduring, widespread improvements in the well-being of societies and their members

Agricultural productivity is low in Africa, leading to food insecurity in a region where agriculture is the mainstay of most people. The low agricultural productivity gives rise to ill health, environmental degradation, and conflict, leading to further deterioration in productivity—a vicious cycle that traps countries in low sustainability. This clearly calls for policies to accelerate the agricultural productivity transition—moving from extensive to intensive production.

Sustainable development—meeting the needs of future generations

Sustainable development is structural change leading to enduring, widespread improvements in the well-being of societies and their members. This process involves self-sustaining economic growth, technological change, the modernization of institutions, and changes in attitudes and values (see, for example, Adelman and Yeldan 2000). From this characterization it follows that enhancing individual and collective well-being is the central aim of sustainable development as well as the key criterion for evaluating it. Sustainable development occurs as a series of parallel and successive transitions to sustainability spanning different dimensions and determinants of well-being.

In *Our Common Future* the World Commission on Environment and Development (1987, p. 43), more commonly known as the Brundtland Commission, defines sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." This definition emphasizes the need to protect future generations while also improving the well-being of current generations, particularly the poor and vulnerable.

Thus sustainable development can be characterized as a pattern of development that ensures a non-decreasing flow of well-being over time (see, for example, Dasgupta 2000). The definition and measurement of well-being can be approached in two related ways (see Dasgupta 1993). One focuses on the constituents of well-being—the utility (consequences) derived from the feasible actions (choices) of individuals, and the types and extent of freedoms they enjoy individually and collectively. Examples include nutrition levels, educational attainment, expected length of life, and such freedoms as civil and political rights. The other approach concentrates on the determinants of well-being—the command over goods and services. Obvious examples are income levels, availability of education and health services, and political structures (including civil, political, and socio-economic rights). Although in principle the two approaches can be applied separately, feasibility calls for their simultaneous use (Dasgupta 1993). Both the constituents and the determinants of well-being are used to identify indicators of sustainability.

One of the main determinants of well-being in a society is its productive base

One of the main determinants of well-being in a society is its productive base (including human, manufactured, and natural capital and the knowledge base), which ultimately determines the production, allocation, and use of goods and services. The size and quality of the productive base essentially dictate the feasible levels of well-being, because they determine what is available for consumption and investment during a period. Economic activity (production as well as consumption) depletes the productive base, while investments replenish it. Thus the pattern of production, consumption, and investment and its impact on capital, productivity, and institutions promote or limit the development of an economy.

This characterization of well-being suggests that the pattern of development in a society can be represented by a sequence of the key constituents and determinants of social well-being. This sequence, which can be referred to as a development programme, emerges from the initial state of the economy and the subsequent choices by the society.[1]

So, sustainable development can be understood as a development programme that increases consumption; enhances health, education, and citizenship rights; reduces inequality; appropriately upgrades and conserves the capital stock (including the environment); advances knowledge; and builds durable and efficient institutions. In short, a sustainable development programme encompasses economic development, environmental conservation, and institutional development. Such programmes would enable African countries to make transitions to sustainability in agricultural productivity and health as well as in the environment, human settlement, population, and education.[2]

Three dimensions of sustainability

The constituents and determinants of well-being and the notion of a development programme suggest three dimensions of overall sustainability:

- *Economic sustainability* spans three key elements of the productive base of an economy—manufactured capital, human capital, and the stock of knowledge—along with the economy's external indebtedness and the level of economic inequality (in health, education, and access to other assets). Thus economic sustainability refers to a pattern of economic development that leads to lasting improvements in educational status, health status, economic equality, the stock of foreign assets (or debt), and the stocks of manufactured capital and knowledge.

- *Environmental sustainability* relates to the stock of natural capital and changes in that stock. Specifically, it implies a temporal pattern of natural resource use that leads to the conservation of an economy's natural capital base, including its land, renewable and non-renewable natural resources, and climatic conditions. Environmental sustainability therefore involves reducing environmental stress (pollution, deforestation, population pressure, excessive extraction of mineral resources) and maintaining or improving environmental quality (biodiversity, air quality, water quantity and quality), enhancing the well-being of current and future generations.

- *Institutional sustainability* encompasses the political system, the civil and political rights associated with it, the extent and efficiency of the market system, the system of property rights, the quality of government policies and agencies, and mechanisms of conflict management. This dimension of sustainability involves developing an institutional structure that increases the well-being of current and future generations through enduring improvements in the civil and political freedoms enjoyed by all members of society and the emergence of well-functioning markets.

Overall sustainability has worsened in Africa in the last three decades

Breaking down sustainable development in this way makes it possible to explore how economic, environmental, and institutional systems interact in the process of development (box 2.1). More important for measuring sustainability, it also allows the construction of measures for each dimension of sustainability and thus permits a more detailed examination of sustainability across countries.

The overall sustainability index and the economic, environmental, and institutional sustainability indices that compose it are capable of reasonably summarizing the evolution and current state of sustainable development in African countries. Because it is not possible to directly observe either overall sustainability or its three dimensions, an array of observable indicators are aggregated to infer sustainability in each country (see box 2.2 and annex 2.1). These indicators are imperfect proxies for the corresponding dimension of sustainability. Moreover, because each indicator can capture only one aspect of development, aggregating the indicators into a single index is preferable to presenting each alone. Aggregation is particularly useful when different aspects move in opposite directions. The problems of aggregation and of unobservability of sustainability are jointly solved through a latent variable approach (see annex 2.2).

Overall sustainability—a mixed history

Overall sustainability has worsened in Africa in the last three decades. Cluster analysis was used to classify the 38 African countries into three relatively homogeneous groups characterized as having high, moderate, and low sustainability.[3] The results show that only 3 countries, accounting for about 6.5% of the population of these 38 countries, recorded high overall sustainability throughout the period (table 2.1). In the decade after 1975–84 fewer countries achieved moderate overall sustainability, with more countries falling into the low overall sustainability cluster. The main explanation for this is that the significant progress in health and education in 1985–94 was more than offset by a worsening institutional and

Box 2.1

Economic and environmental sustainability—conflicting or compatible?

Depending on the economic choices made, increasing the economic activity in a country is likely to affect the environment. To see the link between economic and environmental sustainability, consider the example of a country facing a choice among the three possible paths of development shown in the figure.

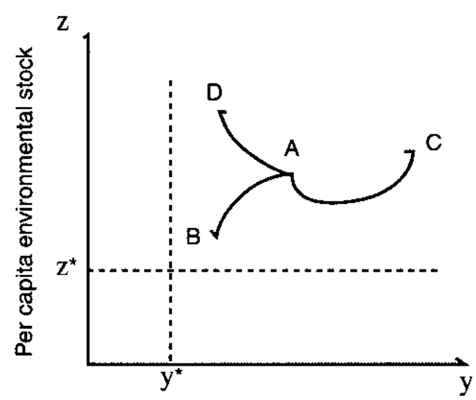
Take z to be a measure of the per capita environmental stock of the country and z^* its critical threshold. Furthermore, take y to be the potential per capita output of the economy and y^* the corresponding critical level (the level of output below which social conflict arises). Assume that the economy is currently at point *A*.

If the economy moves along the trajectory leading to point *B*, it would stagnate, with its environmental stock and economic output both deteriorating. Moreover, it would have a low investment rate and a small capital stock as well as a growing population, forced to deplete the stock of natural capital to survive.

Moving along the trajectory from *A* to *C* could be seen as the most desirable path, because per capita output would be increasing. The environmental stock of the economy would decline, however, though only in the short to medium term. In the long run the environmental stock would increase.

From an environmentalist's point of view, moving along the trajectory from *A* to *D* might seem most desirable, because it would mean increasing the country's environmental stock. But the cost would be lower output.

Three possible paths of development



Source: *Adapted from Taylor 1996.*

Box 2.2

What the indices show

A key objective of this report is to track the performance of African countries in achieving sustainability. To do so, a conceptual perspective that centres on well-being and is comparative in nature is adopted. Based on the report's conclusion that enhancing individual and collective well-being is both the central aim of sustainable development and the key criterion for evaluating it, indicators of constituents and determinants of well-being are combined to construct indices of sustainability. These indices are comparative, developed on the basis of the performance of African countries over the years relative to one another.

In selecting the indicators to construct the indices, three goals were considered important: including as many appropriate indicators of economic, environmental, and institutional sustainability as possible; spanning a sufficiently long time horizon; and covering an adequate number of African economies. Many potential indicators were initially identified, but a review of the temporal and spatial coverage of the available data made it clear that there would be trade-offs among the three goals.

Within the constraints dictated by these trade-offs, 27 indicators were selected, covering 38 African countries (representing 90% of Africa's population) over the period 1975–2000. These include 17 indicators of the economic state of countries, 6 indicators of the rights of citizens, institutionalized constraints on political leaders, and market development; and 4 indicators of environmental conditions (for a list of the indicators, see annex 2.1).

Clearly, it would have been preferable to include more indicators, particularly on the environmental sphere, such as measures of biodiversity, climatic conditions, intensity of fertilizer use, water quality and use, and extraction and reserves of natural resources. But data on such indicators are largely unavailable for most African countries, and even scarcer over time. Nevertheless, the indicators selected capture the key dimensions of sustainability for most African countries. Moreover, comparison with sustainability measures computed by others suggests that the indices of sustainability perform fairly well.

The indices are constructed by combining the initial levels of and changes in the indicators in a latent (or "unobserved") variable framework (see annex 2.2). The assumption underlying this approach is that sustainability cannot be explicitly observed, but it is possible to identify indicators of each dimension of sustainability. These indicators are used to infer the unobserved dimension of sustainability through factor analysis. Through this approach, index scores are computed for each dimension of sustainability and for overall sustainability.

The scores summarize the relative performance of African countries in improving indicators of well-being while accounting for the initial levels of these indicators. These scores allow the ranking of countries for purposes of comparison. They are not absolute measures of sustainability. So, while a higher score shows that a country is making greater progress towards sustainability than all those with a lower score, the differences among scores should not be interpreted as a measure of the extent to which one country is more sustainable than another. Put simply, the indices show which countries are doing better and which worse relative to the countries in the sample, but they do not show how much better or worse. More technically, the indices are ordinal rather than cardinal measures.

Table 2.1

Overall sustainability clusters for 38 African countries, 1975–2000

	High		Moderate		Low	
Period	Number of countries	Population share (percent)	Number of countries	Population share (percent)	Number of countries	Population share (percent)
1975–84	3	7.0	19	58.9	16	34.1
1985–94	3	6.7	15	52.8	20	40.6
1995–2000	3	6.4	16	39.5	19	54.0

Source: Calculations by Economic Commission for Africa.

A major blemish on the sustainability record of the top five countries is their performance in environmental sustainability

environmental situation. Institutional constraints on chief executives weakened considerably in several African countries in 1985–94. In addition, both population density and carbon dioxide emissions increased substantially in some large countries, including Algeria, Egypt, Ethiopia, Morocco, Nigeria, and South Africa.[4]

In 1995–2000 the number of countries with low overall sustainability declined slightly, but the share of the population living in such countries increased—an outcome largely explained by the deterioration of economic, institutional, and environmental management in Nigeria during most of the period (box 2.3). In many other African countries a recovery began, though it remained tentative. Output per worker and capital per worker rose in Egypt, Ethiopia, Morocco, Tanzania, and Uganda, and civil and political rights improved significantly in many countries.

When the 38 African countries are ranked by their average overall sustainability scores for 1975–2000, Mauritius, South Africa, Botswana, Zimbabwe, and Tunisia come out as the top five (figure 2.1). Burundi, the Democratic Republic of Congo, Guinea, Chad, and Burkina Faso make up the bottom five.

There is little surprise in the make-up of the top five. South Africa, with its large and mainly industrialized economy, is quite distinct from other African economies. Indeed, it tops the economic sustainability rankings. Mauritius and Botswana were the star performers in economic growth in Sub-Saharan Africa for the last three decades. Socio-political stability was also quite good in these countries, as shown by their top two rankings in institutional sustainability. Similarly, Tunisia and, until recently, Zimbabwe made reasonable progress in economic and institutional arenas.

That Zimbabwe ranks among the top five may be puzzling in light of its recent performance. But until recently Zimbabwe had been doing rather well, particularly in economic and institutional terms. Thus Zimbabwe ranks 4th in overall sustainability and 6th in institutional sustainability in 1985–94, while it ranks only 12th and 23rd in 1995–2000, reflecting its recent slide.

A major blemish on the sustainability record of the top five countries is their performance in environmental sustainability. Mauritius, Tunisia, and Zimbabwe rank among the bottom five in environmental sustainability, while Botswana ranks 30th. Only South

Box 2.3

Overall sustainability—declining in Nigeria, improving in Ghana

Nigeria—ranking dominated by performance during military rule

In Nigeria the institutional situation deteriorated until 1999, which marked the end of 16 years of military rule culminating in the Abacha regime of the 1990s. During the period of military rule, civil and political rights eroded, institutional constraints on the chief executive weakened, and economic mismanagement and corruption were rampant. Investment fell in sectors other than oil, with the result that capital per worker declined and road and telephone networks contracted. Agricultural production failed to keep up with population growth, turning Nigeria from an exporter of food to a large importer. External indebtedness grew, increasing fivefold between 1975–84 and 1995–2000. And the HIV/AIDS pandemic has taken a toll, with about 3.5 million people living with HIV/AIDS by 2001.

The democratically elected civilian regime, inaugurated in May 1999, has improved economic management considerably and had some success in institutionalizing good governance. But these achievements in 1999–2000 were not enough to fully offset the poor outcomes in earlier years. So, Nigeria dropped further in the overall sustainability rankings in 1995–2000.

Ghana—ranking rises 13 places thanks to greater political stability

In Ghana the deterioration in institutional structures in the 1970s and 1980s was reversed starting in 1992. After carrying out a peaceful transfer of power, the country has achieved political stability, increased the accountability of the chief executive, and strengthened civil and political rights. As a result of this progress Ghana rose 21 places in the institutional sustainability rankings in 1995–2000.

Ghana also improved its performance in other dimensions of sustainability. During 1995–2000 it reversed its economic decline, with output per worker and capital per worker growing thanks to substantially higher investment rates. School enrollment rose, and gender parity in education improved, particularly in primary education. These improvements pulled the country up two places in the economic sustainability rankings in 1995–2000. Between 1975–84 and 1995–2000 Ghana also slightly improved its ranking in environmental sustainability, with lower carbon dioxide emissions and with deforestation that, while a problem, was less rapid than that in many other African countries.

As a result of all these improvements in economic, environmental, and institutional sustainability, Ghana rose 13 places in the overall sustainability rankings in 1995–2000.

Countries can do well for a while without giving due consideration to environmental factors, but this may not last long

Africa does better in this dimension of sustainability, ranking 19th. The evidence shows that for these top performers, environmental concerns are becoming increasingly binding constraints on further improvements in the overall well-being of their populations. One lesson emerging from this experience is that countries can do well for a while without giving due consideration to environmental factors, but this may not last long.

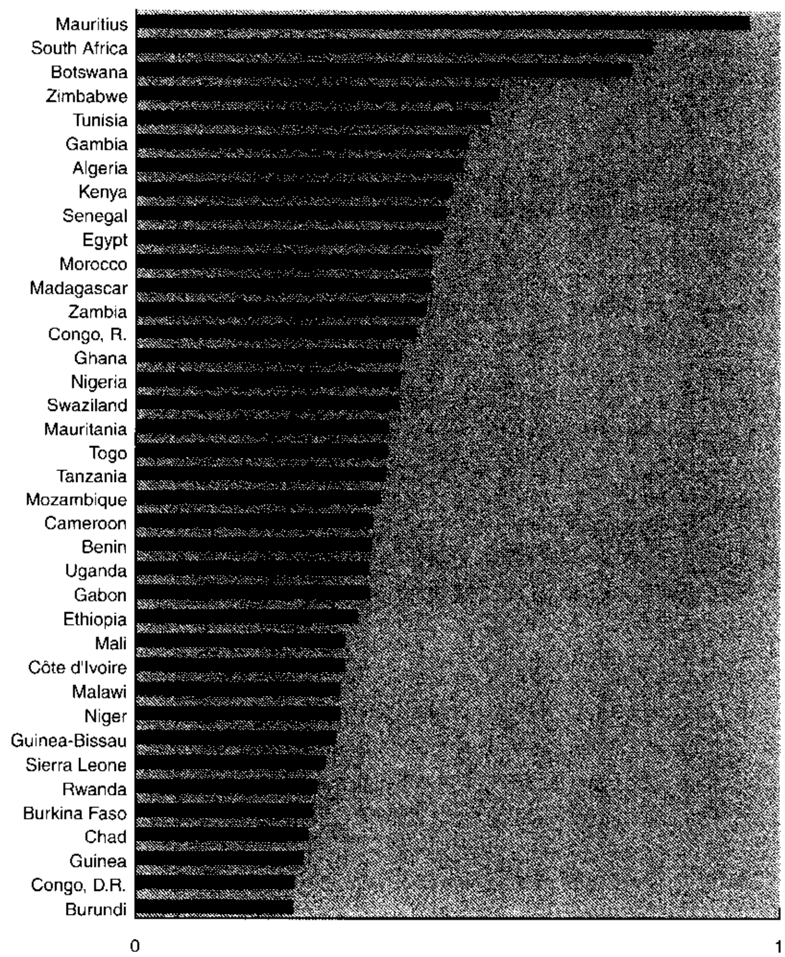
Recognizing this, Botswana and Mauritius have been implementing fairly strict environmental policies. But because of data limitations, this performance is not captured by the index of environmental sustainability. Efforts made by countries in areas for which data were not widely available, such as improving water quality or implementing environmental standards, could not be recorded.

The bottom five countries are also broadly consistent with expectations. Despite its huge potential, the Democratic Republic of Congo has been misgoverned for decades and, more recently, crippled by civil war. Burundi's history is punctuated by ethnic tensions and civil conflict. Chad suffered from similar problems of instability until recently. And Burkina Faso has had a poor economic growth record. Indeed, almost all these countries rank low in economic and institutional sustainability. Burundi, the Democratic Republic of Congo, and Chad rank among the bottom five countries in institutional sustainability, while Guinea ranks 30th and Burkina Faso 27th. In economic sustainability Burkina Faso ranks 38th, Guinea 37th, Chad 32nd, Burundi 30th, and the Democratic Republic of Congo 29th. But these countries rank relatively high in environmental sustainability, from 2nd to 11th. This contrast highlights the fact that economic performance (or the lack of it) has a negative (or positive) impact on the environment.

The bottom five countries rank low in economic and institutional sustainability

Figure 2.1

Overall sustainability index scores by country, 1975–2000



Note: *The index scores shown are averages of the scores for 1975–2000. The scores are standardized to range from 0 to 1.*

Source: *Calculations by Economic Commission for Africa.*

Overall sustainability is positively and strongly correlated with a number of indicators of sustainability relating to institutional development, human and physical capital accumulation, and productivity. Greater overall sustainability goes hand in hand with greater institutional constraints on the decision-making powers of the chief executive, greater institutionalization and openness of political competition, and more widespread civil and political rights. In addition, overall sustainability rises with growth in human capital, as reflected in higher infant and child survival rates, longer life expectancy, greater gender parity in education, and higher literacy and school enrolment. Physical capital also plays a part, with evidence showing that more extensive road and telephone networks tend to contribute to overall sustainability. Higher productivity per worker is another key driver of overall sustainability.

Overall sustainability is positively and strongly correlated with institutional development, human and physical capital accumulation, and productivity

Countries with higher overall sustainability also tend to have more stable governments, a military with little or no role in political matters, little or no conflict (except South Africa until the early 1990s and Zimbabwe more recently), lower corruption, higher-quality bureaucracies, considerably higher saving rates, and higher per capita spending on health and education.

All this evidence points to a message that has been repeated often recently: national efforts to achieve sustainable development should emphasize productive capacity and its key determinants—institutions and human resources. They also highlight two areas of policy priority for most African countries: ill health and food insecurity.

A key area of policy intervention—reducing ill health

A comparison of infant and child survival rates and life expectancy in the countries ranking highest and lowest in overall sustainability confirms the correlation between these human capital indicators and overall sustainability. In 1995–2000 infant and child mortality rates were two-thirds lower and life expectancy 13 years longer in the top five countries than in the bottom five. Moreover, health outcomes are also closely and positively correlated with both productivity levels and education outcomes. These findings convey two important messages.

First, health status is both an important outcome of, and a key input into, Africa's sustainable development. The health status achieved by Africans, individually and collectively, is a core result of the continent's level of development. And without substantial improvements in the health status of Africans, the continent cannot achieve sustained growth and meaningful structural transformation. Given the urgent need for rapid development in Africa, its countries should therefore sharpen their efforts to enhance health outcomes through efficient investments in health and its determinants.

Second, the HIV/AIDS pandemic and the resurgence of malaria and tuberculosis have had a devastating impact on Africa. The combined socio-economic burden of these diseases has led Sub-Saharan Africa towards major crises that are reversing decades of development gains. Among the top five countries in the overall sustainability rankings, for example, average life expectancy declined by about three years between 1985–94 and 1995–2000 (three of these countries, Botswana, South Africa, and Zimbabwe, are among those most affected by HIV/AIDS). The damage from these diseases clearly calls for accelerating the epidemiological transition in Africa. Indeed, this is the most important development challenge for many

African countries. Meeting this challenge requires a prudent exploitation of techniques and products developed by recent advances in medical biotechnology (see chapter 4). These medical technologies have the potential to reverse the damage by HIV/AIDS, malaria, tuberculosis, and other diseases and put Africa back on the path of the epidemiological transition to sustainability.

A second key area of policy intervention—addressing food insecurity

Compared with the top performers on the continent, most African countries are doing poorly in addressing food security issues. And Africa is doing worse than other regions.

Most African countries are doing poorly in addressing food security issues. And Africa is doing worse than other regions

In the five countries at the top of the overall sustainability rankings, the average annual output per worker ($6,870) was more than 10 times that in the bottom five countries ($560) in 1995–2000. In the same period the top five also had cereal yields (1.9 tonnes a hectare) that were twice those in the bottom five (0.97 tonnes). Moreover, the productivity gap has been either widening (for output per worker) or not narrowing fast enough (for cereal yields). In the last three decades output per worker grew at an average annual rate of about 2% in the top five countries while falling an average 0.1% a year in the bottom five. The growth rates of cereal yields, however, were comparable, at 0.6% a year in the top five and 0.7% a year in the bottom five.

Nevertheless, even in these top five countries in Africa both output per worker and cereal yields not only were lower than in other regions, they also were growing more slowly. In 1975–95 the world's average cereal yield grew by 1.5% a year, reaching 2.9 tonnes a hectare by 1997. Asia had even faster growth in cereal yields. East Asia recorded growth of 2.3% a year in the same period, South Asia 2.7%, and South-East Asia 2.8%. By the end of the period East Asia had achieved cereal yields of 4.8 tonnes a hectare, South Asia 2.2 tonnes, and South-East Asia 2.1 tonnes.

The low overall productivity in African countries restricts their ability to import food, while the low agricultural productivity limits their capacity to regularly produce enough food themselves. The dismal outcome: a high level of food insecurity and high rates of child malnutrition. Here again the top five countries, with 15% of children under five who are underweight, do better than the bottom five, with 33% underweight. Similar gaps exist in rates of stunting (24% and 38%) and wasting (6% and 11%) among children. The malnutrition among the children of today reduces the potential productivity and well-being of the adults of tomorrow.

Shifting to more productive, sustainable agriculture has become increasingly critical. Deforestation and soil degradation have become a greater concern as African countries confront limits on crop area expansion and increased demands on land already in production. Moreover, the majority of Africans, including most of the poor, live in rural areas and rely on agriculture for their livelihoods. In 1995–2000, 78% of the population of the bottom five countries lived in rural areas. The top five countries were less rural, with 52% living in rural areas.

For all these reasons, accelerating the agricultural productivity transition to sustainability is clearly urgent. The urgency is particularly great in African countries that have low or moderate overall sustainability with substantial food insecurity, high poverty rates, and large rural populations. The agricultural productivity transition involves increasing agricultural production by raising the output per unit of land through advances in knowledge and technology rather than by expanding the area cultivated. Biotechnology could play an important role. Indeed, under the right circumstances, modern biotechnology could speed Africa's agricultural productivity transition to sustainability—and expedite reductions in poverty and food insecurity (see chapter 3).

Overall in Africa economic sustainability initially improved and then deteriorated in the last 25 years

Economic sustainability—initial gains lost

The economic sustainability index measures the extent to which a country has achieved lasting economic transformation. The measure combines a number of indicators on foreign assets, human capital (education and health status), gender inequality, manufactured capital, and productivity.

Overall in Africa economic sustainability initially improved and then deteriorated in the last 25 years (table 2.2). Within the group of 38 countries, the share of the population living in those with low economic sustainability fell from about 85% in 1975–84 to 50% in 1985–94, thanks mainly to investments made in the first decade. But in 1995–2000 this share grew to 72%. This reversal reflected in part the limited effective investment in 1985–94. But it was driven mostly by the fact that Kenya and Nigeria joined the low economic sustainability cluster in the third period, pushing the population share of that cluster up by 22 percentage points. In most other countries economic sustainability remained roughly the same.

What accounts for the gains in 1985–94? Data on individual indicators point to better health and greater education, a growing stock of manufactured capital, rising productivity, and an expanding market system. These positive trends slowed in 1995–2000. Many countries had smaller achievements in health and education. Indeed, in the countries affected by HIV/AIDS, gains in life expectancy were reversed. Moreover, output per

Table 2.2
Economic sustainability clusters for 38 African countries, 1975–2000

Period	High: Number of countries	High: Population share (percent)	Moderate: Number of countries	Moderate: Population share (percent)	Low: Number of countries	Low: Population share (percent)
1975–84	2	6.7	5	7.9	31	85.4
1985–94	2	6.5	12	42.8	24	49.7
1995–2000	1	6.0	11	21.9	26	72.1

Source: *Calculations by Economic Commission for Africa.*

Box 2.4

Economic sustainability—stagnating in Uganda, deteriorating in Kenya

Uganda—poor health outcomes dampen achievements in economic sphere

Misrule and civil conflict in the 1970s and early 1980s did considerable damage to Uganda's productive base. But since the end of internal conflict in 1986 economic policy reforms combined with donor assistance have led to substantial improvements in the economic sphere. As investments increased, capital per worker grew and the road network expanded. School enrollment ratios rose, particularly in higher education. These improvements led to the fastest growth ever in output per worker in Uganda.

What makes these achievements all the more remarkable is that they occurred while Uganda was facing an HIV/AIDS epidemic. Uganda took early action to combat the epidemic and was more successful than other countries as a result. Still, life expectancy fell in 1995–2000, and infant and child mortality rates declined less rapidly than in many other African countries. These health outcomes dampened Uganda's achievements in the economic sphere. Because the country also started with a much smaller base than those ranking at the top in economic sustainability, its ranking did not improve.

Kenya—economic progress in the early 1970s eroded

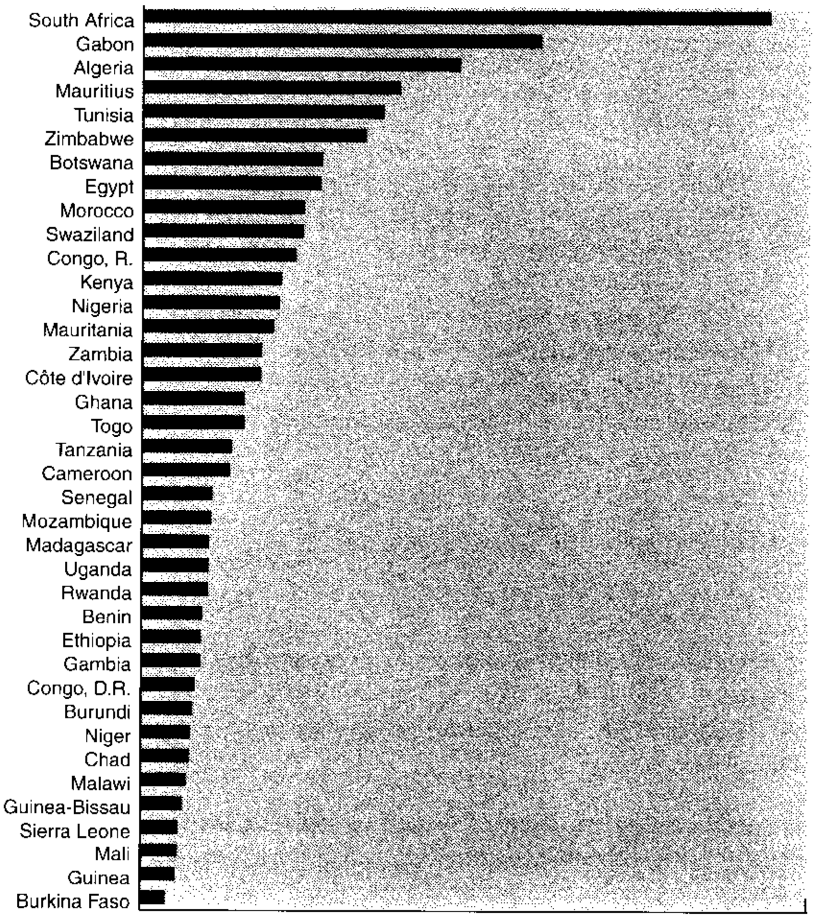
Kenya showed good potential in the 1970s and 1980s, when the outlook in much of Sub-Saharan Africa looked quite bad. But it failed to realize that potential. Economic growth slowed, and the country saw some of its achievements reversed. In 1995–2000 output and capital per worker declined (in part because of lower investment), the road network shrank, corruption and the quality of the bureaucracy worsened, mortality rates rose, and life expectancy shortened (in part because of the spread of HIV/AIDS). As a result Kenya dropped six places in the economic sustainability rankings between 1975–84 and 1995–2000.

worker declined in Algeria, Congo, Kenya, and South Africa, while capital per worker fell in Algeria, Kenya, and Nigeria (box 2.4). Telephone networks contracted in many countries, including Algeria, Ethiopia, Kenya, Tanzania, and Uganda. And external debt grew in many, rising most in Algeria, Congo, and Uganda.

When economic sustainability index scores are averaged for 1975–2000, South Africa, Gabon, Algeria, Mauritius, and Tunisia top the rankings, while Burkina Faso, Guinea, Mali, Sierra Leone, and Guinea-Bissau come out at the bottom (figure 2.2). The composition of the top five largely accords with expectations. All are middle-income countries. South Africa, clearly the strongest economy in Africa, scores highest on most of the indicators making up the economic sustainability index, including productivity, education status, and infrastructure. The other four countries also rank high in these indicators.

But two results are surprising. First, Gabon and Algeria outrank Mauritius, a particularly good performer in health and education. The explanation lies in the first two countries' better performance in areas most closely correlated with economic sustainability. Compared with Mauritius, Gabon has almost twice as much output and capital per worker, while Algeria has more than twice as much capital per worker and a comparable level of output per worker. Second, Botswana fails to make the top five, ranking seventh despite its stellar economic growth performance over the last three decades. This outcome

Figure 2.2
Economic sustainability index scores by country, 1975–2000



Note: *The index scores shown are averages of the scores for 1975–2000. The scores are standardized to range from 0 to 1.*
Source: *Calculations by Economic Commission for Africa.*

largely reflects its relatively low attainments in literacy, school enrolment, and life expectancy. In recent years the country's life expectancy has declined, mainly as a result of the HIV/AIDS epidemic.

The five countries at the bottom of the rankings have some of the lowest incomes in Africa and perform poorly on many indicators of economic sustainability. Indeed, they rank among the bottom 10 countries in most such indicators, with short life expectancies and high child mortality, low literacy and school enrollment, and low gender parity in school enrollment.

Economic sustainability is most strongly (and positively) related to output per worker, capital per worker, and the size of the telephone network. It is also positively and strongly

The environmental sustainability of African countries declined considerably between 1975–84 and 1985–94

Table 2.3
Environmental sustainability clusters for 38 African countries, 1975–2000

	High		Moderate		Low	
Period	Number of countries	Population share (percent)	Number of countries	Population share (percent)	Number of countries	Population share (percent)
1975–84	1	0.2	36	99.6	1	0.2
1985–94	1	0.2	24	68.8	13	31.0
1995–2000	0	0.0	29	74.9	19	25.1

Source: *Calculations by Economic Commission for Africa.*

correlated with all indicators of health and education status and the indicator of market development (how much of a country's economic activity takes place in markets). These correlations suggest that raising productivity through technological innovation and increased human and manufactured capital is an important means of promoting sustainable economic development in Africa.

Environmental sustainability—a slight recovery since the mid-1990s

The environmental sustainability index attempts to capture the change in a country's natural capital base. Because of the scarcity of time-series data for environmental indicators, the measure is limited to only four indicators: forest cover, arable land, carbon dioxide emissions, and population density.

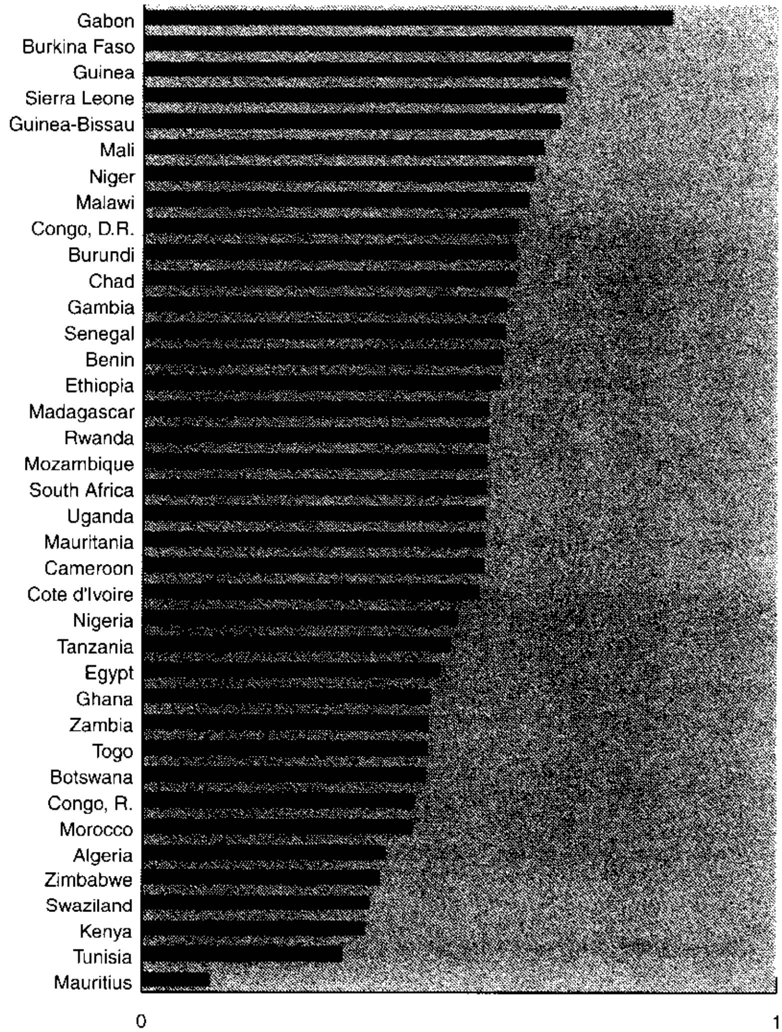
The environmental sustainability of African countries declined considerably between 1975–84 and 1985–94, with more countries falling into the low sustainability cluster (table 2.3). This outcome appears to be explained largely by population growth, rapid growth in carbon dioxide emissions, the expansion of road networks, and market development. Environmental sustainability recovered slightly in 1995–2000 with slower growth (and in some cases reductions) in carbon dioxide emissions and less rapid population growth in almost all the most populous countries of Africa.

Average environmental sustainability index scores for 1975–2000 put Gabon, Burkina Faso, Guinea, Sierra Leone, and Guinea-Bissau at the top of the rankings, and Mauritius, Tunisia, Kenya, Swaziland, and Zimbabwe at the bottom (figure 2.3).

The top five have high or moderate forest coverage, low population density, relatively low road density, and limited market development. Four also have low carbon dioxide emissions. The exception is Gabon, with the second highest average emissions rate. But Gabon has also reduced emissions the most, and it has the greatest forest coverage, the third lowest population density, and the smallest growth in population density.

By contrast, the bottom five countries have relatively high and rapidly growing population density. Their carbon dioxide emissions are also high and rising faster than emissions

Figure 2.3
Environmental sustainability index scores by country, 1975–2000



Note: *The index scores shown are averages of the scores for 1975–2000. The scores are standardized to range from 0 to 1.*
Source: *Calculations by Economic Commission for Africa.*

in most other countries. Moreover, almost all have denser road networks and greater market development. Several also started out with fragile environmental conditions.

Institutional sustainability—good progress over time

The institutional sustainability index combines indicators of rights (civil and political freedoms) and institutional development (institutional constraints on executive power, competitiveness in the transfer of executive power, and the depth of market development).

Institutional sustainability improved at an accelerating rate in 1975–2000 (table 2.4). Africa began the period with 20 countries in the low institutional sustainability cluster. That number fell to 18 in 1985–94 and to only 7 in 1995–2000. Measured by the share of the population in each cluster, however, the performance was more mixed. By that yardstick institutional sustainability in Africa declined initially and then recovered strongly towards the end of the period. These trends were again driven mostly by the performance of large countries—the deterioration of institutional sustainability in Ethiopia, Nigeria, and South Africa in 1985–94 and its recovery in the second half of the 1990s.

Beginning in the early 1990s many African countries initiated significant economic and political reforms, including Benin, Burkina Faso, Ethiopia, Ghana, Malawi, Mali, Mozambique, Togo, and Zambia (box 2.5). Political competition became more open and institutionalized. Political participation and the accountability of leaders grew. But even as the socio-economic impact of these reforms continues to unfold, the need for further deepening of the reforms is becoming apparent. These reforms are perhaps the most important change that most African countries are undergoing.

Table 2.4

Institutional sustainability clusters for 38 African countries, 1975–2000

	High		Moderate		Low	
Period	Number of countries	Population share (percent)	Number of countries	Population share (percent)	Number of countries	Population share (percent)
1975–84	4	7.1	14	60.0	20	32.8
1985–94	4	1.9	16	45.7	18	52.4
1995–2000	11	20.3	20	50.2	7	29.5

Source: *Calculations by Economic Commission for Africa.*

Box 2.5

Institutional sustainability—down sharply in Gambia, up dramatically in Benin

Gambia—ranking falls 23 places because of deteriorating institutional indicators

Although economically weak, Gambia started the period 1975–2000 with a relatively good institutional structure. But this changed over the years. During most of the 1990s (beginning with the coup d'etat in 1994), almost all institutional indicators deteriorated: institutional constraints on the decision-making powers of the chief executive weakened, the institutionalization and openness of political competition declined, and civil and political rights became more restricted. This deterioration led to a fall of 23 places for Gambia in the institutional sustainability rankings in 1995–2000.

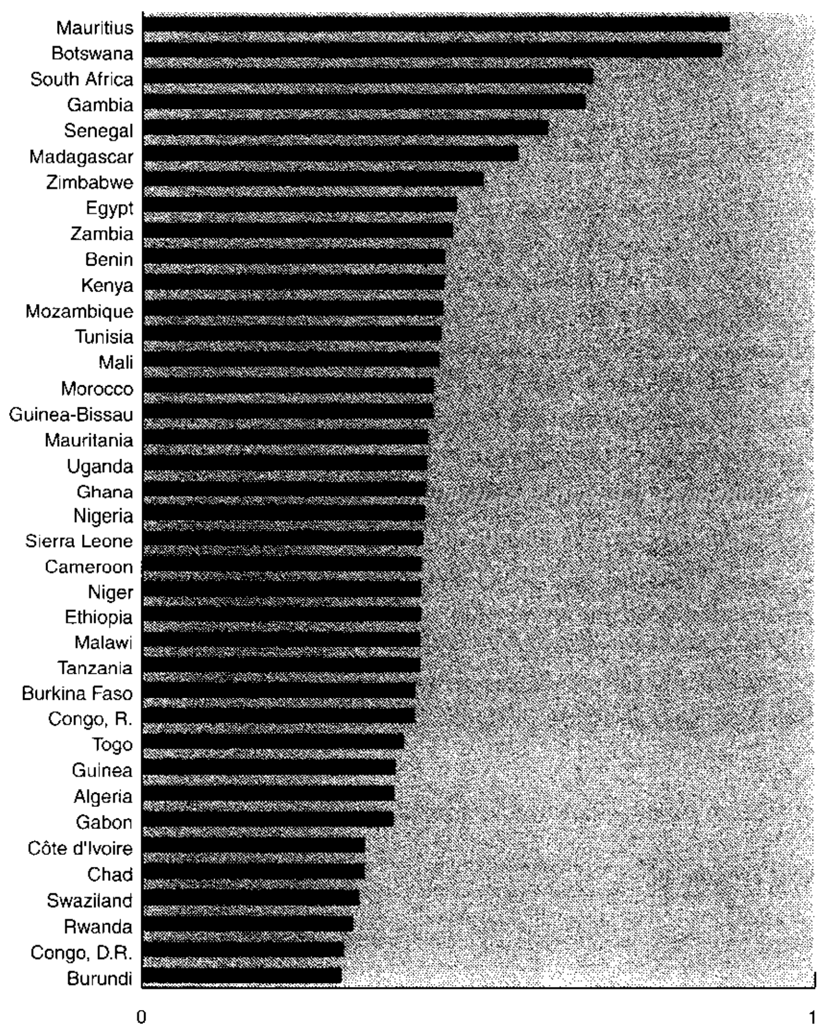
Benin—ranking determined by transition from one-party state to multiparty democracy

In 1975 Benin was a one-party state dominated by a Marxist ideology. But since 1991 it has transformed itself into a successful multiparty democracy. The country has improved civil and political rights considerably, strengthened institutional constraints on the decision-making powers of the chief executive, increased the independence of the judiciary, and kept the army out of politics. These reforms led to the largest climb in the institutional sustainability rankings, with Benin rising 31 places between 1975–84 and 1995–2000.

Ranked by average institutional sustainability index scores for 1975–2000, the top five countries are Mauritius, Botswana, South Africa, Gambia, and Senegal (figure 2.4). The bottom five are Burundi, the Democratic Republic of Congo, Rwanda, Swaziland, and Chad.

The composition of the top five conforms to conventional wisdom. Mauritius and Botswana top all the rankings by indicators of institutional development except for market development (in which they rank 3rd and 17th). The other three rank among the top five in almost all the indicators. By contrast, the bottom five perform poorly in almost all indicators of institutional development, with restricted political competition, limited accountability of political leaders, and weak market systems (except in Swaziland).

Figure 2.4
Institutional sustainability index scores by country, 1975–2000



Note: *The index scores shown are averages of the scores for 1975–2000. The scores are standardized to range from 0 to 1.*
Source: *Calculations by Economic Commission for Africa.*

Accelerating the transition to sustainability

A closer look at the indicators of well-being has shown that more sustainable African countries are also more productive. Their people are better fed, healthier, and more educated, and consequently live longer. Moreover, their political institutions and individual rights are stronger. But in these high performers of today, environmental factors may be emerging as binding constraints on further improvements in well-being.

African countries need to raise productivity and build institutions to accelerate the transition to sustainability

All this suggests that African countries need to raise productivity and build institutions to accelerate the transition to sustainability. That means combating ill health (particularly that caused by HIV/AIDS, malaria, and tuberculosis), tackling food insecurity, and reducing environmental stress. Thus the epidemiological and agricultural productivity transitions are the current priorities in the continent's efforts to achieve sustainability. Indispensable to such transitions is the prudent exploitation of new technologies—particularly medical and agricultural biotechnology.

Annex 2.1 The indices of sustainability

The need for sustainable development, especially in poor countries, is now generally accepted. The effort to construct measures of sustainability has grown in parallel with that acceptance. This effort has produced such measures as the environmental sustainability index (ESI) developed by the Global Leaders of Tomorrow Environment Task Force (under the auspices of the World Economic Forum), the human development index (HDI) devised by the United Nations Development Programme, and alternative measures of genuine savings developed by the World Bank. To track the performance of African countries in achieving sustainability, this report combines indicators of both constituents and determinants of well-being to construct indices of sustainability.

These measures of sustainability are conceptually and computationally different. It is thus to be expected that they lead to different country rankings. However, comparison with other measures show that the sustainable development index compares fairly well. Rank correlations between country rankings by the four measures show that the correlation between the overall sustainability measure with the ESI and HDI is strong, while the one with genuine savings is positive but weak (table A2.1)

Table A2.1
Rank correlation matrix—alternative measures of sustainability

	Overall sustainability	ESI	HDI	Genuine savings
Overall sustainability	1.00			
ESI	0.56***	1.00		
HDI	0.59***	0.66***	1.00	
Genuine savings	0.33*	0.53***	0.46**	1.00

Notes:**, **, and * imply that the correlation is significant at 1%, 5%, and 10%, respectively.*

The indicators: specification and data

Measuring sustainability requires data on a large number of indicators. The set of indicators used in constructing the indices was assembled in two steps. First, indicators were selected in accordance with the concept of sustainable development outlined in this chapter. Second, the indicators for which there was little or no data were dropped. Because of data availability problems, the final set is more limited than would be desired, particularly for inequality and environmental change. The weight attached to the resulting measures of sustainability should reflect this fact.

Following is a list of the indicators selected for the three dimensions of sustainability. Each is an indicator of the state of the corresponding dimension of development in a country during a period (the only exception is the indicator for carbon dioxide emissions, which refers to the change in the stock of carbon dioxide in a country's atmosphere). The data set covers 38 African countries (and 90% of the African population) over the period 1975–2000.[5]

Indicators of economic sustainability

1. Foreign assets or debt (total external debt as a percentage of GDP)
2. Human capital
   - 2.1 Education
     - 2.1.1 Literacy rate, ages 15 and over
     - 2.1.2 Gross primary enrollment ratio
     - 2.1.3 Gross secondary enrollment ratio
     - 2.1.4 Gross tertiary enrollment ratio
   - 2.2 Health
     - 2.2.1 Infant survival rate (= 1,000 minus the infant mortality rate per 1,000 live births)
     - 2.2.2 Life expectancy at birth (years)
     - 2.2.3 Child survival rate (= 1,000 minus the under-five mortality rate per 1,000 live births)
   - 2.3 Inequality
     - 2.3.1 Inequality in literacy, ages 15 and over (ratio of female to male literacy rate)
     - 2.3.2 Inequality in gross primary enrollment (ratio of female to male gross primary enrollment)
     - 2.3.3 Inequality in gross secondary enrollment (ratio of female to male gross secondary enrollment)
3. Manufactured capital
   - 3.1 Capital per worker (based on aggregate investment; thousands of U.S. dollars)
   - 3.2 Rail route length per 100 square kilometres (kilometres)
   - 3.3 Paved road length per 100 square kilometres (kilometres)
   - 3.4 Telephones per 1,000 people
4. Productivity
   - 4.1 Irrigated land as a percentage of arable land
   - 4.2 Output per worker (thousands of U.S. dollars)

Indicators of environmental sustainability (natural capital)

1. Forest and woodland as a percentage of total land area
2. Arable land as a percentage of total land area
3. Emissions of carbon dioxide (tonnes per 1,000 people)
4. Population density (people per square kilometre)

Indicators of institutional sustainability

1. Rights[6]
   1.1 Civil liberties (low = 1, high = 8): a measure of the extent to which a society's members have the freedom to develop views, institutions, and personal autonomy apart from the state. More specifically, it covers freedom of expression, belief, and association; rule of law and human rights; and personal autonomy and economic rights.
   1.2 Political rights (low = 1, high = 8): a measure of the ability of people to particpate freely in the political process, including the right of all adults to vote and compete for public office, and for elected representatives to have effective participation in making decisions affecting their society.
   1.3 Political competition (low = 1, high = 10): a measure of the degree of institutionalization (or regulation) of political competition together with the extent of government restriction on political competition. The measure thus also indicates the degree of inequality in the political system.
2. Institutions[7]
   2.1 Executive constraints (low = 1, high = 7): a measure of the extent of institutional constraints on the decision-making powers of the chief executive, whether an individual or a collective executive. This concept is similar to the notion of "horizontal accountability" found in the literature on democracy, but it assumes that dictators may also be bound by certain institutional constraints. Any "accountability group" in the polity may impose limits on the chief executive.
   2.2 Executive recruitment (low = 1, high = 8): a measure of how institutionalized, competitive, and open the mechanisms for selecting a political leader are. It combines the extent of institutionalization (or regulation) of transfers of executive powers, the competitiveness of executive selection, and the openness of executive recruitment. Thus it can also serve as an indicator of the degree of inequality in the political system.
   2.3 Liquid liabilities (money plus quasi-money, or M2) as a percentage of GDP. This measure serves as an indicator of the extent of market development.

The data sources

The key sources of data used for the indicators are as follows:

- World Bank, *African Development Indicators CD-ROM 2001.*
- World Health Organization, *World Health Report* (editions for 1995–2001).

- O. B. Ahmad, A. D. Lopez, and M. Inoue, "The Decline in Child Mortality: A Reappraisal," *Bulletin of the World Health Organization 78*, no. 10 (2000): 1175–91.
- Polity IV Project data set (Political Regime Characteristics and Transitions, 1800–1999), University of Maryland, Center for International Development and Conflict Management, College Park (http://www.cidcm.umd.edu/inscr/polity/).
- International Monetary Fund, International Financial Statistics database (May 2001).
- Global Development Network database (http://www.worldbank.org/research/growth/GDNdata.htm).
- Freedom House database on Annual Survey of Freedom, 1972–73 to 2000–01 (http://www.freedomhouse.org/ratings/index.htm).

Annex 2.2 Note on methodology

The unobserved (latent) components model expresses the observed indicators of sustainability as a function of unobserved sustainability. The key assumption is that the latent sustainability indices account for all the correlations among the indicators. In other words, the effects of the latent variables and measurement error drive the correlation among observed indicators. Accordingly, the covariation among indicators is used to estimate latent scores for the unobservable indicators of sustainability. These latent scores represent the degree of sustainability of African countries relative to one another. More explicitly, the latent scores allow the ranking of African countries in the sample according to the degree of sustainability.

The criterion of sustainability can be specified in terms of a linear combination of changes in the state variables (variables that capture the state of the constituents and determinants of well-being, such as health, education, consumption, citizenship status, institutions, inequality, and capital). The criterion thus means that such linear combinations can be used to compare the degree of sustainability over time and across countries. The initial values of the state variables are also important determinants of the change in well-being; therefore, both can be used as indicators of sustainability.

In the latent variable model changes in the indicators of the state of development and one-period lagged levels of these indicators were used as indicators of sustainability during each year. The one-period lagged levels were included as corresponding indicators of the initial state of the economy at the beginning of each year.

To obtain indices of both overall sustainability and the separate dimensions of sustainability, a second-order factor analysis model was used. Measurement equations of the form (one for each indicator y_{jk})

$$y_{jk} = \lambda_j z_k + \varepsilon$$

were jointly estimated with equations of the form (one for each latent variable z_k)

$$z_k = \gamma_k' Z + \zeta_z$$

where y_{jk} is the jth observed indicator of the kth unobserved dimension of sustainability; z_k is the kth unobserved dimension of sustainability; $k = \{ec, en, i\}$ with ec, en, and i identifying economic, environmental, and institutional sustainability; Z_i is overall sustainability; and ε_j and ζ_k are errors. While these relationships are estimated, the impact of $z_{l \neq k}$ on y_{jk} as well as covariation among the ε_js are allowed for whenever appropriate (see Asea 1996 for a more detailed description of the latent variable model).

Test statistics indicate a relatively high goodness of fit for the jointly estimated model, implying that the model fits the data reasonably well (table A2.2).

Table A2.2

Goodness of fit statistics

Statistic	Value
Root mean square error of approximation (RMSEA)	0.0486
90% confidence interval for RMSEA	(0.0466, 0.0506)
p-value for test of close fit (RMSEA < 0.05)	0.8804
Goodness of fit index	0.8962
Adjusted goodness of fit index	0.8520
Parsimony goodness of fit index	0.6287

Source: *Calculations by Economic Commission for Africa.*

Annex 2.3

Rankings of 38 African countries by overall sustainability index scores, 1975–84, 1985–94, and 1995–2000

Country	Overall sustainability		
	1975–84	1985–94	1995–2000
Algeria	9	8	7
Benin	31	25	8
Botswana	3	2	3
Burkina Faso	27	37	34
Burundi	34	36	37
Cameroon	25	19	21
Chad	36	35	33
Congo, Dem. Rep.	33	34	38
Congo, Rep.	10	12	16
Côte d'Ivoire	28	28	29
Egypt	12	9	11
Ethiopia	23	26	28
Gabon	22	22	27
Gambia	5	5	25
Ghana	18	23	10
Guinea	37	38	32
Guinea-Bissau	30	30	30
Kenya	7	10	9
Madagascar	13	14	6
Malawi	32	33	17
Mali	38	32	13
Mauritania	17	16	23
Mauritius	1	1	1
Morocco	11	11	15
Mozambique	24	20	19
Niger	35	27	22
Nigeria	6	18	31
Rwanda	29	31	35
Senegal	14	7	14
Sierra Leone	26	29	36
South Africa	2	3	2
Swaziland	16	13	20
Tanzania	15	17	26
Togo	20	21	18
Tunisia	8	6	4
Uganda	21	24	24
Zambia	19	15	5
Zimbabwe	4	4	1

Rankings of 38 African countries by economic sustainability index scores, 1975–84, 1985–94, and 1995–2000

	Economic sustainability		
Country	**1975–84**	**1985–94**	**1995–2000**
Algeria	3	3	2
Benin	25	27	26
Botswana	11	8	7
Burkina Faso	38	38	38
Burundi	31	30	28
Cameroon	21	19	19
Chad	30	32	32
Congo, Dem. Rep.	28	31	27
Congo, Rep.	8	11	10
Côte d'Ivoire	16	15	14
Egypt	12	7	8
Ethiopia	27	26	25
Gabon	2	2	5
Gambia	33	28	20
Ghana	15	18	16
Guinea	37	37	31
Guinea-Bissau	34	34	35
Kenya	9	12	15
Madagascar	22	22	30
Malawi	32	33	29
Mali	36	35	34
Mauritania	18	13	12
Mauritius	4	4	3
Morocco	13	9	9
Mozambique	20	21	37
Niger	29	29	33
Nigeria	14	14	13
Rwanda	26	24	22
Senegal	23	25	23
Sierra Leone	35	36	36
South Africa	1	1	1
Swaziland	7	10	11
Tanzania	19	20	21
Togo	17	17	18
Tunisia	5	5	4
Uganda	24	23	24
Zambia	10	16	17
Zimbabwe	6	6	6

Rankings of 38 African countries by environmental sustainability index scores, 1975–84, 1985–94, and 1995–2000

Country	Environmental sustainability 1975–84	1985–94	1995–2000
Algeria	33	33	32
Benin	15	13	15
Botswana	28	28	31
Burkina Faso	3	4	2
Burundi	10	10	12
Cameroon	17	23	18
Chad	13	11	9
Congo, Dem. Rep.	11	9	13
Congo, Rep.	34	32	25
Côte d'Ivoire	22	22	20
Egypt	19	30	30
Ethiopia	14	15	17
Gabon	1	1	1
Gambia	8	12	22
Ghana	30	26	29
Guinea	2	2	6
Guinea-Bissau	5	5	4
Kenya	36	35	35
Madagascar	24	18	11
Malawi	7	7	10
Mali	6	6	8
Mauritania	21	20	14
Mauritius	38	38	38
Morocco	26	31	33
Mozambique	25	21	7
Niger	9	8	5
Nigeria	23	25	26
Rwanda	18	16	21
Senegal	12	14	19
Sierra Leone	4	3	3
South Africa	16	17	24
Swaziland	35	34	36
Tanzania	27	24	23
Togo	29	29	28
Tunisia	37	37	37
Uganda	20	19	16
Zambia	32	27	27
Zimbabwe	31	36	34

Rankings of 38 African countries by institutional sustainability index scores, 1975–84, 1985–94, and 1995–2000

	Institutional sustainability		
Country	**1975–84**	**1985–94**	**1995–2000**
Algeria	32	25	19
Benin	**38**	**18**	**7**
Botswana	2	1	1
Burkina Faso	**10**	**28**	**24**
Burundi	33	38	36
Cameroon	**20**	**15**	**21**
Chad	37	37	29
Congo, Dem. Rep.	**34**	**34**	**38**
Congo, Rep.	19	23	18
Côte d'Ivoire	**36**	**35**	**33**
Egypt	11	8 1	5
Ethiopia	**13**	**21**	**25**
Gabon	21	26	31
Gambia	**3**	**3**	**26**
Ghana	22	32	11
Guinea	**23**	**33**	**20**
Guinea-Bissau	17	20	16
Kenya	**15**	**12**	**14**
Madagascar	8	7	3
Malawi	**29**	**29**	**10**
Mali	31	27	6
Mauritania	**12**	**11**	**27**
Mauritius	1	2	2
Morocco	**16**	**9**	**28**
Mozambique	27	13	9
Niger	**35**	**17**	**13**
Nigeria	6	24	34
Rwanda	**26**	**36**	**37**
Senegal	7	4	8
Sierra Leone	**9**	**16**	**32**
South Africa	4	5	4
Swaziland	**30**	**31**	**35**
Tanzania	18	14	30
Togo	**24**	**30**	**17**
Tunisia	25	10	12
Uganda	**14**	**19**	**22**
Zambia	28	22	5
Zimbabwe	**5**	**6**	**23**

Source: *Calculations by Economic Commission for Africa.*

Notes

1. The concept of a development programme is in the spirit of the notion of an "economic programme" used in Dasgupta (2000). But the development programme differs from that notion in that it endogenizes the institutional structure of the economy. This institutional structure is the major part of what Dasgupta (2000) calls a resource allocation mechanism. The other part is the set of behavioural characteristics of economic agents such as households, firms, and governments.

2. The transition to sustainability in the environment involves moving from high to lower material and energy intensity. The transition to sustainability in human settlement relates to the shift from rural to urban, and that in population to the shift from high to low birth and death rates. And the transition in education means progressing from low to high literacy and numeracy rates.

3. The classification procedure used is K-means cluster analysis, in which the means of the selected characteristics are used to classify countries into relatively homogeneous clusters. Countries are iteratively assigned to the nearest cluster centre using the simple Euclidean distance. To ease comparison across periods, the cluster centres for 1975–84 are used as reference points.

4. The 10 most populous countries in Africa are Nigeria, Egypt, Ethiopia, the Democratic Republic of Congo, South Africa, Tanzania, Algeria, Morocco, Kenya, and Uganda, accounting for about two-thirds of the continent's population and output.

5. A complete data set covering all African countries could not be obtained, even after an intensive data collection effort. The countries excluded are Angola, Cape Verde, the Central African Republic, Comoros, Djibouti, Equatorial Guinea, Eritrea, Lesotho, Liberia, Libya, Namibia, São Tomé and Principe, Seychelles, Somalia, and Sudan.

6. Data on civil liberties and political rights are from the Freedom House database, while data on political competition are from the Polity IV Project database.

7. Data on executive constraints and executive recruitment are from the Polity IV Project database.

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Chapter 3

Realizing the Promise of Green Biotechnology for the Poor

Thirty years ago I was chosen to receive the Nobel Peace Prize, representing the thousands of researchers who created the higher crop yields of the Green Revolution. Today, we are faced with another equally enormous task. We must learn to produce nearly three times as much food for the more populous world of 2050. The International Food Policy Research Institute recently projected that Africa is a "building catastrophe." African farms are currently locked in a downward spiral, in which the traditional bush fallow periods are shortened from 15 or 20 years to as little as two or three—which means crop yields are declining, soil nutrients are depleted and still more land must be planted every year to feed the people. I've spent the past 20 years trying to bring the Green Revolution to Africa—where farmers use traditional seeds and organic farming systems that some call "sustainable." But low-yielding farming is only sustainable for people with high death rates. Africa desperately needs the high-yield farming systems that have made the First World's food supply safe and secure.

—Norman Borlaug, Winner of the 1970 Nobel Peace Prize
(*Wall Street Journal*, 13 May 2002)

Some key facts

- About 70% of Africans live in rural areas and depend, directly or indirectly, on agriculture.
- Average cereal yields in Africa are half those in the other developing regions—Asia and Latin America and the Caribbean.
- Across Africa, yields of maize—the staple food crop in most of East and Southern Africa—average about 1.7 tonnes a hectare, compared with a global average of 4 tonnes.
- About 5 million hectares of forest are lost annually in Africa, mostly to the expansion of crop area.
- By 2010 more than 35% of the Sub-Saharan African population will be undernourished, the highest rate among all regions.
- Advances in crop biotechnology promise to produce superior variants: crops with higher yields, higher nutritional content, and tolerance to pests and drought.
- In Kenya the genetically modified sweet potato is expected to raise yields to levels up to 60% higher than those of traditional varieties—without the use of pesticides.
- In South Africa the use of Bt (*Bacillus thuringiensis*) cotton seed has increased cotton yields by an average of 20%.

- Modern biotechnology offers possibilities for amplifying the achievements of the green revolution by improving the ability to diagnose plant and animal pathogens and accelerating conventional plant and animal research.
- Like any other scientific discovery, biotechnology will not work magic on its own. African governments need to develop appropriate policies bearing in mind the needs of poor people dependent on agriculture for their livelihoods.
- Both modern biotechnology and conventional breeding techniques should be supported and encouraged.

Rapid developments in science allow people to understand living organisms in greater detail than ever before

Rapid developments in science allow people to understand living organisms in greater detail than ever before. The new knowledge enables scientists to modify the very building blocks of life—the genes themselves. But many concerns about modern biotechnology have been raised in the developed world.

- Consumer concerns about the short- and long-term safety of genetically modified (GM) foods for people.
- Environmental concerns, including worries about such effects as reduced biological diversity, proliferating superbugs, gene leakages, and the sustainability of agriculture using GM seeds.
- Ethical, religious, and other societal concerns stemming from the possible impact of GM crops on society.

Africa has an important stake in this debate, but its concerns have not been adequately voiced (Juma 2000a). Dictating those concerns is the urgent need to feed its growing population and reduce widespread poverty, hunger, and starvation. Africa's current population of 750 million is projected to rise to 1.7 billion by 2050, growing faster than the population of any other major region—and twice as fast as food production in the region (Pinstrup-Andersen and Pandya-Lorch 1999). So, in the absence of significant productivity gains or expansion of agriculture into tropical forests and marginal lands, it is clear that there will not be enough food to feed people and reduce poverty (Wambugu 1999; McGloughlin 1999).

The green revolution has demonstrated that technological change in agriculture can be a powerful force in increasing crop yields and reducing poverty. The new high-yielding varieties introduced in the green revolution doubled cereal production and lowered real food prices. The poor benefited more than the rich, since they spend more of their income on food (FAO 2000). The high-yielding varieties of rice and wheat were based on new genes for dwarfing that made the varieties shorter and more responsive to fertilizers.

Of particular importance to Africa today is whether recent advances in biotechnology can be safely harnessed to produce foods that have greater yields, resist pests and diseases, and offer other positive nutritional, health, and environmental attributes (Brink, Woodward, and DaSilva 1998). Many African countries depend heavily on agriculture, so they stand to benefit disproportionately from any technology that can increase the production of food, enhance its nutritional quality, and minimize the exploitation of forests and marginal lands.

Top leaders in Kenya have embraced the promise of GM crops, stressing that "while the Green Revolution was a remarkable success in Asia, it largely bypassed Africa. Today the international community is on the verge of a biotechnology revolution that Africa cannot afford to miss" (Paarlberg 2001, p. 46). Nigeria's Minister of Agriculture underscores that same point: "Agricultural biotechnology, whereby seeds are enhanced to instil herbicide tolerance or provide resistance to insects and disease, holds great promise for Africa...We don't want to be denied this technology because of a misguided notion that we don't understand the dangers of the future consequences" (UNDP 2001, p. 69).

African countries need to develop appropriate national policies and identify key national priorities for biotechnology

Despite support for biotechnology from some governments (the United Kingdom, the United States) and international organizations (Consultative Group on International Agricultural Research, Food and Agriculture Organization, Organisation for Economic Co-operation and Development, United Nations Development Programme), opposition remains strong in several industrial countries, particularly in Europe. Concerns about GM foods, cultural preferences, resource sustainability, and environmental protection have led to restrictions on modern agricultural technology, including a moratorium by the European Union on the approval of commercial use of GM foods.[1] Highly publicized outbreaks of food-borne diseases (such as mad cow disease) have rooted food safety issues at the heart of this debate and heightened consumer awareness.

Much more needs to be done to clarify the issues. In most public debates biotechnology has become synonymous with genetically modified organisms (GMOs), though these are only one of many products (box 3.1). Moreover, the debate over GMOs has so far focused on risks to human health and the environment, with little attention to the concerns of developing countries (Juma 2000a).

The economic stakes are high because Africa needs to diversify away from traditional export crops to higher-value-added foods, such as tropical and subtropical fruits and fresh vegetables. GM products could be met with non-tariff barriers to trade, which would limit Africa's ability to exploit its comparative advantage in non-traditional exports and thus the ability of the nascent private sector to create jobs and raise incomes. But biotechnology could catalyse enterprise development, enhance the competitiveness of agricultural products, and thus promote Africa's integration into the world economy (Juma 2000c).

This chapter critically evaluates the debate on crop biotechnology in the African context. Illustrating the range and nature of current risks and opportunities inherent in the technology, it focuses on how to ensure that access to agricultural biotechnology benefits poor farmers in Africa. The conclusion: while there are serious concerns about the impact of agricultural biotechnology on human health and environmental safety, the benefits are likely to greatly outstrip the risks (Egwang 2001). But to realize these benefits, African countries need to develop appropriate national policies and identify key national priorities for biotechnology while bearing in mind the potential biological risks and the needs of the poor. All stakeholders should be involved in formulating the national biotechnology policies, strategies, and plans.

Box 3.1
A wide array of "biotechnologies"

The UN Convention on Biological Diversity, adopted in 1992, defines biotechnology as "any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use." The major areas of modern biotechnolgy:

- *Genomics*: the molecular characterization of all species.
- *Bioinformatics*: the assembly of data from genomic analysis into accessible forms.
- *Gene splicing* or *transformation*: the general process of moving one or more genes with certain prospectively useful qualities to plants, domestic animals, or other organisms. The result is transgenic organisms, now referred to as genetically modified organisms (GMOs).
- *Genetic modification*: the direct introduction of desirable characteristics by the artificial transfer of foreign or synthetic DNA (deoxyribonucleic acid) into plants. DNA is the biochemical substance from which genetic material is made.
- *Molecular breeding*: the identification and evaluation of desirable traits in breeding programmes through the use of marker-assisted selection—for plants, trees, and livestock.
- *Diagnostics*: molecular characterization to provide accurate and rapid identification of pathogens and other organisms.
- *Vaccine technology*: modern immunology to develop recombinant DNA (rDNA) vaccines for improving control against lethal diseases.
- *Plant tissue culture*: the growth of undifferentiated plant cells in vitro. The technique allows the regeneration of entire organisms from single cells, to preserve genetic resources and produce disease-free planting materials.

***Source:** Persley and Doyle 1999.*

So, biotechnology is not a "silver bullet" for all of Africa's problems. Many complementary interventions—good governance, better rural infrastructure, broader credit availability, greater access to markets, improved market intelligence, enhanced extension services—are required to realize the promise of the biotechnology revolution.

Most farming communities in Africa are under pressure to adopt more intensive cultivation systems

Reducing poverty and hunger requires agricultural modernization

Poverty in Africa remains widespread and severe, with more than 300 million people living on less than $1 a day and the number of absolute poor on the continent forecast to grow in the next decade. Most of the poor live in rural areas and are engaged in agriculture and agriculture-related activities (FAO 2000, p. 226). Agriculture is the main economic sector in Africa, accounting for about 30% of total GDP and 70% of total employment in 1995 (see table 3.3). So, rapid economic growth can be achieved only with significant and sustained improvement in this sector.

But agriculture has performed poorly in Africa over the past 30 years. The reasons: low productivity, low population density, proneness to drought and disease, weak infrastructure, and civil strife. And a legacy of poor public interventions in input and product markets has not yet been entirely reversed.

Because of growing populations and the desire for higher incomes, most farming communities in Africa are under pressure to adopt more intensive cultivation systems. These needs are not being met in a sustainable manner. Africa's tropical forests are biologically fragile and quickly lose productive potential when under stress. Roughly 5 million hectares of forest are lost each year, mostly to crop area expansion (Paarlberg 2001). Clearly, this expansion cannot be the solution.

Africa's tropical forests are biologically fragile and quickly lose productive potential when under stress

Food outlook—bleak

Africa is the only region where average food production per person has declined over the past 40 years (United Nations 2001). Food consumption exceeded domestic production by 50% in the 1980s and by 30% in the 1990s. Cereal import requirements are set to remain high, reflecting mainly continued drought in some parts of East Africa, displacement due to the escalation of conflicts, and adverse weather in Southern Africa. The total food aid requirement for Africa in 2000/01 was estimated at 2.7 million tonnes, almost the same as imports in 1999/2000. But total food aid pledges for 2000/01, including those carried over from 1999/2000, amounted to only 1.5 million tonnes, with 1 million tonnes delivered.

Chronic food shortages have led to serious undernourishment among broad sections of the population and to stunting among children. It is projected that 35% of the population in Sub-Saharan Africa will be undernourished in 2010, the highest rate among all regions (table 3.1). People consume only 2,190 calories a day on average, the lowest level in the world (FAO 2000). By contrast, average per capita food intake is 3,600 calories a day in North America, 3,500 in Western Europe, 2,770 in Latin America and the Caribbean, 2,627 in all developing countries, and 2,415 in all of Africa.

Some countries have levels much lower than the continent's average. In Burundi and Ethiopia—the two countries with the most dire situations, with hunger indices below 0.40—people consume less than 1,900 calories a day on average (table 3.2). Of 20 Sub-Saharan countries, 16 have an average calorie intake per capita below the minimum average requirement of 2,300 calories stipulated by the Food and Agriculture Organization (FAO). Only Côte d'Ivoire, Ghana, Nigeria, and South Africa exceed that benchmark. In North Africa, Algeria, Egypt, Morocco, and Tunisia, with stronger economies, all have an average daily calorie intake exceeding 3,000 and hunger indices above 0.60.

In 14 of 20 Sub-Saharan countries, more than 30% of children are stunted, a much higher rate than in Latin America and the Caribbean (FAO 2000).

Table 3.1

Incidence of chronic undernourishment in developing regions, 1979–81, 1990–92, and 2010

Region	Period[a]	Population (millions)	Share of population undernourished (percent)
Sub-Saharan Africa	1979–81	357	39
	1990–92	500	41
	2010	874	35
Near East and North Africa	1979–81	233	10
	1990–92	317	10
	2010	513	7
East Asia	1979–81	1,393	17
	1990–92	1,674	16
	2010	2,070	5
South Asia	1979–81	892	33
	1990–92	1,146	22
	2010	1,617	15
Latin America and the Caribbean	1979–81	354	13
	1990–92	443	14
	2010	593	8
Total	1979–81	3,228	27
	1990–92	4,064	20
	2010	5,668	13

a. Three-year averages except for 2010, for which data are estimates based on projections of annual population growth rates for each region.

Source: *FAO 1996a.*

Crop yields—low

Africa has the second least cropland per capita at 0.28 hectare, down from 1.8 hectares in 1960. And while cereal yields increased in Asia and Latin America after the introduction of high-yielding varieties in the mid-1960s, they declined or stagnated in Africa. In 1993–95 cereal yields in Africa were 40% lower than those in Asia and Latin America (Ongaro 1999), and in 1998–99, 50% lower (table 3.3). Yields of maize, the staple food in most of East and Southern Africa, average 1.7 tonnes a hectare in Africa, less than half the global average of 4 tonnes (FAO 2001b).

Irrigation is one means to increase crop yields. But Africa is water stressed, with rainfall on a downward trend and droughts common in large parts of the continent. Water-related problems arise mainly from poor water and land management. Sporadic rains cause widespread flooding, with water running quickly into oceans or wasted.

Table 3.2

Indicators of food availability and hunger in selected African countries, 1998

Country	Average daily calorie intake per capita	Gini index for consumption expenditure[a]	Share of children under 5 stunted (percent)	Hunger index[b]
Ethiopia	1,805	40.0	64.2	0.32
[illegible]	1,579	33.3	47.4	0.38
Madagascar	2,001	46.0	48.3	0.41
[illegible]	2,010	56.0	44.0	0.42
Zambia	1,950	49.8	42.4	0.42
[illegible]	1,866	50.5	41.1	0.43
Sierra Leone	2,045	62.9	34.7	0.43
[illegible]	1,999	38.2	43.4	0.45
Central African Republic	2,056	61.3	28.4	0.47
Mozambique	1,911	39.6	35.9	0.48
Kenya	1,968	44.5	33.6	0.48
Burkina Faso	2,149	48.2	33.3	0.49
Mali	2,118	50.5	30.1	0.50
[illegible]	2,216	39.2	38.3	0.50
Nigeria	2,882	50.6	37.7	0.51
[illegible]	2,153	56.8	21.4	0.52
South Africa	2,909	59.3	22.8	0.55
[illegible]	2,277	41.3	22.9	0.58
Côte d'Ivoire	2,695	36.7	24.4	0.62
[illegible]	2,684	32.7	25.9	0.63
Morocco	3,165	39.5	24.2	0.64
Tunisia	3,297	41.5	22.5	0.65
Algeria	3,020	35.3	18.3	0.68
Egypt	3,282	28.9	24.9	0.69
Sub-Saharan Africa	2,190	—	41.0	—
All Africa	2,415	—	35.2	—

— *Not available.*

Note: *Minimal energy supply needs vary by age, gender, and other factors. Since national populations have different demographic compositions, average daily energy needs therefore vary.*

a. The Gini index for consumption expenditure measures the extent to which the distribution of spending on goods and services within a country deviates from a perfectly equal distribution and thereby gives an indication of the general equality of access to food in that country. A Gini index of 0 represents perfect equality, and an index of 100 perfect inequality. Thus the higher the value of the index, the less access vulnerable people have to food.

b. The hunger index ranges from 0 (most dire hunger problem) to 1 (no significant hunger problem). The index combines data on three indicators: availability of food, access to food, and use of food.

Source: *Bread for the World Institute 2001.*

It is projected that 35% of the population in Sub-Saharan Africa will be undernourished in 2010

Table 3.3

Performance of agriculture in developing regions, selected years, 1986–2001

Indicator	Africa	Asia[a]	Latin America and the Caribbean
Agricultural GDP (billions of U.S. dollars), 1997	62	400	143
Agricultural GDP as a percentage of total, 1995	30	25	10
Agricultural labour force as a percentage of total, 1995	70	72	29
Agricultural exports as a percentage of total, 1995	40	18	20
Agricultural production index (1989–91 = 100)[b]			
1986–90	93.0	93.1	95.6
1991–95	106.4	116.0	107.7
1996–2001	124.6	141.4	127.6
Average cereal yields (kilograms per hectare), 1998–99	1,220	2,896	2,587
Cereal production per capita (tonnes), 1998–99	0.17	0.28	0.29
Fertilizer on arable land (kilograms per hectare), 1998–99	18	128	80
Irrigated cropland as a percentage of total, 1998–99	6.0	25.1	7.7
Rural farm income as a percentage of total rural income, 1998–99	58	58	60
Food production index (1989–91 = 100), 2001	128.3	150.2	140.9
Cereal production and imports (millions of tonnes), 2001[c]			
Wheat production	18	240	89
Wheat imports	25	50	18
Rice production	17	537	17
Rice imports	7	11	13
Coarse grains production[d]	82	260	108
Coarse grains imports[d]	14	56	12

a. Excludes Japan.

b. FAO data from http//:apps.fao.org/page/collections?subset=agriculture (accessed 8 January 2002).

c. Provisional estimates from FAO 2001a.

d. Maize and barley only.

***Source:** Bread for the World Institute 2001; FAO 2000; World Bank 2000a, b.*

Degradation of soil fertility has also contributed to the stagnation in average yields. But applying fertilizer is not the solution under present conditions: existing crop varieties are unable to absorb more fertilizers, holding back the transition to more intensive cultivation. There is thus a need to develop crops that mature early, offer higher yields, and can adapt to the harsh climatic conditions of Africa.

If poverty is to fall, the increase in yields will have to occur on the fields of poor farmers and generate employment opportunities for the rural poor. And if environmental sustainability is to be ensured, the increase in yields will have to be achieved through means other than fertilizer use, area expansion, irrigation, and traditional plant breeding.

The next phase of yield increases in agriculture will have to rely on the new scientific advances offered by biotechnology.

From the green revolution to the gene revolution

Worldwide agricultural productivity has benefited from two green revolutions that have brought crop varieties, allowing higher yields and able to tolerate stress and resist pests and diseases. The gene revolution has amplified the benefits. Nonetheless, Africa has yet to fully benefit from either the green or the gene revolution.

If poverty is to fall, the increase in yields will have to occur on the fields of poor farmers and generate employment opportunities for the rural poor

The first green revolution

The first green revolution—from the early 1960s to 1975—introduced new varieties of wheat, rice, and maize that doubled or tripled yields. The new varieties were highly susceptible to pest infestation and thus required extensive chemical spraying. But they were also responsive to high rates of fertilizer application under irrigation. So, large- and medium-scale farmers in regions with adequate irrigation facilities, easy access to credit, sufficient ability to undertake risks, and good market integration adopted the new varieties (de Janvry and others 1999; Ongaro 1999). But these requirements meant that the new technology bypassed most poor African farmers (Ongaro 1990; David and Otsuka 1994).

Another reason that Africa did not benefit from the first green revolution was the research strategy used. To short-cut the process of varietal improvement, researchers introduced improved varieties from Asia and Latin America rather than engaging in the time-consuming exercise of identifying locally adapted germ plasm and using this as the basis for breeding new varieties.

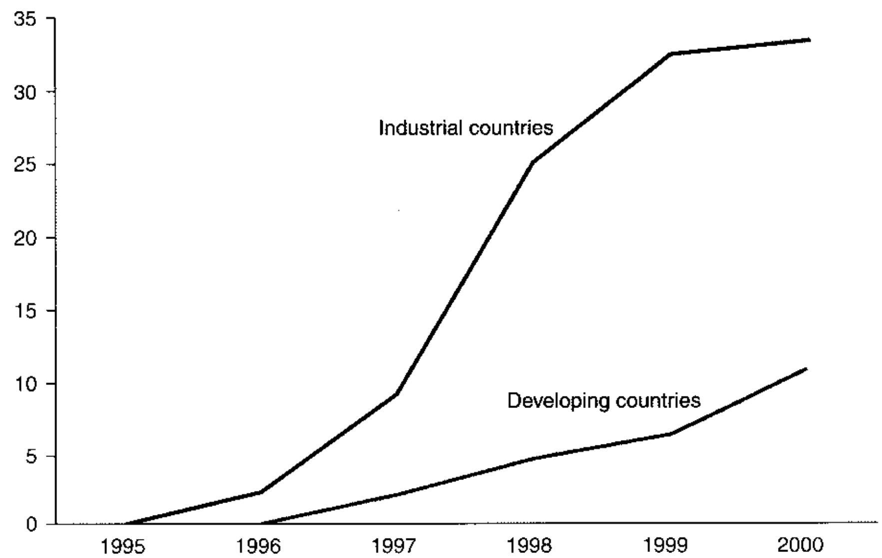
After the early euphoria with the high-yielding varieties, several problems became evident. First, the need for significant use of pest and weed control raised environmental and human health concerns. Second, as areas under irrigation expanded, water management required sophisticated skills that were in short supply. As a result poor farmers growing staple food crops in Africa could not adopt the new varieties. What was crucial for Africa was to develop crop varieties that could thrive in water-stressed regions without heavy use of fertilizers.

The second green revolution

The second green revolution—from 1975 to the 1990s—sought to consolidate lessons from the first by developing crops with a wider range of traits desirable for less well endowed areas and smallholder farmers. These traits included tolerance to stress and resistance to pests and diseases. Increased yields were sought by increasing the productivity of factor use.

The areas where the new crops could be grown were extended to rain-fed and marginal regions. The Sahel region of West Africa (Burkina Faso and Mali) and some parts of East and Southern Africa were prime locations for the new crop varieties. In addition, the range of crops was broadened to include crops suited to marginal environments and consumed by people in tropical and semi-tropical environments, such as sorghum, cassava, and pearl millet. And credit extension services were provided to farmers, particularly small-

Figure 3.1
Global area of genetically modified crops, 1995–2000



Source: *Adapted from Wambugu 2001.*

Biotechnology offers possibilities for further amplifying the achievements of the first and second green revolutions

holders. All this brought only modestly higher cereal production, but significantly greater direct effects on poverty.

The spread of the gene revolution

The third green revolution is the biotechnology or gene revolution. Biotechnology offers possibilities for further amplifying the achievements of the first and second green revolutions. Four areas in which biotechnology is likely to have significant impact (Morris and others 2001):

- Improving genome management (through use of molecular markers for quantitative trait improvement, introgression of new germ plasm into breeding lines, genetic diversity analysis, and parental selection).
- Enhancing genetic analysis (through introduction of new genes, directed mutagenesis, optimization of gene expression, and gene discovery).
- Quickening the pace of conventional plant research (through new biotechnological techniques—conventional breeders must rely on phenotypic evaluation, which does not always accurately indicate the information present in a plant's genome).
- Improving agricultural yields.

In 1983 China became the first nation to release a GM plant—a tobacco plant resistant to an antibiotic (Paarlberg 2001). But it was the United States that undertook large-scale cultivation of GM crops, with 14,153 field trials between 1987 and 1997. Canada conducted 3,747 trials in the same period. By 1996, 23 GM crop varieties had been approved for commercial production in the United States, 12 in Canada, and 7 in Japan.

In 1996, of the world's 2.8 million hectares of GM crops, 1.6 million, or 57%, were in North America (James 2000). By 2000 the global coverage of GM crops reached 44.2 million hectares, with North America accounting for more than 75% (James 2000). China accounted for 3 million hectares in 2000, with Mexico and South Africa having only small areas planted. Argentina is the only developing country with a significant share of GM crops, 22.6% of its total area under cultivation. Worldwide, the largest plantings were in soybeans, corn, canola, and cotton. In 1998 these four accounted for almost all the land under GM crops (James 1999).

Firms that undertook GM crop development targeted wealthier farmers in temperate-zone countries

What is the main reason for the high concentration of GM crop acreage in a few countries? The profit motive of the large private sector firms engaged in biotechnology research and development. The firms that undertook GM crop development targeted wealthier farmers in temperate-zone countries with the financial capacity and commercial seed-buying habits to support the new products. Poor subsistence farmers in the tropics, particularly in Africa, were not considered attractive customers.

Another reason for the high concentration of GM crops in a few countries: agricultural research was not considered a priority for developing countries and the international community (UNDP 2001). As a result subsistence crops (millet and cassava) initially attracted little research attention.

That has changed. Numerous GM crops are being field-tested in Bolivia, Brazil, Chile, Costa Rica, Cuba, Egypt, Guatemala, India, Kenya, Malaysia, South Africa, and Thailand. The crops include rice, maize, melon, papaya, tomato, sweet pepper, and sweet potato. Other GM food crops—such as wheat, bananas, pineapples, and sugar beets—have been developed in laboratories and are expected to go through the approval process for marketing in the next few years.

In Africa field trials have been conducted on GM sweet potato in Kenya and GM maize and cotton in South Africa and are planned for virus-resistant potato in Mauritius. But by 2001 GM maize and cotton were being commercially grown (in small quantities) in only one country in the region—South Africa (Paarlberg 2001).

Banana tissue culture demonstrates that the potential gains from appropriate biotechnology can be great for the small farmer (box 3.2). But it also shows that more public research and development funds should be made available to develop biotechnologies that explicitly tackle the needs of resource-poor producers in Africa. The leaders in biotechnology research and application in Africa—Egypt, South Africa, and Kenya—show that careful planning and implementation of biotechnology strategies are imperative for successful adaptation (boxes 3.3–3.5).

Before GM crops are commercially released, more needs to be done to ensure that their benefits can be fully realized by both farmers and consumers. That calls for a clear understanding of the potential benefits and costs of biotechnology.

Box 3.2

Banana tissue culture—pro-poor crop biotechnology

The potential gains from appropriate biotechnology can be great for the small farmer

While in the Western world bananas are an excellent nutritional choice, in East, West, and Central Africa they provide more than a quarter of all food calories. But their cultivation in Africa is threatened by pests, mainly in the humid tropical production zones. The most serious threats stem from fungi (*Mycosphaerella fijiensis* and *M. musicola*, responsible for black sigatoka and yellow sigatoka, and *Fusarium oxysporum* var. *cubense*, responsible for Panama disease), nematodes (*Radopholus similis*, *Helicotylenchus multicinctus*, and *Meloidogyne* spp.), viruses (banana bunchy top virus, banana streak disease, banana bract mosaic), a bacterium (*Ralstonia solanacearum*, which causes Moko disease), and an insect, the banana borer (*Cosmopolites sordidus*).

The resulting yield losses make the banana relatively expensive for consumers and therefore limit its export potential. They also undercut the cash earnings of producers and the food security of rural households. In Kenya, for example, banana yields average about 14 tonnes a hectare, less than 30% of potential yields under favourable conditions in the humid tropics.

Does biotechnology offer any solution? Yes. A specialized breeding technique called tissue culture propagation produces greater yields of bananas of uniform size (ideal for the export market) in a shorter time than naturally propagated bananas. The tissue culture banana is also resistant to pests and diseases.

South Africa's Institute of Tropical and Subtropical Crops (ITSC) is collaborating with the Kenya Agricultural Research Institute (KARI) to develop and disseminate this technology. KARI has conducted on-station experiments and on-farm trials with tissue culture material in Kenya's Central Province, and in coming years the technology will be disseminated country-wide. With the International Service for the Acquisition of Agro-biotech Applications (ISAAA), KARI has also initiated an effort to extend the banana project to neighbouring countries, in collaboration with national research organizations in Tanzania and Uganda.

Adopting banana tissue culture technology at the farm level in Kenya could substantially increase yields—and income—especially for smallholders. While potential gains in banana income for larger farms are estimated at around 106%, they could be even higher for smallholders—at 156%. Thus banana tissue culture technology is a good example of pro-poor biotechnology.

Source: *Qaim 1999; Thomson 2001.*

Modern biotechnology offers vast opportunities

Modern crop biotechnology offers the possibility of amplifying the achievements of the green revolution in many ways. It promises further increases in crop yields and quality, which will help reduce poverty and improve the nutrient content in foods. It quickens the pace of conventional plant breeding methods and improves the ability to diagnose plant pathogens. And it allows the production of environmentally friendly biofertilizers and biopesticides

Reduce income poverty

Biotechnology can reduce income poverty through at least two channels (other dimensions of poverty are considered below). First, it can help reduce poverty directly by raising the household incomes of poor farmers who adopt the technology—through greater production for home consumption, higher gross revenues from higher sales, higher unit value products, lower production costs, and lower losses before and after harvests (de Janvry and others 1999).

Box 3.3

Egypt—working to ensure food security through genetic engineering plant research

Egypt's strategic goals for agriculture are to optimize crop yields per unit of land and water used, to enhance the sustainability of resource use and protect the environment, and to bridge the food gap and achieve food self-reliance. These goals are imperative: arable land accounts for a mere 3% of Egypt's total land area, and some 99% of cropland is under irrigation. Moreover, agriculture accounts for 36% of employment, 20% of GDP, and 20% of exports.

To help achieve these goals, Egypt is turning to crop biotechnology. The aim is to produce genetically modified (GM) plants that are resistant to biotic stresses—fungi, insects, bacteria, and pathogenic viruses—and abiotic stresses—drought, salinity, and high temperatures. These problems lead to serious yield and post-harvest losses for many economically important crops.

The biotechnology research is centred in the Agricultural Genetic Engineering Research Institute (AGERI), a public sector institution established in 1990 that aims to promote safer transfer and use of biotechnology. The institute attaches high priority to collaboration with the private sector in Egypt, keeping it fully informed of progress in genetic engineering and biotechnology through newsletters and research reports, private sector participation in the design of product research and development (R&D), and private sector representation on its governing board.

AGERI has also formed a partnership with a private U.S. company, Pioneer Hi-Bred. The partnership, set up through an R&D arrangement by the U.S. Agency for International Development, is aimed at providing training for AGERI scientists at Pioneer Hi-Bred/Iowa (in designing and implementing safety regulations, laboratory safety procedures, and field-testing procedures for GM crops) and increasing the potential for product development.

AGERI recently produced its first biopesticide, Agerin, based on the insecticidal bacterium *Bacillus thuringiensis* (Bt). Agerin is capable of protecting a broad spectrum of key agricultural crops and controlling a number of biomedically significant pests. In collaboration with Agricultural Biotechnology for Sustainable Productivity (ABSP), AGERI also conducted field trials of GM potatoes resistant to the tuber moth in 1996 and field trials for virus-resistant tomatoes and cucurbits in1997. To help achieve its aim of bringing research results into use by a large number of farmers,the institute, in collaboration with a private investor, has set up a commercial entity, BIOGRO International. BIOGRO is expected to commercialize the GM crops produced by AGERI and ensure the free flow of related information.

Source: *Madkour 2000.*

Before GM crops are commercially released, more needs to be done to ensure that their benefits can be fully realized

Second, biotechnology can help reduce poverty indirectly through spillovers to both poor and non-poor farmers. For example, herbicide-resistant crops and those using Bt (*Bacillus thuringiensis*), a naturally occurring insecticidal bacterium, have forced tremendous competition in herbicide and insecticide markets. Prices of many herbicides and insecticides have been slashed by more than 50% in these markets to compete with the better economics of biotechnology seed-chemical solutions. Such price reductions have led to significant discounting of weed and insect control programmes, even benefiting farmers who have not adopted GM crops.

Another important spillover from new technologies is the effect on human capital accumulation. Research on the green revolution in India has shown that new technologies

Box 3.4

South Africa—leading the continent in adopting genetically modified crops

Biotechnology can help reduce poverty directly by raising household incomes of poor farmers

Like a host of other African countries, South Africa faces a unique set of problems that beg for the adoption of modern biotechnology to increase agricultural output. Less than 15% of its land is arable, and a growing population means growing demand for food, especially proteins. Most smallholder farmers obtain their scant livelihoods from marginal lands. And there is evidence of increasing damage to the ecological base for agriculture, including land, water, forests, and bio-diversity. The result is unprecedented poverty among a large part of the population.

In response to these conditions, South Africa has put considerable work into producing genetically modified (GM) maize, cotton, potato, and strawberries. Field trials of GM crops began in the early 1990s, the first commercial release of GM varieties occurred in 1997, and commercial planting of crops with insect-resistant and herbicide-tolerant traits started in 1998. About 3,000 hectares of Bt (*Bacillus thuringiensis*) maize were planted in 1998, and 5,000 hectares in 1999.

Studies in November 2000 in Makhathini Flats (in Kwazulu-Natal Province) showed a 20% increase in cotton yields due to the use of Bt cotton seed. And some commercial farmers were able to forgo pesticide spraying entirely, thanks to the effectiveness of the Bt toxin. (The toxin acts on lepidoptera, including bollworm in cotton and stem borers in maize, and is harmless to other insect species.) Today the private sector has taken on an active role, pursing other biotechnology research (such as on Bt maize and strawberries) without much government involvement.

But a cautionary note is in order. The challenge is not only to develop the technology but also to transfer it to the poorest farmers—and the cost of both technology development and transfer is relatively high in South Africa. Moreover, risk assessment and management techniques need to be in place to support the introduction of genetically modified organisms (GMOs) and deal with conflicting interests that may emerge, particularly from environmental and consumer groups.

The government is tackling these challenges. It has instituted a range of measures aimed at making it easy for the poor to adopt new technologies and harness the benefits of technological advances. And in December 1999 it implemented the GMO Act (Act No. 15 of 1997) to promote the responsible development, production, use, and application of GMOs. The act is aimed at protecting human health and the environment by requiring risk assessment and management of each GMO. Under this act all GM crops are evaluated, on the basis of sound science, for human health and environmental safety and for socio-economic implications.

Source: *Thomson 2001.*

increased the returns to education (Foster and Rosenzweig 1995). The returns to primary schooling increased at a higher rate in areas that adopted the new technologies faster. Moreover, technological innovations result in greater private investment in schooling. This suggests that policies resulting in greater technological innovations complement those to increase investment in schooling: the returns to investment in technological change will be higher when primary schooling is accessible, and the returns to investment in schooling will be higher when technological change is faster.

Other spillovers from technological change can result from:

- Increased employment in agriculture and agro-industrial sectors for both adopters and non-adopters.

Box 3.5

Kenya—producing its first "home grown" genetically modified sweet potato

Sweet potato (*pomoea batatas*), potato, and cassava are produced and consumed by most of Kenya's poor, and their cultivation provides an important source of employment and income in rural areas. In recent years these tubers have taken on increasing significance in Kenya. Population growth, rapid urbanization, and low per capita incomes have generated strong demand for cheap starchy staples among poor rural and urban consumers alike. Moreover, changing diets—especially in urban areas—and the emergence of the snack and fast food industry have increased potato consumption. So, it is no surprise that tubers and roots have become the subject of joint research between the Kenya Agricultural Research Institute (KARI) and Monsanto Research Center in the United States.

Most small farmers in the Central, Eastern, Nyanza, and Western Provinces of Kenya grow non-GM sweet potatoes. The crop is highly susceptible to seed-borne diseases because the growers use plant tubers rather than the true seed. With this propagation method, each sweet potato plant is a clone of its mother, and diseases are easily passed on from one plant generation to the next. One of these is the feathery mottle virus, an aphid-borne disease that causes black marks on the tubers and often reduces yields. The average farm-level yield in Kenya is estimated at 6 tonnes a hectare—well below the world average of 14 tonnes. The low yields make sweet potatoes more expensive for consumers and undermine both cash earnings and food security among rural households.

It took a decade of research before KARI and Monsanto could launch the country's first GM sweet potato, in September 2001, a virus-resistant strain expected to raise yields by up to 60% without the use of pesticides. Following approval by the Kenya Biosafety Council, on-station trials of the GM sweet potato have been carried out in Embu, Kakamega, Kisii, Mtwapa, and Muguga. Even so, more on-station trials and research work are called for, particularly on risk management. Projections indicate that it will be three to four years before any GM sweet potato is commercially released.

But the KARI-Monsanto research project has already had benefits. It has trained several Kenyan scientists at Monsanto in gene construction, transformation, and expression and greenhouse test resistance. And it has opened ways of transferring technologies and extending the benefits to other African countries. South Africa has already shown interest in the technology, and KARI, which holds the intellectual property rights for the GM sweet potato on behalf of all of Africa, is working to effect the transfer. The International Potato Centre (CIP) also is eager to join the project and extend its impact in the region.

Source: *KARI 2001.*

Biotechnology can help reduce poverty indirectly through spillovers to both poor and non-poor farmers

- Increased employment in other sectors through production, consumption, and savings links with agriculture; lower costs of agricultural raw materials; lower nominal wage bills for employers (as a result of lower food prices); and foreign exchange contributions by agriculture to overall economic growth.

Through the price of food, spillovers can benefit a broad spectrum of the national poor, including landless farm workers, net food-buying smallholders, and the rural non-agricultural and urban poor, who spend a large share of their incomes on food. Employment creation is important for landless smallholders, net labour-selling smallholders, and the rural non-agricultural and urban poor.

The tradability of a crop in international markets determines the relative importance of direct and spillover effects (box 3.6). With non-tradables—teff, cassava, bananas, sweet potatoes—falling prices extract the net social gain from technological change to the benefit of rural and urban consumers. But even when technological change is biased towards cash crops for export, the spillovers are important because of the multiple roles of agriculture in economic development.

Scientists are exploring ways to use genetic modification to confer desirable characteristics on food crops

Increase crop yields and quality

Techniques to improve crops have been used for ages. Today applied plant science has three overall goals: to increase crop yields, improve crop quality, and reduce production costs.

In one active area of plant research scientists are exploring ways to use genetic modification to confer desirable characteristics on food crops. One of the desirable traits is tolerance to such adverse environmental conditions as drought, soil salinity, alkaline earth metals, and anaerobic (lacking air) soil conditions.

Box 3.6

Maximizing the benefits of biotechnology through rural development interventions

To quantify the effect of technological change on poverty, de Janvry and others (1999) use a standard computable general equilibrium model in which economic agents respond to relative prices so as to maximize profit and utility. Rational economic agents determine production and consumption levels, and markets reconcile endogenous supply and demand decisions through adjustments in relative prices.

Simulations of the model indicate that a 10% increase in total factor productivity due to technological change in all crops creates income gains for poor households in both urban and rural areas. Most of these gains (75%) accrue to the rural poor, with 25% going to the urban poor.

What crops should be targeted for maximum poverty reduction? The model shows that the impacts depend on the type of crop. Targeting technological change to cereals, which have low tradability, leads to a sharp decline in price (–12%). This price decline is transmitted to the food processing sector (mills and bakeries), benefiting consumers. But since the cereal sector is a small part of the economy (13%), the aggregate effect on GDP growth is only 2.9%. As a result the urban poor benefit essentially from lower food prices, not general growth effects. And income gains to the rural poor accrue mainly through benefits in home consumption, because the sharp drop in cereal prices adversely affects their marketed surplus. When technological change is tar-geted to cash crops, the urban poor capture most of the income gains (64%), with the rural poor receiving only 36%.

Which sector of society should be targeted for maximum poverty reduction? The model shows that targeting technological change to the rural poor gives rise to an aggregate growth effect similar to that of untargeted technological change, since the rural poor control almost 75% of agricultural value added. If technological change is targeted to large farmers, however, the impact on the rural poor is clearly outweighed by the impact on urban poor who are the main beneficiaries, capturing 68% of the income gains to the poor. In Africa rural development interventions to ensure that poor farmers can participate in technological change are thus important to reduce rural poverty.

Source: *de Janvry and others 1999.*

Another is higher yields and greater resistance to pests and diseases. Bt technologies have been developed to increase yields, while herbicide resistance technologies have been developed to reduce costs and the use of inputs (Kalaitzandonakes 1999). A number of studies have now established that resistance to insects and herbicides is generally associated with higher yields and profits (Klotz-Ingram and others 1999; Falk-Zepeda, Traxler, and Nelson forthcoming; De Maagd, Bosch, and Stiekema 1999; Abelson and Hines 1999).

Much research has gone into improving export crops that are not native or indigenous to Africa. Yet Africa has several indigenous crops of economic value. Juma (2000b, pp. 3–4) quotes the U.S. National Academy of Science:

> Africa has more native cereals than any other continent. It has its own species of rice as well as finger millet, fonio, pearl millet, sorghum, teff, guinea millet and several dozens of wild cereals whose grains are eaten. This is a food heritage that has fed people for generations, possible stretching back to the origins of mankind. It is also a legacy of genetic wealth upon which a good future might be built. But strangely it has largely been bypassed in modern times.

In Africa biotechnology research could yield tremendous benefits if it leads to drought- and pest-resistant rice (box 3.7), drought-tolerant maize, and insect-resistant millet, sorghum, or cassava. The development of cereal plants capable of capturing nitrogen from the air could contribute greatly to plant nutrition, helping small farmers who often cannot afford fertilizers.

The gene revolution might provide a better way to extend productive potential to poor farm communities, pre-packaged in genetically engineered seeds rather than delivered haphazardly through many separate purchased inputs. It also offers the potential for reducing yield variability through improved pest and disease resistance. And it holds out possibilities of higher production on previously unusable lands through crops that can tolerate drought, salinity, and aluminum.

Genetic engineering methods to improve the characteristics of fruits and vegetables—such as size, taste, colour, texture, sweetness, acidity, and ripening—are being explored as potentially superior to traditional cross-breeding. Research in this area of agricultural biotechnology is complicated by the fact that many of a crop's traits are encoded not by one gene but by many genes working together. So, one must first identify all the genes that function as a set to express a particular property. This knowledge can then be applied to altering the germ lines of commercially important food crops. For example, it will be possible to transfer the genes regulating nutrient content from one variety of tomatoes into a variety that naturally grows to a larger size. Similarly, by modifying the genes that control ripening, agronomists will be able to provide supplies of seasonal fruits and vegetables for extended periods.

Biotechnological methods for improving field crops are also being sought, since seeds serve both as a source of nutrition for people and animals and as the material for producing the next plant generation. By increasing the quality and quantity of protein or varying the types of protein in these crops, it will be possible to improve their nutritional value. For

Box 3.7
New rice for Africa

The gene revolution might provide a better way to extend productive potential to poor farm communities

"Food" implies "rice" to many people in West Africa today—home to some 240 million people. The past three decades have seen rice imports in the region increase eightfold—to more than 3 million tonnes annually, at a cost of almost $1 billion. Today rice contributes more calories and protein than any other cereal in humid West Africa and about the same as all roots and tubers combined.

West Africa also cultivates rice, but about 40% of its 4.1 million hectares of rice are either upland or dryland and yields are only about 1 tonne a hectare. New varieties of rice—dubbed NERICA (NEw RIce for AfriCA)—offer hope for much higher yields. The West Africa Rice Development Association (WARDA), based in Côte d'Ivoire, developed the new varieties by combining African and Asian strains. NERICA varieties mature 30–50 days earlier than the current varieties, allowing farmers to grow extra crops of vegetables and legumes. They are taller than most rices, making the harvesting easier, particularly for women with babies on their backs. And they resist pests and drought—important for farmers cultivating rain-fed rice. The new varieties also grow better on infertile and acid soil, which accounts for 70% of West Africa's upland rice fields.

African and Asian varieties of rice are so different that usually they will not cross-breed. So, scientists have instead used a technique called embryo rescue—the agricultural equivalent of in vitro fertilization—to produce NERICA. Field trials have registered yields as high as 2.5 tonnes a hectare with low inputs and 5 tonnes or more with a minimal increase in fertilizer application.

NERICA varieties have already been released to West African farmers in Côte d'Ivoire, Guinea, and Sierra Leone, where WARDA projects that adoption by just 10% of farmers will return an extra $8 million a year to farmers, and adoption by 25%, $20 million a year. Plans are also under way to distribute NERICA varieties to farmers in Benin, Gambia, Mali, Nigeria, and Togo. The target is to produce 750 million tonnes in 2003, which could save the eight countries some $100 million by reduc-ing rice imports. NERICA varieties may also benefit upland rice farmers in Asia (who grow rice on 17 million hectares) and Latin America (4 million hectares).

Source: *Economic Comission for Africa from official sources.*

example, a major protein of corn has very little of two amino acids essential for human growth: lysine and tryptophan. Greater amounts of these amino acids could make corn products a better source of protein.

Commercial applications of modern biotechnology have already had success in several African countries (see boxes 3.2–3.5). Success has also been registered in:

- Insect resistance in maize and cotton.
- Resistance to a range of viruses in potato (viruses X and Y and leaf roll).
- Ring spot virus (RVS) resistance in papaya.
- Rice with resistance to bacterial blight and higher iron and beta-carotene content.
- Tomatoes with elevated lycopene (provitamin A).
- Crops with abiotic stress tolerance genes (such as aluminum- and manganese-tolerant crops) that can grow in acidic soils and tolerate salt and drought.
- Delayed overripening of fruits and vegetables to reduce post-harvest losses.
- Herbicide-tolerant seeds that allow the use of herbicides to combat weed infestations and thus ease the labour burden for poor women and children.
- Tissue culture for the rapid multiplication of coffee, guava, ginger, papaya, pineapple, and avocado (Rybicki 1999).

Make high-yielding varieties accessible to poor farmers—through "seeds without sex"

Ongoing biotechnology research on apomixis—that is, "seeds without sex"—is likely to bring benefits to many smallholder farmers. Apomixis, a naturally occurring ability of some plant species to reproduce asexually, leads to hybrid plants genetically capable of cloning themselves by producing seeds without the need for pollination. Since the new seed is a carbon copy of the original seed, apomixis prevents genetic dilution. Success in this research would mean that farmers could reuse their own seeds (such as maize) without the yield reduction associated with using second-generation seeds from hybrids. This would free farmers from having to purchase hybrid seeds every season, making high-yield technology more accessible to poor farmers. Indeed, apomixis is the antithesis of the terminator gene technology, designed to produce infertile second-generation seeds so that farmers would have to buy fresh hybrid seeds every season.

One must first identify all the genes that function as a set to express a particular property

Apomixis also has the potential to simplify the breeding of adapted genotypes, preserve hybrid vigour, and improve the propagation of crops that now rely on vegetative propagation. For example, millions of farmers in Sub-Saharan Africa, particularly in West Africa, grow starchy roots—yams and cassava—as their staple food, while in East Africa sweet potato (*Ipomoea batatas*) and potato are important crops in countries' food systems. All these crops propagate asexually, which means that fungi or viruses in the parent tissue will carry into the offspring. But if these crops could be made to reproduce through seed, as in apomixis, this infectious legacy might be left behind.

Enhance the nutritional and health benefits

Research is under way on genetically engineered crops that will provide enhanced nutritional qualities. Nutritionally fortified crop varieties should prove especially valuable in African countries, where hundreds of thousands of people suffer from deficiencies in such nutrients as vitamin A and iron. Already, nutritionally optimized staple crops—such as golden rice, high-iron rice, and high-quality protein rice—have proved useful in combating vitamin A deficiency disorders, nutritional anaemia (especially iron-deficiency anaemia), and protein-energy malnutrition.

Golden rice represents a genetic engineering breakthrough, a nutrient-dense rice that can reduce vitamin A deficiency in developing countries. Today vitamin A deficiency affects 800 million people. Despite intensive traditional interventions, every year it causes blindness in half a million children and two million deaths (Potrykus 1999). It is particularly severe in areas where rice is the staple because rice contains no provitamin A, such as beta-carotene. In golden rice, transgenic research has introduced all genes necessary to establish biochemical pathways for beta-carotene (Ye and others 2000).

High-iron rice was created to deal with iron deficiency, which affects nearly 3 billion people worldwide. Anaemia, characterized by low hemoglobin, is the most widely recognized symptom of iron deficiency. But iron deficiency also impairs body growth, mental and motor development, and intellectual and emotional development. An adequate supply of iron is crucial in the first two years of life because of rapid body growth. A lack of iron makes children susceptible to infectious diseases, leads to premature birth, and is a major cause of maternal and child death in pregnancy. Introducing iron into rice posed several daunting problems because polished rice contains an inhibitor of iron resorption and does not support iron uptake in the intestine. The transgenic approach has reduced the inhibitor, doubled iron content, added uptake-promoting substances, and increased resorption-enhancing cysteine sevenfold, all under endosperm-specific control (Goto and others 1999).

Nutritionally fortified crop varieties should prove especially valuable in African countries

High-quality protein rice was developed to combat protein-energy malnutrition. A diet of 300 grams of standard varieties of rice provides less than 10% of the required essential amino acids, critical for numerous cellular functions. This deficiency impairs child development. High-quality protein rice contains a balanced mix of all essential amino acids.

The traits of these three strains of rice—provitamin A, iron availability, and essential amino acids—will all be combined in common varieties to serve those who suffer from malnutrition. They can also be transferred to other important crops, such as teff, millet, plantain, cassava, and sweet potato (Potrykus 2001).

Nutritionally enhanced GM crops will also benefit animals. Work is under way to engineer feed crops with high nutritional value. Animal health specialists are even examining the possibility of engineering feed crops capable of delivering vaccinations against common diseases.

Some GM crops could reduce the need to spray pesticides that harm soil quality and human health. Sustained exposure to pesticides can cause sterility, skin lesions, and headaches. One study of potato farm workers using pesticides in Ecuador found that chronic dermatitis was twice as common among them as among other people (UNDP 2001). And a recent study in China found pesticide contamination most serious in vegetables, fruits, and rice (Liu, Cheng, and Wang 1995).

Produce environmentally friendly biofertilizers and biopesticides

Modern high-yield agriculture requires the use of vast amounts of chemicals as fertilizers and as agents to control pests and plant diseases. Any mechanism that permits plants to do this work themselves could result in significant savings for farmers. For example, soybeans and certain other legumes produce their own source of usable nitrogen fertilizer through a process known as nitrogen fixation, made possible by a bacterium that grows symbiotically on the plant's roots. (In a symbiotic relationship dissimilar organisms live together in a mutually beneficial way.) In the nitrogen-fixing process microbes capture atmospheric nitrogen and biochemically convert it into water-soluble nitrogen, an essential nutrient for increasing the quantity and quality of plant yield.

The bacterium will not aid the growth of other important crops, such as corn and cereals. But research on nitrogen-fixing bacterium and legumes may show how we can modify either the bacteria or non-leguminous plants, making many crops more nearly self-sufficient in obtaining nitrogen.

Biotechnology makes it possible to develop bacteria that are essential in herbicide compounds. Certain chemicals produced by these organisms—allelopathic agents—act as natural herbicides, preventing the growth of other plant species in the same geographic area. Black walnut trees, for example, release an allelopathic agent that affects tomato plants.

Biotechnology can also help develop bacteria that can be used in effective, environmentally safe, and economically sound alternatives to chemical pesticides. Bacterial pesticides, or biopesticides, can protect commercial crops from insect pests while guarding against further environmental deterioration. They degrade rapidly in the environment—a major environmental benefit. The active elements of bacterial pesticides are proteins that are fragile molecules. Once exposed to the sun and other natural elements, they are quickly broken down, precluding their spread to groundwater and to other plant species as well as animals. This characteristic will help keep water safe to drink and lakes and streams habitable for water life and recreation.

Some GM crops could reduce the need to spray pesticides that harm soil quality and human health

The potent proteins used in biopesticide technology are produced in nature by such micro-organisms as Bt (*Bacillus thuringiensis*). Discovered at the turn of the last century, Bt has been used without risk in the United States for almost three decades by home gardeners, farmers, and forestry officials. Its active component, a protein, specifically attacks the stomachs of target pests, disrupting their digestive tracts so thoroughly that the pests stop eating and eventually die of starvation. Higher organisms—such as mammals, fish, birds, and other non-target species—remain unthreatened because their stomach acid easily breaks down the protein toxin.

The delivery of these biopesticides varies in method and design. In one method dormant spores of Bt are dusted on crops. The spores then become active and multiply, covering plants with bacteria poisonous to the target insects that feed on them. The Bt toxin gene can also be inserted into the genetic makeup of crops, giving them a built-in resistance to insects. Similarly, the toxin gene can be put into a third party, such as a micro-organism that lives in the plant's sap. These organisms—known as endophytes—multiply in the host plant and move throughout the plant's vascular system, forming a microscopic defence against feeding insects. This process resembles vaccines moving throughout a person's vascular system to defend against harmful disease.

Thus biotechnology may well address some of the environmental concerns raised about the use of dangerous pesticides to produce adequate crops. While some uses of chemical pesticides will be necessary for decades to come, further research in agricultural biotechnology and biopesticide development should lead to viable alternatives that will lower the unit cost of production and enable farmers to compete in highly cost-sensitive world markets.

Biotechnology also offers possibilities for reducing environmental degradation. It opens new avenues in designing agricultural production systems for varied conditions and environments by increasing the set of genetic materials available for producers and allowing finer adjustments of these materials to match eco-agronomic conditions. Thus biotechnology could help farmers produce more food on land already in use. The results:

fewer trees cut, fewer watersheds damaged, fewer hillsides ploughed, less soil lost, less habitat destroyed, and more biodiversity preserved.

Like any scientific discovery, biotechnology also poses risks

Biotechnology also offers possibilities for reducing environmental degradation

Questions are naturally raised about the possible risks associated with applying new advances in biotechnology to agriculture. The issues range from the potential impacts on the poor, on human and animal health, and on the environment to the risk of Africa's losing its comparative advantage in tropical crops (see box 3.8).

Exacerbate income inequality?

Whether the potential benefits of GM crops accrue to smallholder farmers is a question of the type of technology and the degree of inequality in a country. Where land tenure reforms are implemented, there is support for small farmers, and other elements of a development-friendly environment are in place, a new technology can benefit all farmers. But where, say, 70% of the land belongs to 5% of the population and agricultural extension and credit services are available only to big landowners, a new technology will widen the income gap between large and small farmers. Thus the social and economic impact of genetic engineering and biotechnology can only be as good as the socio-political soil in which the resulting new varieties are planted.

Some types of biotechnology could deepen poverty in Africa. For example, commercialization of the terminator gene technology, designed to prevent seed reproduction and thus ensure repeated seed purchases, would harm the millions of small farmers who depend on replanting farm-saved seeds. These farmers simply do not have the money to buy new seeds each year. Critics argue that this technology removes one of the foundations of rural agriculture, forcing smallholders into colonial dependence on rapacious multinationals. Proponents of this type of biotechnology maintain that it is only a concept and that it is not being developed. But it is believed that terminator gene technology is now on the fast track to commercialization (RAFI 2000), though no products are planned for Africa. Critics also cite concerns about the spread of the terminator trait to other plants. These concerns have fostered hostility towards multinationals, and in some parts of the world crops in field trials have been burned.

Damage human and animal health?

There is still no conclusive evidence to show that any of the transgenes found in GM foods are injurious to humans. But one frequent concern is that if foreign genes were present in GM foods at excessive levels, they could build up in the consumer's body, increasing the resistance of diseases to several types of antibiotics (Malcolm 1999).

Another potential risk is that people with allergies could suffer reactions after unwittingly consuming GM foods containing allergenic proteins introduced from external sources (Altieri 2000). For example, someone who is allergic to peanuts might suffer a reaction after consuming GM soybeans modified by the insertion of the peanut gene that produces the allergic reaction.

In fact, all the proteins that have been placed into foods through the use of biotechnology and are currently on the market are non-toxic; are sensitive to heat, acid, and enzymatic digestion (and thus rapidly digestible); and have no structural similarities to proteins known to cause allergies. Similarly, current evidence does not support the argument that inserting a new gene can alter the metabolism of plants and animals to produce allergens and toxins (Thompson 2000).

Box 3.8

Fact and fiction in the biotechnology debate in South Africa

FICTION	FACT
• Genetically modified crops are commerciallyavailable in South Africa	• There have been commercial releases of insect-resistant cotton (in the Northern Province and the yellow variety of maize for animal feed, corn starch, and corn syrup (accounting for about 4% of the total crop). But the South African Genetic Experimentation Committee (SAGENE) has not been approached about any other commercial release of GMOs. SAGENE has, however, approved numerous trials of GM crops in the past few years, focusing mainly on herbicide or insect resistance in such plants as maize, cotton, soybean, and strawberries.
• South Africa has no legislation restricting the release of GMOs, freeing multinationals to "dump" GM foods in the country	• Before the South African parliament passed the GMO Act in December 1999, compliance with SAGENE's requirements for the release of GMOs—including no direct or indirect human health risks, and minimal impact on livestock, beneficial non-target organisms, and the environment—was voluntary. Now contravention of the act, which formalizes those requirements, can result in a fine or imprisonment. To strengthen enforcement, SAGENE will be replaced by an advisory committee of up to eight members knowledgeable in the relevant scientific fields and two from the public sector knowledgeable in ecological matters and GMOs.
• Farmers—particularly small farmers—will be forced to buy GM seeds	• Market forces will prevail. If the GM seeds provide a better yield, farmers will buy them. If they do not, farmers will buy other seeds

Box 3.8 (continued)
Fact and fiction in the biotechnology debate in South Africa

FICTION	FACT
• Engineered foods can be easily separated from non-engineered foods.	• Many food items on supermarket shelvescontain soybeans—from canned soups to baby foods. The United States is one of the largest suppliers of soybeans, and some of its exported soybeans may have been genetically modified for insect or herbicide resistance. But since all the soybeans are pooled, it is impossible to separate the GM from the non-GM soybeans. (The cooking of the soybeans during the preparation of the foods denatures all proteins, however, including those produced by introduced genes.) The story will soon be the same for maize. How should manufacturers label such food items? There is no easy answer. Perhaps they should label them as "Possibly containing plant material that may have been subject to genetic modification."
• GM insect-resistant crops contain lectins, which are known to be potentially toxic to humans and animals.	• Lectins may indeed be toxic to humans and animals. But the GM insect-resistant crops produce the Bt toxin, which is not a lectin and, although toxic to certain insect species, is not toxic to humans or animals.
• Genes from GM crops can be passed on to other plants, wreaking environmental havoc.	• Plants can be pollinated only by closely related crops. So, SAGENE looks closely at the potential of GM crops to cross-pollinate other plants, especially weedy relatives. Major food crops such as maize do not have weedy relatives. The production of GM crops will reduce biodiversity. Hundreds of new crop varieties are produced every year by conventional plant breeding, increasing biodiversity. GM crops will simply add to this.
• Insects will quickly become immune to the Bt toxin, so planting crops containing the gene is a waste of time.	• The widespread use of GM insect-resistant crops has not yet resulted in insects becoming resistant to the Bt toxin, though it could. That is why seed companies require farmers planting such crops to also plant a certain percentage of non-Bt seeds—such as by selling the farmers a mix of Bt and non-Bt seeds or requiring them to enter into a contract. But the policing of such contracts is problematic, and the whole question of how to prevent insect immunity to Bt is under debate. It is certainly something that the advisory committee replacing SAGENE will consider seriously if a seed company applies for commercial release of Bt seed.

Box 3.8 (continued)
Fact and fiction in the biotechnology debate in South Africa

FICTION	FACT
• Terminator gene technology—which causes crops to produce sterile seeds—will force small farmers to continue buying seed from multinationals rather than planting seeds that they produce themselves.	• The U.S. Department of Agriculture and one commercial company have patented so-called terminator technology. But the technology has not yet been perfected. Nor has it been used anywhere—and thanks to public pressure, may never be.
• GM foods are inherently allergenic or harmful.	• There is no evidence that GM foods in general are any different from "normal" foods in terms of toxicity or allergenic potential. Many of the genes used to modify plants occur naturally in plants or in the viruses or micro-organisms that infect them or are associated with them—so humans have already been exposed to them. One exception, however, is transgenic Rowett potatoes, which are believed to be toxic in some cases.

Note: *Information is as of June 2002.*
Source: *Economic Commission for Africa from official sources.*

Some of the concerns about the potential threat posed by GMOs to human health have also been raised for animal health—concerns much publicized in the North, particularly in Europe. Since livestock and poultry consume large amounts of GM corn and soybeans, some livestock producers have raised the prospect of antibiotic resistance. If GMOs lead to a build-up of antibiotic resistance, commonly used antibiotics might become ineffective, increasing the cost of maintaining animal health. Concerns have also been expressed about the risk that antibiotic resistance could be passed on to people who consume livestock products. No evidence has emerged to show that consumption of GM feeds has affected animal health. But such feeds have not been around long enough to carry out effective feeding trials, so it would be premature to conclude that the issue has been definitely resolved (Abelson and Hines 1999).

Degrade the environment?

Probably the most controversial issues surrounding biotechnology relate to the long-term impact on the environment. The key issues:

- Whether GM crops lead to genetic uniformity and, as a result, vulnerability to new matching strains of pathogens.
- Whether herbicide-resistant crops reduce agro-biodiversity.
- Whether cultivation of herbicide-resistant plants will result in super weeds because

gene flow (exchange of genetic information between crops and its spread to weedy relatives growing nearby) is increased.

- Whether Bt crop hybrids destroy non-target insects, as Bt corn was thought to do to monarch butterflies (Losey, Rayor, and Carter 1999).

Probably the most controversial issues surrounding biotechnology relate to the long-term impact on the environment

Only extensive, well-designed, and well-monitored field tests will provide conclusive answers to these questions. But the evidence so far is that the risk of environmental degradation is minimal (McGloughlin 1999). More than 4,000 field tests of GM crops have been performed at 18,000 sites throughout the United States over the past 15 years for efficacy, performance, and suitability for release into the environment (USDA/ERS 1999b). These and thousands of similar field tests performed in other countries have produced no conclusive evidence of danger to the environment.

Nor has biotechnology increased the vulnerability of germ plasm to homogeneous strains of pathogens or led to genetic erosion. For example, more than 1,000 Roundup Ready varieties of soybean are cultivated in the United States alone (USDA/ERS 1999a, b). But more impact assessment studies are needed to expand the empirical evidence, answer unanswered questions, and put these risks and benefits of GM crops and foods into better perspective.

Reduce Africa's comparative advantage in tropical crops?

With biotechnology, it will become possible to produce, in the laboratory or in temperate zones, crops that have been grown exclusively in the tropics. This prospect gives rise to concerns that the resultant competitive edge could drive a number of tropical products off the market. The common example is laboratory production of vanilla aroma, which could threaten the livelihoods of tens of thousands of smallholders in Madagascar, Uganda, and other African countries.

GM cacao seed varieties, which could raise yields and lower prices, could dislodge smallholder production of cocoa, through plantation-scale farming in the newly industrialized economies of Asia. A comparable outcome might occur for vegetable oils. And such countries as Mauritius, which depends on sugarcane for a significant share of its export earnings, could find themselves hard-pressed if industrially manufactured low-calorie sweetener or similar substances supplant sugarcane.

Encourage biopiracy?

One area of concern to Africa is the granting of intellectual property rights on biotechnological inventions. Until recently such rights were granted primarily for mechanical inventions. With the advent of biotechnology—particularly the transfer of genes between unrelated species of plants, animals, and micro-organisms—patents have been applied for and granted not only for the process to isolate and characterize genes but also for the genes themselves. There is serious concern that this appropriation will block access to materials for research in developing countries, by public sector institutions, and for downstream product development (Svastad 1999).

Gene patenting is likely to lead to concentrated ownership of crop seed production capacity, often through what is called biopiracy—the unauthorized or uncompensated

Table 3.4

National legislation and grass-roots initiatives on biodiversity and resource sharing in selected African countries

Cameroon	• Has broad provisions regulating access to genetic resources. • Issues dealt with in the UN Convention on Biological Diversity (benefit sharing, incentive measures, local involvement in resource management) included in the forestry law and the 1996 Framework Law on Environmental Management.
Ethiopia	• Does not permit the export of any indigenous germ plasm for commercial development. • Does not permit the import of GM products, nor GM crops or experiments. • Has drafted legislation on community rights, farmers' rights, and access to biological resources.
Kenya	• Farmers' groups and non-governmental organizations (NGOs) have led calls to control GM imports, reject the patenting of life forms, and assert the importance of collective ownership of genetic resources and associated innovations.
Malawi	• Is drafting policy on access to genetic resources and benefit sharing.
Namibia	• Has officially rejected GM imports, trials of GM crops, and patenting of living materials. Returned South African maize intended for animal feed because it had been genetically modified.
South Africa	• Conducted first GM field trial in 1990, allowed first commercial release of GM varieties in 1997, and began commercial planting of Bt cotton and maize in 1998. • NGOs have formed a coalition to monitor and challenge these developments and inform the public. A flourishing coalition of trade unions, political parties, NGOs, consumer bodies, and farmers' groups is demanding a five-year freeze on the use and release of GM crops.
Uganda	• Has rejected patents on living materials, under a policy similar to Namibia's. • An NGO forum on biodiversity, with some regional representation, works to promote and protect biological and cultural diversity. • There have been calls to tighten legislation on GMOs, again backed strongly by farmers' groups, and to assert the importance of collective ownership of genetic resources and associated innovations.

(Table continues on next page)

Gene patenting is likely to lead to concentrated ownership of crop seed production capacity

Table 3.4 (continued)

National legislation and grass-roots initiatives on biodiversity and resource sharing in selected African countries

Zimbabwe	• Has no legislation yet on patents. • Scientific and consumer groups are calling for tighter legislation on imports of GM seeds, plants, and food and for a freeze on such imports until the benefits and risks have been scientifically evaluated. • The Communal Areas Management Programme for Indigenous Resources (CAMPFIRE) is investigating the threat of patents on indigenous knowledge of medicinal herbs, with the aim of creating a system to identify properties that belong to Zimbabwe.

Source: *Wynberg 2000.*

gathering for commercial advantage of developing countries' biological resources. Local farmers, the main custodians of plant genetic resources, claim that they have not been compensated for the flow of genetic resources to industrial countries. They argue that the results of their past, present, and future efforts to conserve and improve genetic resources—traditional knowledge and landraces (collections of different varieties of the same crop species)—are equally entitled to protection. They claim farmers' rights for their informal innovations.

The two concepts—intellectual property rights and farmers' rights—are often in conflict. The challenge is to devise regulations that would turn biopiracy into "bioprospecting"—to find the middle ground in which the financial and scientific resources of biotechnology companies are exploited to the benefit not only of their shareholders but also of the communities in which these companies are prospecting (Nuffield Foundation 1999; Wynberg 2000). Several countries in Africa have taken initiatives to protect access to genetic resources and manage biodiversity.

As GM crops are introduced into African countries, both benefits and costs are likely to emerge (table 3.5). Given the importance of agriculture for the poor and the potential of the biotechnology revolution to reduce poverty, it is clear that Africa cannot let this technology pass the continent by. But biotechnology may also pose risks—of deepening poverty, environmental degradation, and threats to human and animal health. So, countries have to carefully understand the conditions under which biotechnology would be pro-poor and develop strategies to increase its potential benefits for the poor.

Strategic interventions required to make biotechnology pro-poor

No new technology is automatically disseminated widely, especially to poor social groups. Making the promise of biotechnology a reality and ensuring that it has a significant effect on rural poverty will require the strategic interventions discussed here. And it will depend on the ability to put in place the institutions for generating, delivering, adopting, and diffusing biotechnology innovations favourable to poverty reduction (Chrispeels 2000). This "joined up" thinking about biotechnology and economic development has been coined "biopolicy" (Juma 2000b). Biopolicy goals appropriate for Africa are shown in figure 3.2 and discussed in detail in the following sections.

The future prosperity of rural Africa depends on political stability, a sound macroeconomic environment, and sustained growth in agricultural production. This requires attention by policy-makers to fostering the right institutional, infrastructural, and financial investment for rural growth. It also requires reducing the incidence of poverty and malnutrition, both as a primary objective of policy and as a necessary instrument for maintaining the stability needed for sustained growth.

Intellectual property rights and farmers' rights are often in conflict

A strategy to meet food production and development goals must include access to productive assets (such as land), modern inputs (such as improved crop varieties), and credit, technical assistance, and improved farm management practices. And efforts to enhance farmers' access to modern inputs must recognize women's role in farming and marketing and design programmes accordingly.

In the context of rapid urbanization, the importance of investments in rural infrastructure cannot be overstated. Even without rapid urbanization, such investments are needed to support rural and agricultural development. Better rural infrastructure improves access to export markets, modern production inputs, and consumer goods. It also reduces marketing costs, promotes market exchange within and between countries, and increases efficiency in production and marketing.

Although essential, rural infrastructure is not enough to ensure rapid increases in food production in Africa. Yield-enhancing technology is the most promising avenue to sustainable agricultural production. Future growth in food production must come primarily from higher yields per unit of land rather than from crop area expansion. Higher yields on land with high production potential will reduce the pressure on fragile land and (with better definition and distribution of land ownership and user rights) reduce deforestation and desertification.

Conventional plant breeding and GM crop biotechnology have already made great progress in developing plants that are tolerant or resistant to pests and in controlling pests biologically, reducing the need for chemical pesticides. Accelerated research could further reduce the dependence on pesticides. Moreover, by increasing the iron or vitamin A content of food or making other nutritional improvements, biotechnology could address the serious nutritional problems among the poor in Africa. And by raising productivity, it could bring higher incomes for small farmers and lower food prices—improving rural welfare. Those higher incomes and lower food prices are essential for the poor.

Table 3.5

A framework for weighing the adoption of biotechnology by African countries

Strengths

- Rich in biodiversity
- Growing scientific knowledge of biotechnology
- Local field ecosystems for product development
- Strong partnerships between national agricultural research centres and the Consultative Group on International Agricultural Research
- Inadequate public participation in the biotechnology debate

Weaknesses

- Low investment in public sector agricultural research
- Weak scientific expertise for tracking and mapping global trends in biotechnology
- Weak regional capacity for participating effectively in the international debate on protocols for biosafety, technology transfer, licensing, and similar issues

Potential benefits

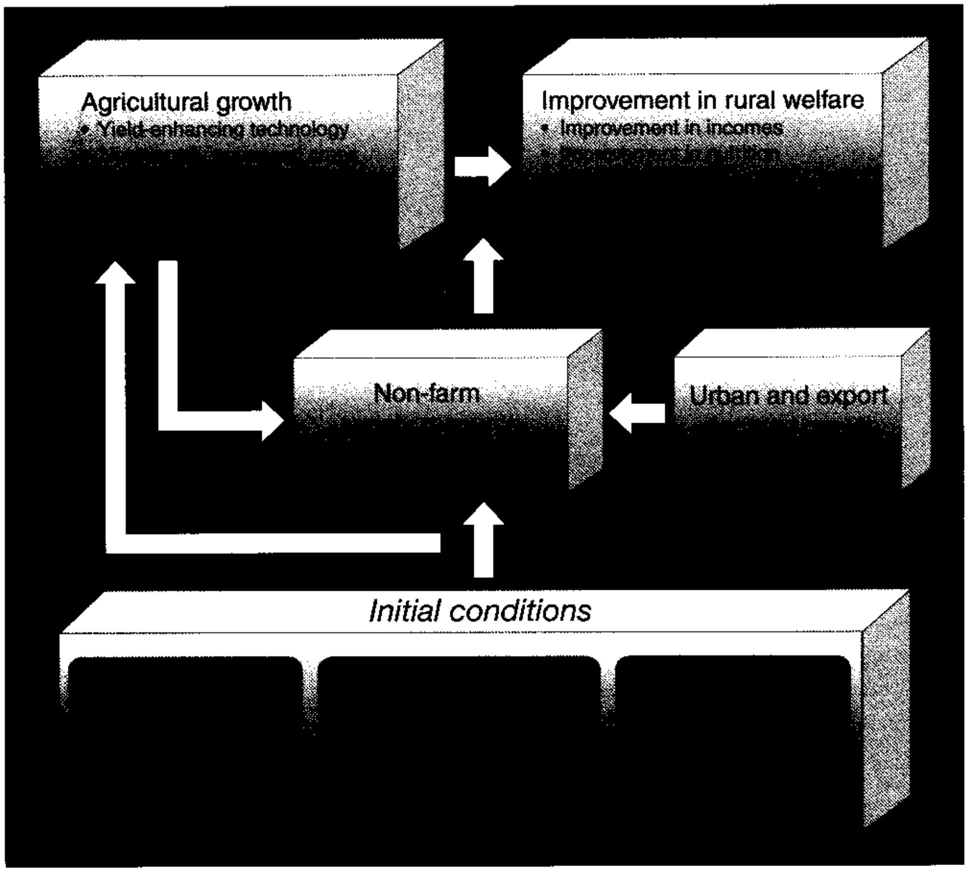
- Higher crop yields
- Higher incomes
- Lower food aid dependency
- Less use of chemicals (pesticides, herbicides)
- Less toxic herbicide runoff to surface water and groundwater
- Less exposure of farmers to chemicals
- Lower farm input costs
- Higher nutritional quality of foods
- Reduced pre- and post-harvest losses
- Longer storage life for foods
- Minimal exploitation of forests, grasslands, marginal lands, and swamplands for food crops
- Preservation of biodiversity
- Broader range of crops suited for marginal areas and consumed by poor people in tropical and semi-tropical areas (sorghum, cassava, pearl millet)

Potential threats

- New allergens
- Antibiotic resistance
- New viruses
- New weeds
- Effects of terminator gene—preventing reproduction of seed, increasing input costs
- Monopoly on biotechnology research by a few powerful private firms
- Lack of scientific and financial support for GM crop research from countries prohibiting such technology
- Trade ban on GM export products
- Aggravation of the prosperity gap between North and South
- Exploitation of natural genetic resources without appropriate compensation
- Unresolved issues relating to intellectual property rights and farmers' rights

Source: *Ongaro 2001.*

Figure 3.2
Biopolicy goals: reinforcing links between technology development and rural welfare



Source: *Adapted from Balisacan 2001.*

Better rural infrastructure improves access to export markets, modern production inputs, and consumer goods

Off-farm sector activities—especially processing, storage, retailing, transportation, and distribution—often are not appreciated in the formulation of national food and agricultural policies. But it is critical to undertake the necessary adjustments in sector policies to allow maximum contribution by these parts of the economy to sustained growth and development in the rural and agricultural sector.

Ensure that biotechnology research is African-focused

Only a small fraction of the current research effort in biotechnology goes into what is most needed in African countries—labour-intensive, robust, and high-yielding staple crops that can adapt to harsh climatic conditions. Most field trials and commercial releases have been for GM crops resistant to pests and herbicides—not for those that could make a real impact on African food production, such as crops resistant to drought and viruses. Industry emphasizes high-volume crops that offer the most opportunities for export sales, rather than staple food crops grown by rural farmers, such as rice, millet, sorghum, cassava, and sweet potato (called "orphan crops," since they have been largely ignored).

In South Africa, for example, where 165 field trials and 5 commercial releases of GM crops have been approved in the past few years, more than 90% of applications for GM crop testing were for insect- and herbicide-resistant strains. The herbicide-resistant strains are engineered to the corporation's own brand of herbicides, so that the farmer is forced to buy the seed and herbicide as a package.

Biotechnology research in Africa must instead be pro-poor, targeting crops that low-income farmers use and the traits they need. That means greater emphasis on quality, resistance to abiotic stresses, and high-value cash crops, such as tropical and subtropical fruits and horticulture for export. Biotechnology that is pro-poor will be simple to adopt, low in cost to ensure widespread availability, and easily accessible to women. And it will be appropriate for use by the most marginal African farmers, plagued by poor soils, weak infrastructure, and poor access to markets.

Biotechnology research in Africa must be pro-poor, targeting crops that low-income farmers use and the traits they need.

Given the costs and complexity of biotechnology research, international collaboration is imperative. To maximize the benefits from international collaboration, national organizations participating in international collaborative research should consider several management issues:

- Ensuring that the research priorities of the international partner or donor agency match the national priorities for agricultural research, particularly agricultural biotechnology research.
- Assessing whether the local research infrastructure is adequate for effective participation in advanced collaborative research and training.
- Ensuring that research activities lead to actual product, which may involve biosafety review, private sector partnership, and adherence to intellectual property rights.

Ensure that biotechnology policies are African-owned

Diverse stakeholders should be involved in the formulation of national biotechnology policies, strategies, and plans. Continual networking and monitoring by civil society groups is fundamental to conserving and using biodiversity and protecting the rights of Africans to safe food. Governments, non-governmental organizations, and farmers' organizations need to continue to evaluate and monitor the introduction of GM crops into their countries. In addition, governments should require environmental and social impact studies and full disclosure of all information about releases and commodities. And they should promote a broad public discussion on the appropriateness of genetic engineering of crops for Africa. Failure to involve everyone concerned in a consultative process could mean:

- Dealing with opposition to GM crops from farmers and consumers that is based on unfounded fears.
- Missing opportunities to capitalize on farmers' unique informational advantages in local circumstances and their potential contributions to the design and adoption of technological packages.

Giving a voice in priority setting to membership-based groups that are truly representative of resource-poor farmers could help reorient biotechnology towards the previously neglected needs of poor farmers, greatly increasing its effect in reducing poverty. To make their research more demand-driven and client-responsive, several national agricultural research organizations in Burkina Faso, Guinea (Institut de la Recherche Agronomique de Guinée), Mali (Institut d'Economie Rurale and National Agricultural Research Council), and Senegal (Institut Sénégalais de Recherches Agricoles and Agence Nationale pour le Conseil Agricole et Rural) are developing partnerships with farmer-producer organizations (Collion 1995; Collion and Rondot 1998).

Increase regional integration to boost intra-African trade

Diverse stakeholders should be involved in the formulation of national biotechnology policies, strategies, and plans

Africa remains highly dependent on agricultural exports to the developed world. In 1998, 12 of 48 countries in Sub-Saharan Africa depended on agriculture for half or more of their export earnings, and some of these for 70% or more—Burundi, Côte d'Ivoire, Ethiopia, Guinea-Bissau, Kenya, Malawi, Rwanda, Sudan, and Uganda (FAO 2000, 2001b; Mihyo 2001).

For these countries and others in Africa, the opposition in many industrial countries, especially in Europe, to the use of modern biotechnology in agriculture and food production could have serious implications. [2] The Cartagena Protocol on Biosafety, adopted by the parties to the Convention on Biological Diversity on 29 January 2000, lays the foundation for a global system to manage the impact of biotechnology on biodiversity. Under this protocol a country is free to ban imports of GMOs. Such limits could be devastating for African economies unless attempts are made to expand regional markets and market access through regional integration.

Strong actions need to be taken to increase intra-African trade (now only 10% of African trade) while simultaneously pursuing market access and dispute resolution measures in the World Trade Organization (WTO). Such disputes are becoming common. The United States, which has a pro-biotechnology stance, threatened to take the European Union to the WTO over restrictions on GMO imports in July 2000 (Srinivasan and Thirtle 2000a).

Scale up financial support for biotechnology research capacity

A good indicator of efforts to strengthen or create biotechnology capacity is the funding available for investment. In Africa underinvestment in agricultural research is a critical problem (Egwang 2001). In 1995, for example, developing countries had fewer than 100 agricultural researchers per million economically active people in agriculture, compared with 2,500 in the industrial countries. But Sub-Saharan Africa, desperately in need of productivity increases in agriculture, had only 42 agricultural researchers per million people engaged in agriculture. Annual growth in African spending on agricultural research declined in the 1970s, and declined even faster in the 1980s and 1990s (Philip, Roseboom, and Beintama 1995).

Financial assistance from industrial countries for agricultural research has also fallen. According to the Food and Agriculture Organization, total official development assistance (ODA) to agriculture declined by about 10% in real terms between 1986–88 and 1995–97. And agriculture's share of total ODA fell from 25% to 14%, despite the gravity of rural poverty in developing countries. The Consultative Group on International Agricultural

Table 3.6

Agricultural biotechnology research personnel in selected developing countries, various years

Researchers by academic degree	Indonesia 1989	Indonesia 1997	Kenya 1989	Kenya 1996	Mexico 1985	Mexico 1997	Zimbabwe 1989	Zimbabwe 1998
Ph.D.	50	102	14	41	14	127	5	27
M.Sc.	28	93	12	15	12	49	5	31
B.Sc.	47	154	6	9	25	62	9	23
Total	125	349	32	65	51	238	19	81
Ratio of technical support personnel to researchers	1.3	1.4	2.0	1.4	3.1	2.1	1.1	2.1

Note: *Excludes researchers on leave.*
Source: *Adapted from Falconi 1999.*

Africa needs a critical mass of trained scientists for a laboratory-based initiative to develop or modify new technologies from elsewhere

Research (CGIAR), an informal public-private association supporting a network of 16 international agricultural research centres, has seen its support (which comes overwhelmingly from ODA) stagnate since 1990 (FAO 1996b, 1999).

Not all the news is bad. A recent survey of biotechnology research capacity in developing countries revealed that the number of researchers in Kenya more than doubled between 1989 and 1996—and that in Zimbabwe increased threefold between 1989 and 1998—while in both countries the number of researchers with Ph.D.s tripled or more (table 3.6). But the requirements are still great. Africa needs a critical mass of trained scientists for a laboratory-based initiative to develop or modify new technologies from elsewhere, making them suitable for the continent's needs and environment (Rybicki 1999). Africa also needs more technical support personnel. For genetic engineering and tissue culture the recommended ratio of technical support personnel to researchers is 2 to 1. In Zimbabwe the ratio just meets that benchmark, but in Kenya it falls far short. This shortage of support personnel can undermine the development of research outputs.

The survey also found that the number of researchers in agricultural biotechnology grew much more quickly than research expenditures (table 3.7). As a result spending per researcher declined by 7% annually in Kenya and by 8% in Zimbabwe. In Kenya this meant a decline from $77,200 per researcher in 1989 to $45,500 by 1996 (in 1985 dollars adjusted for purchasing power parity). The research intensity ratio—the ratio of expenditures on agricultural biotechnology research to agricultural GDP—has risen. But the share of agricultural GDP going to biotechnology research remained quite small, particularly in Kenya—at about 0.05% in 1996, compared with 0.23% in Zimbabwe in 1998. But biotechnology research claimed a larger share of total spending on agricultural research—around 2.8% in Kenya in 1996 and 10% in Zimbabwe in 1998.

The survey found, in addition, that public research institutions in Kenya and Zimbabwe were funded mainly by donor contributions, concentrated in each country's primary research institution. Almost 85% of Kenya's donor support in 1996 went to Kenya Agricultural Research Institute (KARI), while almost 90% of Zimbabwe's in 1998 went to the Biotechnology Research Institute (Paarlberg 2001, p. 60). In Kenya almost two-thirds of the donor assistance to KARI for agricultural biotechnology was spent on infrastructure. While commendable, this means that less went to actual research. By contrast, donor assistance played a much smaller role in Mexico and Indonesia. In Mexico the government contributed about 60% of the spending on agricultural biotechnology research in 1997, while the donor share was 25%. And in Indonesia in that same year, the government accounted for 93% of spending and donors for a mere 2% (Falconi 1999). In both Kenya and Zimbabwe funding from non-traditional sources remained limited, indicating a weak relationship between the private sector and public research institutes.

To realize the full potential of scientific and technological innovations requires an entrepreneurial culture

The CGIAR centres are well placed to strengthen the capacity of national agricultural research centres through training programmes and information services related to the new technology. Five of these international agricultural research centres have their primary base operations in Sub-Saharan Africa: the International Livestock Research Institute (ILRI, in Ethiopia and Kenya), International Institute of Tropical Agriculture (IITA, in Nigeria), International Centre for Research in Agroforestry (ICRAF, in Nairobi), and West Africa Rice Development Association (WARDA, in Côte d'Ivoire). In addition, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has research substations in Mali, Niger, and Zimbabwe. And the International Potato Centre (CIP), International Centre for Tropical Agriculture (CIAT), and International Maize and Wheat Improvement Centre (CIMMYT) have minor bases on the ILRI campuses in Ethiopia and Kenya as well as in some other African countries. As the 1998 report on the third external review of CGIAR stated, "Investment in the CGIAR has been the single most effective use of the Official Development Assistance (ODA). There can be no long-term agenda for eradicating poverty, ending hunger, and ensuring sustainable food security without the CGIAR" (CGIAR 2000, p. 5).

Moreover, the CGIAR centres could usefully expand their activities to further aid national institutes in applying modern biotechnology:

- Setting up regional links and networks to pool information and share biosafety data.
- Providing training and guidance on risk assessment and risk management issues.
- Assisting in the development of media and informational materials to increase public awareness and knowledge about intellectual property rights and the fundamentals of patents, trademarks, and copyrights.
- Providing incentives for expatriate African scientists to pursue biotechnology-related work in their own countries.

To realize the full potential of scientific and technological innovations also requires an entrepreneurial culture (Juma 2000b). African countries lack the knowledge and skills to take advantage of business opportunities opened by biotechnology and to make informed

Table 3.7
Expenditures on agricultural biotechnology research in selected developing countries, various years

Expenditures	Indonesia 1989	Indonesia 1997	Indonesia Annual growth, 1989–97 (percent)	Kenya 1989	Kenya 1996	Kenya Annual growth, 1989–96 (percent)	Mexico 1985	Mexico 1997	Mexico Annual growth, 1985–97 (percent)	Zimbabwe 1989	Zimbabwe 1998	Zimbabwe Annual growth, 1989–98 (percent)
In millions of 1985 PPP dollars[a]	2.4	18.7	29.3	2.5	3.0	2.6	9.7	20.4	8.5	1.8	3.5	7.5
In millions of U.S. dollars	0.7	6.0	30.8	1.8	1.2	2.5	4.3	11.5	6.3	1.0	1.4	3.8
Per researcher, in thousands of 1985 PPP dollars[a]	19.1	53.6	13.7	77.2	45.5	–7.2	187.5	85.1	–6.4	92.0	43.0	–8.0
As a percentage of agricultural GDP	0.003	0.018	25.1	0.046	0.048	0.6	0.026	0.052	6.9	0.12	0.23	7.5
As a percentage of total agricultural research spending	1.7	9.6	24.1	3.3	2.8	–2.3	3.1	9.6	9.8	4.6	10.0	9.0

a. U.S. dollars adjusted for purchasing power parity (PPP).

Source: *Adapted from Falconi 1999.*

decisions about the potential advantages it offers (Lynam 1995). Countries therefore need to build on the local capacity emerging in the form of local companies and small and medium-size enterprises.

Protect indigenous genetic knowledge and stimulate private investment

Concerns have been raised that Africa's rich biodiversity may be exploited by rich countries appropriating indigenous African knowledge and resources. These concerns arise in part from the claim that today's global intellectual property rights system favours countries that have a strong base of innovation. This system is based on the 1995 WTO Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS), which requires all signatories to extend intellectual property protection to micro-organisms, plant genetic materials, and techniques used for genetic manipulation. Intellectual property is also protected under the Convention on Biological Diversity and the World Intellectual Property Organization (WIPO). But many observers have argued that the current system is biased against access by poor countries to their own conventional plant varieties and genetic resources.

African countries need to support efforts to create an intellectual property clearinghouse

Africa needs to safeguard the region's threatened biodiversity and indigenous knowledge. Some groups have taken initiatives to do so. In early 2000, for example, a consortium of farm groups in Southern Africa launched the South African Seed Initiative to ensure food and nutrition security for farmers and consumers. They appealed to the international community to prevent the importation of inappropriate seeds to Southern Africa because it could undermine agro-biodiversity and thus food security for years.

African countries also need to support efforts to create an intellectual property clearinghouse—an international or regional agency to collect and distribute information on patents. An intellectual property clearinghouse could help to move the privately claimed knowledge of genetic resources into the hands of specific users able to add value through their applications of that knowledge. Moreover, if the patent system is considered a solution to the tension between granting private intellectual property rights to otherwise intrinsically public goods and keeping those goods in the public domain, the clearinghouse could serve as an important mechanism for making patents effective. Its main functions would be to:

- Connect technology holders in industrial countries with companies, universities, and national and international research centres as well as with donors.
- Develop and provide a patent database.
- Assist in the negotiation of licence agreements.
- Disseminate research material.
- Provide training services to developing countries, including on the drafting of technology transfer protocols.

Who would run such a clearinghouse? And who would cover the costs? The questions remain open. One possible solution to the financing issue would be to have member countries contribute a share of revenues from patents.

Clearinghouse activities to facilitate access by poor farmers to patented research results are already being undertaken by CAMBIA IP Resource (Australia), which is funded by the Rockefeller Foundation. The institution aims to enhance the ability of public sector institutions and small and medium-size enterprises to develop biotechnology for improving crops worldwide (see http://www.cambiaip.org). Another initiative, the Global Knowledge Centre on Crop Biotechnology, part of the International Service for the Acquisition of Agri-biotech Applications (ISAAA) family, is committed to sharing information on crop biotechnology with as many people as possible (http://www.isaaa.org/kc). The CGIAR system itself could become the virtual host for an Internet-based exchange system.

Creating a sound system for risk assessment requires several strategic interventions by governments

Efforts also need to be made to create the biotechnology equivalent to the open source movement in the software industry, so that new scientific discoveries worldwide can be assessed and applied to food insecurity and poverty in a timely manner. This would entail:

- Providing public access to open source research results, under the condition that those who use the freely accessible material will in return make their research results accessible to others.
- Conducting research on the business case underlying the open source movement.

Establish national regulatory institutions for risk assessment

Most African countries lack the scientific capacity to assess the safety of innovations in biotechnology, the analytical capacity to evaluate their worth, the regulatory capacity to implement guidelines for their safe deployment, and the legal capacity to enforce sanctions for transgressions of laws relating to their use. Introducing and implementing biosafety regulations can overstretch local capabilities and slow or inhibit technology transfer. The systems required are complex. For example, genetic engineering requires extensive monitoring and implementation of complicated protocols, such as the Cartagena Protocol on Biosafety.

Several countries that are developing or applying modern biotechnology—such as Egypt, Kenya, Morocco, Nigeria, and Zimbabwe—do so with limited capacity for assessing and managing risk. GM crops have been released in South Africa and are in the process of being released in Egypt, Kenya, and Morocco, but their environmental impact has not yet been thoroughly assessed nor their desirability adequately appraised.

Establishing a system of biosafety review is complex. It requires not only formulating and adopting safety guidelines and establishing national and institutional biosafety committees, but also creating the infrastructure for contained field-testing of GMOs. Kenya, South Africa, Uganda, and Zimbabwe have taken steps to develop biosafety review mechanisms, with the process most advanced in South Africa. And Cameroon, Côte d'Ivoire, Ethiopia, Ghana, Malawi, Nigeria, Senegal, and Tanzania are initiating discussions of biosafety issues among the national agencies involved (map 3.1).

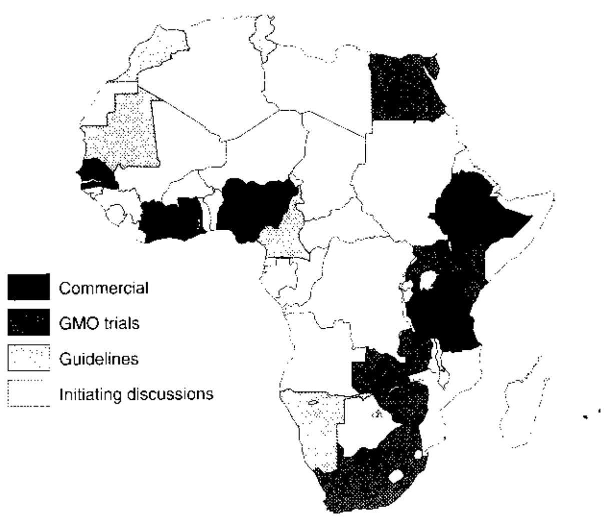
Creating a sound system for risk assessment requires several strategic interventions by governments:

- Establishing a clear policy framework with coherent guidelines outlining where responsibility for the introduction of innovations in biotechnology begins and ends.
- Developing policy that guarantees the systematic and comprehensive testing of all new technology with inputs not just from the natural sciences, assessing the health risks, but also from research and regulatory bodies able to map out potential socio-economic risks. This broad review is necessary to ensure that the ludicrous and heartbreaking does not arise—that more people die from hunger while more food is being produced, because they cannot afford the food.
- Ensuring that risk assessment has a built-in system of checks and balances to safeguard the independence of test results—so that the potential risk of new products is not assessed by those wanting to release the product on the market.

Form strategic public-private alliances

To realize the promise of biotechnology for the neediest in the initial phases, many products must reach the poor free of charge. Ensuring that they do will require strategic alliances

Map 3.1
Status of biosafety in Africa, 2000



Source: *Adapted from Wambugu 2001.*

between scientists and industry. The development of golden rice—a nutrient-rich rice—provides a good example of how this can work in practice. Before golden rice could be put to use for the poor, the project had to resolve myriad patent rights issues involving 70 intellectual property offices. The inventors solved the problem by creating an alliance with Zeneca, which acquired the patent rights for commercial use and in turn provided the technology through free licences to public research institutions (Potrykus 2001).

In the medium term there is a need to promote local seed companies to ensure a smooth transfer of the technology to the neediest

To reach the poor, free distribution of seeds is possible in the short term, but in the medium term there is a need to promote local seed companies to ensure a smooth transfer of the technology to the neediest. Countries also need to ensure that poor farmers have access to extension services, local markets, productive resources (land, water, credit), and infrastructure. Given the already strained budgets of many African countries, strategic public-private partnerships should be encouraged. Such partnerships have had excellent successes in telecommunications (mobile telephony), in micro-finance and education, and in the construction of dams, roads, ports, and railways.

Conclusion

Biotechnology offers rich opportunities to increase agricultural productivity and address current food shortages in Africa. It accelerates plant and animal breeding efforts. It offers solutions to previously intractable problems. But it is no panacea. African countries need to develop appropriate national policies and identify key national priorities for biotechnology, bearing in mind the potential biological risks and the needs of poor people who rely on agriculture for their livelihoods. And the international community needs to loosen the arrangements for access to proprietary technology—enabling developing countries to provide poor farmers with improved seeds while protecting them from inappropriate restrictions on propagating their crops.

Open debate is essential. Governments should involve diverse stakeholders in the development of national biotechnology policies, strategies, and plans. And they should encourage full and candid discussions on biotechnology, aimed at determining how best to address problems while building achievements. Biotechnology policy should take into account national development policies, private sector interests, market opportunities, and mechanisms and links for the diffusion of technology. The biggest risk for Africa would be to do nothing, allowing the biotechnology revolution to pass the continent by. If that happens, Africa will miss opportunities for reducing food insecurity and child malnutrition and see the agricultural productivity gap with industrial countries widen. The result could be what Ismail Serageldin (1999), former chairperson of the CGIAR, calls "scientific apartheid," with cutting-edge science oriented exclusively towards industrial countries and large-scale farming.

Annex

Current efforts in plant biotechnology in selected African countries

Country	Area of research
Burkina Faso	Biological nitrogen fixation, production of legume inoculants, fermented foods, medicinal plants
Burundi	In vitro production of ornamental plants (orchids) Tissue culture of medicinal plants Micro-propagation of yam, potato, banana, and cassava Supply of disease-free in vitro plants
Cameroon	Tissue culture of cocoa trees (*Theobroma cacao*), rubber trees (*Hevea brasiliensis*), coffee trees (*Coffee arabica*), yam (*Dioscorea* spp.), and cocoyam (*Xanthosoma mafutta*) In vitro propagation of tea, cotton, banana, pineapple, and oil palm
Congo, Dem. Rep.	In vitro propagation of rice, maize, potato, soybean, and multipurpose trees (such as *Acacia auriculiforius* and *Leucaena leucocefhala*) Experimental production of biofertilizers based on rhizobials, nitrogen-fixing bacteria Tissue culture of medicinal plants (such as *Nuclea latifolia* and Phyllanthus niruroides)
Congo, Rep.	In vitro culture of spinach (*Basella alba*) Plant pathology studies in controlling tomato rot due to the pathogen *Pseudomonas solanacearum* Bioprospecting of nitrogen-fixing species
Côte d'Ivoire	In vitro production of coconut palm (*Cocos nucifera*) and yam Virus-free micro-propagation of eggplant (*Solanum* spp.) Production of rhizobial-based biofertilizers
Egypt	Genetic engineering of maize, potatoes, and tomatoes
Ethiopia	Tissue culture of teff Micro-propagation of forest trees
Gabon	Large-scale production of virus-free banana and plantain (*Musa* spp.) and cassava plantlets (*Manihot esculenta*)
Ghana	Micro-propagation of yam, cocoa, plantain, cassava, banana, and pineapple Polymerase chain reaction facility for virus diagnostics
Kenya	Production of disease-free plants and micro-propagation of citrus, pyrethrum, bananas, potatoes, strawberries, sugarcane, and sweet potato Micro-propagation of ornamentals (carnations, alstromeria, gerbera, anthurium, leopard orchids) and forest trees In vitro selection for salt tolerance in finger millet Transformation of beans, tobacco, and tomato Transformation of sweet potato with proteinase inhibitor gene

Current efforts in plant biotechnology in selected African countries (continued)

Kenya *(continued)*	Transformation of feathery mottle virus–infected sweet potato with coat protein gene (a collaborative effort involving Monsanto, International Service for the Acquisition of Agro-biotech Applications, U.S. Agency for International Development, Agricultural Biotechnology for Sustainable Productivity, and Kenya Agricultural Research Institute) Tissue culture regeneration of papaya Decay-reducing technology for long-term storage of potato and sweet potato Marker-assisted selection in maize for drought tolerance and insect resistance Well-established microbial resource centres providing microbial biofertilizers in East Africa
Madagascar	Tissue culture programme supporting conventional production of disease-free rice and maize plantlets and medicinal plants Production of biofertilizers to boost production of groundnuts (*Arachis hypogea*) and bambara groundnuts (*Vigna subterranea*)
Malawi	Micro-propagation of tea, trees (*Uapaca*), banana, and tropical woody species
Morocco	Micro-propagation of forest trees and date palms Development of disease-free and stress-tolerant plants Molecular biology of cereals and date palms Molecular markers Field tests for transgenic tomato
Nigeria	Micro-propagation of yam, ginger, cassava, and banana Long-term conservation of yam, cassava, banana, and medicinal plants Embryo rescue for yam Transformation and regeneration of yam, cowpea, cassava, and banana Genetic engineering of cowpea for virus and insect resistance Marker-assisted selection of maize and cassava DNA fingerprinting of yam, cassava, banana, and pests and microbial pathogens Genome linkage maps for yam, cowpea, cassava, and banana Human resource development through group training, degree-related training, fellowships, and networking

Madagascar	Tissue culture programme supporting conventional production of disease-free rice and maize plantlets and medicinal plants Production of biofertilizers to boost production of groundnuts (*Arachis hypogea*) and bambara groundnuts (*Vigna subterranea*)
Malawi	Micro-propagation of tea, trees (*Uapaca*), banana, and tropical woody species

Current efforts in plant biotechnology in selected African countries (continued)

Morocco	Micro-propagation of forest trees and date palms Development of disease-free and stress-tolerant plants Molecular biology of cereals and date palms Molecular markers Field tests for transgenic tomato
Nigeria	Micro-propagation of yam, ginger, cassava, and banana Long-term conservation of yam, cassava, banana, and medicinal plants Embryo rescue for yam Transformation and regeneration of yam, cowpea, cassava, and banana Genetic engineering of cowpea for virus and insect resistance Marker-assisted selection of maize and cassava DNA fingerprinting of yam, cassava, banana, and pests and microbial pathogens Genome linkage maps for yam, cowpea, cassava, and banana Human resource development through group training, degree-related training, fellowships, and networking
Rwanda	Production of biofertilizers based on rhizobials and azolla (nitrogen-fixing bacteria) for rice cultivation Tissue culture of medicinal plants Micro-propagation of disease-free potato, banana, and cassava
Senegal	Well-established microbial resource centres serving West Africa in microbial-plant interaction Production of biofertilizers based on rhizobials and mycorhizals (mycorhize fungi) for rural markets Well-established in vitro propagation of ana tree (*Faidherbia albida*), gum tree (*Eucalyptus Canaldulensis*), sesbania (*Sesbania rostrate)*, and Senegal gum (*Acacia Senegal*), in cooperation with several international agencies
South Africa	*Genetic engineering* Cereals and seeds (maize, wheat, barley, sorghum, millet, soybean, lupins, sunflowers) Sugarcane Vegetables and ornamentals (potato, tomato, cassava, cucurbits, sweet potato, ornamental bulbs) Fruits (peaches, apples, bananas, apricots, strawberries, table grapes) Molecular marker applications Diagnostics for pathogen detection Cultivar identification (potatoes, sweet potato, ornamentals, cereals, cassava) Seed-lot purity testing (cereals) Marker-assisted selection in maize and tomato Markers for disease resistance in wheat and forestry crops

Current efforts in plant biotechnology in selected African countries (continued)

South Africa *(continued)*	*Tissue culture*
	Production of disease-free plants (potato, sweet potato, cassava, dry beans, banana, ornamental bulbs)
	Micro-propagation of coffee, banana, potato, avocado, blueberry, strawberry, chrysanthemum, date palm, rose rootstocks, apple rootstocks, ornamental bulbs, and endangered species
	Embryo rescue of sunflowers, table grapes, and dry beans
	In vitro selection for disease resistance (tomato nematodes, guava wilting disease)
	Long-term storage (cassava, potato, sweet potato, ornamental bulbs)
	In vitro gene bank collections (cassava, potato, sweet potato, ornamentals)
	Forest trees, medicinal plants, indigenous ornamental plants
Tunisia	Abiotic stress tolerance and disease resistance
	Genetic engineering of potatoes
	Tissue culture of citrus, date palms, and prunus rootstocks
	DNA markers for disease resistance
Uganda	Micro-propagation of coffee, citrus, banana, cassava, granadella, pineapple, and sweet potato and potato
	In vitro screening for disease resistance in banana
	Production of disease-free banana, potato, and sweet potato plants
Zimbabwe	Genetic engineering of maize, sorghum, and tobacco
	Micro-propagation of coffee, potato, cassava, tobacco, sweet potato, and ornamental plants
	Marker-assisted selection
Zambia	Micro-propagation of trees (*Uapaca*), cassava, potato, and banana
	Hosting Nordic-funded gene bank for the Southern African Development Community

Source: *Adapted from Brink, Woodward, and DaSilva 1998.*

Notes

1. For example, Friends of the Earth is calling for a moratorium on the production and use of GM foods until their safety can be guaranteed (Jonquires 1999). Greenpeace is demanding a prior agreement between countries before international trade in GM foods takes place. Countries or trading blocs try to ban or otherwise prevent the importation of such foods either by treaty or unilaterally (DeGregori 2000; Srinivasan and Thirtle 2000a).

2. There is an increasing tendency in many industrial countries towards labelling GMOs. In January 2000 the governments of Australia and New Zealand announced that they would require labelling of GM foods. In Japan new labelling requirements in force since April 2001 have already compelled food processors to reject GM ingredients, prima-

rily maize and soybeans, rather than pay for labelling and risk consumer disfavour. Negative public perceptions of GMOs are most pronounced in the European Union, where the labelling of GM additives and flavourings has been compulsory since April 2000 under European Commission Regulation No. 50/2000 (Jonquires 1999; Lehmann and Pengue 2000). It is perhaps understandable that GM crops have not made inroads into Europe and Japan, where consumers are well fed, farmers are prosperous without GM crops, and green parties and anti-globalization non-governmental organizations promote a precautionary approach to food safety.

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Chapter 4

Tackling the Diseases of Poverty through Red Biotechnology

The human genome undoubtedly offers unprecedented opportunities for understanding mechanisms of disease and developing new drugs and vaccines. Through new technologies 50,000 new drugs can be produced and screened by laboratories in a week—more than a major pharmaceutical company could test in a year.

—Barry Bloom, Dean, Harvard School of Public Health

New technologies are revolutionizing medicine and promise significant improvements in the health of millions of Africans

Some key facts

- HIV/AIDS-related infections are the leading cause of death in Africa. Malaria is the third leading cause, while tuberculosis causes nearly 40% of premature deaths among HIV/AIDS patients.
- In 2001 about 28.5 million Africans were living with HIV/AIDS, and fewer than 1% of them had real access to antiretroviral therapy.
- In 2001, 81% of the world's HIV/AIDS-related deaths and 90% of the world's malaria deaths occurred in Africa.
- HIV/AIDS reduces GDP growth in Africa by an estimated 0.5–2.6% a year on average, while malaria causes economic losses of $12 billion a year.
- Less than 10% of global spending on health research is allocated to 90% of the world's health problems, most concentrated in poor countries.
- Of the 1,233 drugs that reached the market between 1975 and 1997, only 13 were for tropical diseases.
- The average price of some antiretroviral drugs in Africa has fallen by as much as 85% thanks to the growing availability of generics and agreements with pharmaceutical companies.
- First-generation HIV vaccines could become available in the next two to six years.
- International collaboration is vital for the success of efforts to increase the accessibility and affordability of HIV/AIDS treatments for the poor.

Genomics and its applications (genetic engineering) to health care—"red" biotechnology, in contrast to "green" biotechnology in agriculture and the environment—are creating powerful new tools that are changing the ways diseases are prevented, diagnosed, managed, treated, and possibly cured. These new technologies are revolutionizing medicine and promise significant improvements in the health of millions of Africans.

Examples of this promise abound. Applications of biotechnology to diagnostic testing are speeding up and simplifying the identification of diseases, while advances in pharmacogenics are allowing a better understanding of how the human body responds to drugs, making it possible to develop more accurate and effective medications. Gene therapy brings the possibility of directly correcting genetic disorders and could lead to cures for these disorders instead of treatments.

African countries are not benefiting from these developments because of several obstacles

Advances in vaccine development are also significant. Modern biotechnology is creating the possibility of developing vaccines capable of tackling a wider range of diseases—and with greater efficiency. Equally important are technological improvements in the delivery of existing vaccines. New vaccines are being designed and developed to overcome the problems of access—scheduling, storage, stability, and cost.

These new possibilities are especially welcome at a time that the health gains achieved by Africa over the past four decades are being threatened by the emergence of new diseases—such as the acquired immunodeficiency syndrome (AIDS), caused by the human immunodeficiency virus (HIV)—and the re-emergence of old diseases—such as malaria and tuberculosis (TB)—as leading causes of death. Both malaria and tuberculosis have developed resistance to existing drugs, making current treatments ineffective. HIV/AIDS has spread rapidly, reaching epidemic proportions in some parts of the continent. By the end of the 1990s HIV/AIDS-related infections had become the leading cause of death in Sub-Saharan Africa.

The social and economic consequences of the three diseases are enormous. They threaten to reverse decades of development gains and undermine national security. They hinder savings and investment and overwhelm health services, undermining countries' productive capacity, increasing social distress, and perpetuating poverty. Their impact is also felt at the macroeconomic level. It is estimated that HIV/AIDS reduces GDP growth in Africa by 0.5–2.6% a year on average. Other estimates suggest that Africa's GDP would be as much as $100 billion greater had malaria been eliminated years ago. And in countries with a high burden of tuberculosis, the loss of productivity due to the disease is estimated at 4–7% of GDP annually.

These losses can be stemmed if the diseases are brought under control. Advances in biotechnology offer hope of achieving this. Ten years ago an HIV diagnosis was akin to a death sentence. Today the means exist to fight HIV/AIDS. Antiretroviral therapy is prolonging life and restoring health for HIV-infected individuals. Several HIV vaccines, including some directed at HIV strains common in Africa, now in various stages of clinical trials, are showing promise. Prevention and treatment technologies for malaria and tuberculosis are benefiting from genetic research and new genetic engineering tools.

But African countries are not benefiting substantially from these developments because of several obstacles. Much more research based on the new techniques could be undertaken on the three leading causes of death in Africa—but is not because of lack of resources. Most medical research focuses on diseases prevalent in industrial countries. According to the Global

Forum for Health Research (1999), less than 10% of global spending on health research goes to 90% of the world's health problems, most concentrated in poor countries. Moreover, countries with the greatest need for drugs and vaccines lack the resources to pay for or produce them. Though such treatments as antiretroviral drugs have been declining in price, they are still too costly and too insufficiently marketed to reach the majority of Africans—living on less than $1 a day. In addition, the lack of a strong, well-equipped health infrastructure hampers the delivery of drugs.

Even so, some African countries have benefited from the new developments in medical technology. The positive experiences suggest that strong commitment and leadership at the highest level are needed—to scale up resources and implement the highest-impact interventions on the ground. New partnership arrangements—particularly between the public and private sectors—and regional agreements have also shown great promise in both research and application of new medical technologies. These successes show that biotechnology can be harnessed to tackle the diseases of poverty if decisive efforts, commitment, and innovative approaches are undertaken at all levels.

Biotechnology can be harnessed to tackle the diseases of poverty if decisive efforts, commitment, and innovative approaches are undertaken at all levels

This chapter briefly discusses the health status of the continent and explores some of the more innovative techniques used in biotechnology that could help reverse the present deterioration in health status. It examines each of the three major diseases, along with new technologies opening new ways for their prevention and treatment. It also discusses challenges and obstacles in introducing and applying new technologies in Africa. Finally, it sets forth policy actions that African governments could take to make these new technologies and health products accessible and affordable to the people who need them most—the poor.

Reversal of health gains

At the beginning of the 21st century Africa faces a health crisis that threatens to reverse—and indeed in some countries is reversing—the development gains of the post-independence years. A spectre of death and devastation hangs over the continent. Between 1960 and 1990 life expectancy at birth in Sub-Saharan Africa rose from 40 years to 50, and the mortality rate fell considerably for both adults and children (table 4.1). But since 1990 life expectancy at birth has fallen, and mortality risen.

Poor health is also reflected in other indicators. The World Health Organization (WHO) reports that 81% of the world's HIV/AIDS-related deaths and 90% of the world's malaria deaths occur in Africa (table 4.2). Although only 23% of the world's tuberculosis deaths occur in Africa, the number of tuberculosis cases reported every year is high: in 1998, 121 cases per 100,000 people were reported in Sub-Saharan Africa, the highest incidence among all regions. By comparison, the incidence was 71 per 100,000 for all developing countries and 63 for the world (UNDP 2001).

Table 4.1
Mortality and life expectancy trends in Sub-Saharan Africa, 1960–99

Indicator	1960	1970	1980	1990	1999
Adult mortality rate for women (per 1,000)	450	438	403	374	453
Adult mortality rate for men (per 1,000)	547	529	486	448	489
Under-five mortality rate (per 1,000 live births)	254	222	189	155	161
Life expectancy at birth (years)	40	44	48	50	47

***Source**: World Bank 2001b.*

Table 4.2
Distribution of deaths from HIV/AIDS-related causes, malaria, and tuberculosis by region, 2000

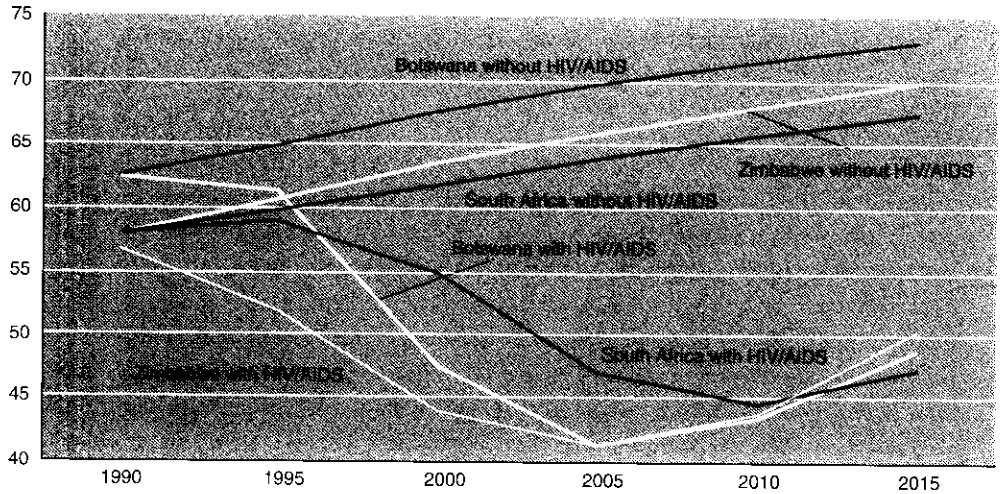
	HIV/AIDS-related causes		Malaria		Tuberculosis	
Region	Thousands	Percentage share	Thousands	Percentage share	Thousands	Percentage share
Africa	2,392	81.27	966	89.44	381	22.95
The Americas	72	2.44	2	0.18	57	3.42
Southeast Asia	371	12.61	51	4.72	674	40.55
Europe	21	0.17	0	0	74	4.45
Eastern Mediterranean	54	1.83	47	4.35	136	8.18
Western Pacific	32	1.09	13	1.20	340	20.45
Total	2,943	100	1,080	100	1,660	100

***Source**: Adapted from WHO 2001c.*

HIV/AIDS has also facilitated the re-emergence of infectious and parasitic diseases, especially tuberculosis

Communicable diseases—especially HIV/AIDS, malaria, and tuberculosis—are implicated in Africa's deteriorating health indicators and thus present a major development challenge to the continent. HIV/AIDS-related infections are the leading cause of death in Africa. HIV/AIDS has also facilitated the re-emergence of infectious and parasitic diseases, especially tuberculosis. Co-infection with HIV/AIDS and tuberculosis—the dual epidemic—accelerates illness and death. Indeed, tuberculosis is thought to be the major cause of premature deaths among HIV/AIDS patients (Robertfroid 2000). The frequent concurrence of HIV/AIDS and tuberculosis in patients makes it difficult to isolate their effects on the population. But according to analysis by the United Nations (2000), HIV/AIDS is largely responsible for the recent precipitous decline in life expectancy at birth in many Sub-Saharan countries (figure 4.1).

Figure 4.1
Life expectancy with and without HIV/AIDS in some of the hardest hit countries in Sub-Saharan Africa, 1990–2015



Source: *United Nations 2000.*

Malaria-associated mortality has also risen significantly: in 2001 malaria was the third leading cause of death in Africa. The resurgence of malaria is closely linked to the increasing resistance of the malaria parasite to drugs and the deterioration in public health systems. The parasite affects up to 500 million people across the globe and in tropical developing countries causes deaths mainly among children. Even though 9 of 10 cases of malaria occur in Sub-Saharan Africa, African governments have not adequately responded to the growing threat. Even basic control programmes, such as spraying and environmental sanitation, are seldom undertaken because of the weak economies of most countries.

The social and economic consequences of poor health are enormous. In addition to causing premature deaths, poor health is becoming a significant constraint on labour productivity in many African countries, with malnutrition adding to the effects of parasitic and infectious diseases. Work absenteeism rates are rising as a result of illness or needs to care for the sick and attend funerals. Poor health also contributes to low school enrolment ratios and high dropout rates, hinders savings and investment, overburdens health services, adds to social distress, and perpetuates poverty. The socio-economic burden of HIV/AIDS, malaria, and tuberculosis threatens to reverse decades of development by African countries and undermine national security.

To respond to the health and development crisis posed by these diseases, more powerful and efficient medical solutions are needed—and more decisive political commitment. Just as medical advances brought major epidemics under control among past generations, new technologies and scientific developments offer opportunities to reduce the toll of HIV/AIDS, malaria, and tuberculosis in Africa.

Emerging innovations in red biotechnology

Broadly defined, red biotechnology is a cluster of scientific techniques applied to the medical field that include genetic engineering, genomics, and pharmacogenics. Red biotechnology uses substances naturally produced in the human body, such as proteins and enzymes, to fight infections and diseases, or substances in plant and animal cells to produce medicines for human use (Europabio 2001).

Red biotechnology uses substances naturally produced in the human body to fight infections and diseases

Biotechnology is an old science, used centuries ago to produce beer and cheese using micro-organisms. Modern biotechnology began in 1953 when biochemists James Watson and Francis Crick determined the structure of DNA (deoxyribonucleic acid), the molecule that encodes genetic information (PhRMA 2001). DNA contains all the information needed to build an entire organism, be it a bacterium, plant, or animal. Modern biotechnology mainly uses the genes of organisms. Modern techniques of genetic engineering and information provided by genomics enable scientists to use genes in new ways and with greater precision. As one researcher puts it, "in the past, we could look under the microscope and say a cell looks abnormal, but we didn't know what was going on inside it. Now, researchers can find genetic defects and attack cancer cells with substances naturally found in the body" (PhRMA 2001, p. 3).

Red biotechnology applies genetic engineering techniques and genomics knowledge for medical or pharmaceutical purposes. *Genetic engineering* is the technique used to alter or move genetic material of living cells. It has evolved enormously thanks to advances in computerization and mechanical techniques and in the knowledge of genes. The technique is based on the artificial production of new genetic material by joining segments of DNA from different organisms, a process called recombination (Fell 1998). Such genetic manipulation allows scientists to change the genetic structure of an organism on the spot, quickly and more efficiently than with any other technique (Unilever 2001).

Genomics is the study of the genome—the sum total of the genetic material in a particular organism—and how it affects the human body (Lea 2000). One of the most promising innovations for medical science today, genomics was made possible by the invention of the gene sequencer in 1975 and the development of rapid computer analysis of DNA in the early 1990s (Pontin 1998). Genomics makes it possible to understand the structural components of an organism, and thus of a disease caused by or affecting that organism, by sequencing the organism's genome (that is, determining the exact order of the base pairs in a segment of DNA). The landmark mapping of human genes recently completed promises further innovations in research.

Four promising areas of medical advance

Through genetic engineering and genomics, biotechnology is expanding the scope of health care in four main areas: medicines, diagnostics, gene therapy, and vaccines.

Medicines developed through modern biotechnology use proteins that aid the body in fighting off infections. By bringing together different strands of genetic material through laboratory manipulation, it is possible to engineer safer and more powerful medicines (PhRMA 2001). Genetically engineered medicines are now available in Europe and the United States for treating infections, diabetes, anaemia, hepatitis, haemophilia, leukaemia, heart disease, immune system deficiencies, and many forms of cancer. A major breakthrough for medical treatment is pharmacogenics, which combines genomics with molecular pharmacology (the development, use, and marketing of drugs). Pharmacogenics is the study of what determines the response of the patient's genes to a drug. This information allows more effective design of therapies and more accurate results in clinical trials. The greater knowledge of how genes respond to different medications makes it possible to better target and tailor drugs and adjust dosing for each case. This is supported by evidence from some HIV drug trials in West Africa (Schaeffeler and others 2001 as cited in Singer and Daar 2001).

Diagnostics developed through biotechnology are used to identify a wide range of diseases and genetic conditions. One example is the screening of blood to detect HIV and hepatitis. New biotechnological tests simplify the procedures and the requirements (Europabio 2001). For example, tests based on monoclonal HIV antibodies can be designed to give results in minutes rather than hours or days (Australian Biotechnology Association 2001). Genomics tests could allow the detection of HIV before any symptoms are apparent (Patel 2001). HIV drug resistance tests designed to evaluate viral resistance to specific antiviral drugs are considered to be one of the major benefits of applied biotechnology today in high-income countries.

Gene therapy is based on the premise that it should be possible to treat genetic disorders by replacing the faulty or missing gene rather than treating the secondary effects and symptoms (Lea 2000; Europabio 2001). The technique consists of transferring corrected or altered genes into a person's cells to correct hereditary genetic disorders. It is considered to be one of the most promising medical advances because it makes it possible to tackle the origin of a disease, thanks to advances in the understanding of the human genome (Lea 2000). Gene therapy has been used, for example, to treat severe combined immunodeficiency disease (Europabio 2001).

Vaccines have been particularly revolutionized by the advent of biotechnology and genomics. New genetic engineering techniques have changed the approach to developing vaccines, providing unprecedented opportunities to create safer and more effective ones. Conventional vaccines use viruses previously weakened or killed to introduce antigens into the body. These antigens inform the body about the virus, so that it can recognize it and then produce the protective antibodies. By contrast, vaccines developed through modern biotechnology use only the antigen (isolated and produced in a laboratory), not the actual virus, to provoke an immune response (Europabio 2001). This makes it possible to vaccinate without the risk of transmitting the virus itself. The new vaccines also allow the simultaneous introduction of several elements to boost immune response and can thus induce a more natural response. Several major breakthroughs have occurred in high-technology vaccine development.

High-technology vaccine development

The past decade has seen an explosion of research and development (R&D) activity in high-technology vaccines. Expectations were so high that the number of biotechnology firms with a vaccine-dominated portfolio rocketed from a dozen or so to more than 70 in the 1990s (CVI 1999). Vaccine research is expanding both in the number of diseases tackled and in new approaches to research. Applications of technology to vaccine development have led to four fascinating advances: naked DNA vaccines, edible vaccines, Trojan horses, and sugar glass vaccines.

Vaccine research is expanding both in the number of diseases tackled and in new approaches to research

Naked DNA vaccines are genetically engineered vaccines made with a form of viruses or bacteria that do not contain the undesirable genes, so that they are avirulent (CVI 1999). In the development of these vaccines—touted as "the hottest field in vaccinology" (Fell 1998, p. 15)—a DNA sequence is modified and inserted into a host cell in a process called transfection. The DNA-transfected host cell produces a new protein that will interact with the body's immune cells in a way predetermined to trigger a protective immune response. Thus with the DNA vaccine it is the cells of the protein that produce the response. This method, considered more "natural" than the traditional methods, may offer more lasting protection. Moreover, DNA vaccines can carry an entire range of vaccinating antigens that combat, for example, the complex malaria parasite. They also require simpler production and delivery systems than any other vaccine technology. Several clinical trials of DNA vaccines against HIV, malaria, and hepatitis B are now under way. Although promising, the trials have yet to produce the strong immune response expected. More worrying are fears of possible damage to host DNA or of mutation of the vaccines into a new, unknown virus.

Edible vaccines are created by transferring genes from an organism into plants—through a process called transgenesis—so that the plants contain the vaccine. As the cells of the plants grow, they express the foreign genes in their tissues, and the genes order the production of a vaccine protein in the cells. The vaccine would be administered by simply eating the plant. Tobacco plants have been successfully transfected with the gene for the antigen of the hepatitis B virus, and potatoes have been transfected with the gene for the binding subunit of E. coli LT-B, which causes diarrhoea. Both have demonstrated that such vaccines can stimulate an immune response (CVI 1999; Fell 1998). Transgenic plants have enormous potential for improving the delivery of vaccines (the plants could be grown locally) as well as their acceptability (eating some vegetables could replace the needle jab; Fell 1998). In 1999 five biotechnology companies had as their sole or major aim in business the development of edible vaccines (CVI 1999).

Trojan horses are organisms designed to carry a vaccine, developed by replicating organisms without the genes linked to virulence. The new organisms could be used as a vaccine, or they could carry vaccine antigens to teach another organism (such as the human body) to protect itself, acting as a "Trojan horse." This technique has several advantages, including ease of genetic manipulation and the use of established methods to grow and process the organisms (CVI 1999).

Sugar glass vaccines, another product under research, are based on the use of trehalose, a double-sugar molecule that has the capability to preserve and protect the proteins and other molecules of an organism so that they can be "revived" with a few drops of water (CVI 1999). Trehalose is used today in Japan for preserving food and beverages. Its use in the production of vaccines would allow vaccines to be kept in the form of sugar glass (that is, in crystalline form) until water is poured on them, greatly facilitating their transport and storage.

HIV/AIDS

Around 95% of HIV infected Africans have not been tested and do not know their HIV status

AIDS is caused by the human immunodeficiency virus, which enters the body through the exchange of fluids or the use of contaminated medical instruments. Once in the body, the virus replicates gradually over a long period, destroying CD4 cells, which protect the body against infections. In this way it damages the immune system and weakens the body's capacity to resist other infections. When the immune system reaches severe CD4 deficiency, the infected person develops AIDS.

Epidemiology and status

There are two types of human immunodeficiency virus: HIV-1 and HIV-2. The first, more easily transmissible, is found in all parts of the world. The second, less easily transmissible, is found mostly in West Africa. Nine HIV-1 subtypes have been identified. The one most common in East and Southern Africa, HIV-1C, is believed to be transmitted faster than other subtypes. HIV-1B is the prevailing subtype in Europe and the United States.

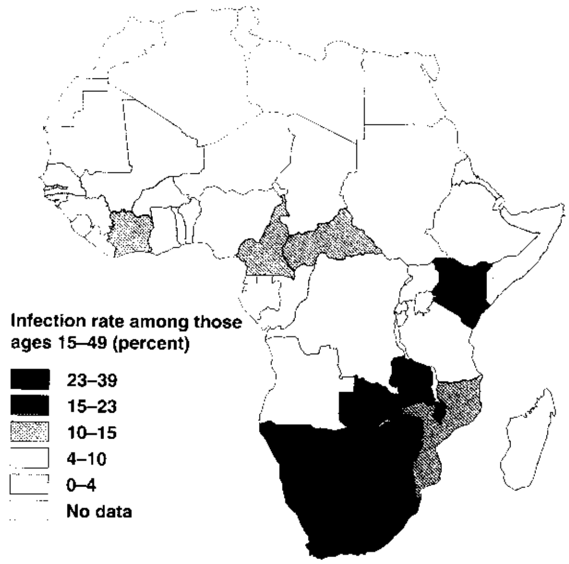
Most HIV infections in Africa are transmitted through heterosexual intercourse. The risk of HIV transmission during a single sexual act varies considerably, increased by the presence of other sexually transmitted diseases, such as those leading to genital ulcerations (chancroid, genital herpes). Women are at disproportionate risk of contracting HIV. Biologically, they are four times as likely to be infected sexually. Moreover, they face added social vulnerability arising from lack of bargaining capacity to negotiate sex and the use of condoms. HIV is also transmitted through mother to child transmission, also called vertical transmission, and transfusions of HIV-infected blood.

Poor nutrition is a catalyst for transmission. The probability of transmission from an HIV-positive mother to her child without a preventive intervention is 25–35% in developing countries but 15–25% in industrial countries, where nutrition levels are higher and drugs and treatments more widely used.

The epidemic is spreading rapidly. In 2001 about 28.5 million Sub-Saharan Africans were living with the virus, and of these cases 3.5 million were new infections (UNAIDS 2002b). In the same year 2.2 million people in Sub-Saharan Africa died of HIV/AIDS-related causes, leaving 11 million children orphaned. About a third of those living with HIV/AIDS are in the age group 15–24. Moreover, it is estimated that around 95% of HIV-infected Africans have not been tested and do not know their HIV status. Thus they cannot be treated and are more likely to spread the virus to others.

Map 4.1
Estimated adult HIV infection rates in Sub-Saharan Africa, end of 2001

The export sector is poorly diversified and lacks competitiveness



Source: UNAIDS 2002b.

HIV infection rates vary sharply across Africa. Southern Africa is the most affected, with adult infection rates estimated at 39% in Botswana, 34% in Zimbabwe, 33% in Swaziland, and 31% in Lesotho at the end of 2001 (map 4.1). But infection rates are growing rapidly in East Africa, reaching 15% in Kenya, 9% in Rwanda, and 8% in Tanzania. In West Africa prevalence rates have already exceeded 5% in some countries. In North Africa prevalence remains low, although here too HIV infection rates are increasing. In most African countries urban areas are affected more than rural areas as a result of migration, family separation, and the absence of other anchors of safe behaviour. But recent studies suggest that the infection rate is rising faster in rural areas, driven by circular migration and the increasing integration of rural areas into the wider national economy and the resulting changes in social practices.

Socio-economic burden

HIV/AIDS has changed the demographic profile of several countries in Sub-Saharan Africa, especially in Southern Africa, giving rise to unprecedented threats to economic and social development (box 4.1). In Southern Africa population growth rates are beginning to slow dramatically, and mortality has increased sharply in the working-age population and among the very young, damaging productive capacity.

The consequences of the epidemic for the productive capacity of the region are becoming evident. Employers of all types face high rates of turnover, absenteeism, and illness, and higher costs for training, insurance, and employee benefits. Children are withdrawn from school to care for family members who are ill and to regain lost income. As more adults die, more children are becoming orphans. And families face income losses and higher costs for health care and funerals. For two-thirds of Zambian families in which the father died, per capita monthly disposable income fell by more than 80%. All these effects are driving families into destitution, with the poor suffering most. In Burkina Faso, Rwanda, and Uganda the share of the population living in extreme poverty is expected to increase from 45% in 2000 to 51% in 2015 as a result of HIV/AIDS. In Botswana the per capita household income for the poorest quarter of households is expected to drop by 13%, while every income earner in this category can be expected to take on four more dependents (UNAIDS 2002a).

Box 4.1
Demographic impact of HIV/AIDS on Africa

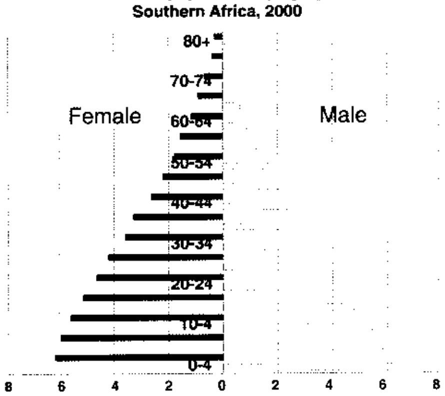
HIV/AIDS is changing the demographic profile of Africa. In 15 Sub-Saharan countries the population is expected to be 3.8% smaller in 2005 than it would have been without HIV/AIDS. Life expectancy has dropped by as much as 39% in Namibia, 33% in Botswana, and 30% in Mozambique. The crude death rate has risen dramatically—by 230% in Togo, 228% in Botswana, and 205% in Namibia. And mortality projections show Botswana registering a 93% increase in the infant mortality rate by 2015 and a 213% increase in the under-five mortality rate (the largest in the region) as a result of HIV/AIDS. Indeed, with nearly 40% of adults now infected with HIV, Botswana is expected to experience the most dramatic effect on the population structure (UNAIDS 2002).

Over time, population age structures in developing countries are being transformed from a pyramid with a wide base that tapers off to one with a shrinking base and a more rectangular shape. As older age groups grow larger than younger age groups, the pyramid becomes more like a column. But HIV/AIDS has introduced a new shape—the population chimney. The sharp rise in death rates among young adults of both sexes as a result of HIV/AIDS has shrunk the base of the pyramid (see figures).

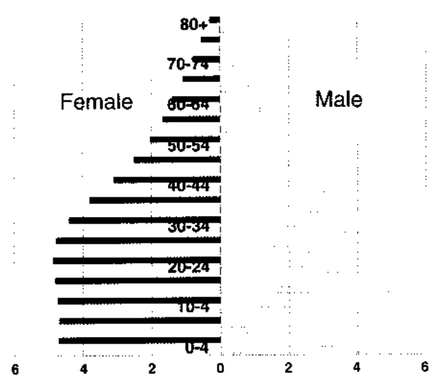
The HIV/AIDS pandemic is also leading to a sharp reduction in the size of younger age cohorts. According to UNAIDS (2000a), up to a third of infants born to HIV-positive mothers will acquire HIV and succumb to HIV/AIDS-related infections. Moreover, many HIV-infected women die or become infertile before the end of their reproductive years. The dramatic change in the population pyramid comes 10–15 years after infection, when those who are infected begin to die, including young adults. The population of women above their early 20s and that of men above their early 30s are therefore projected to shrink radically.

Only those not infected survive to older ages, so the pyramid becomes a chimney. Indeed, the elderly dependency ratio (the ratio of those over age 65 to the working-age population) is projected to increase dramatically between 2005 and 2050, from 6% to 11%, as the elderly today constitute the fastest growing population group in Africa.

Distribution of population by age group in Southern Africa, 2000



Projected distribution of population by age group in Southern Africa, 2025



Source: *Based on data from United Nations 2000.*

Countries across the region are intensifying prevention efforts and by improving access to new drugs and treatments

The epidemic thus has a profound impact on growth, income, and poverty. HIV/AIDS is estimated to reduce GDP growth in Africa by 0.5–2.6% a year on average (Greener 2002). By 2010 per capita GDP in some of the hardest hit countries may drop by 8%, and per capita consumption may fall even more. Jamison, Sachs, and Wang (2001) estimate that the decline in economic welfare (income adjusted for the value of changes in mortality rates) in 1990–2000 as a direct result of HIV/AIDS (2.6%) far exceeded the decline in GDP.

Recognizing the gravity of these consequences, countries across the region are expanding and upgrading their responses to the epidemic in two ways: by intensifying prevention efforts and by improving access to new drugs and treatments. Current prevention efforts—including peer counselling, education campaigns, securing of blood supplies, and marketing and distribution of condoms—have slowed the spread of HIV in some countries. Particularly good examples are Senegal and Uganda, where the prompt and strong political commitment and social engagement in prevention campaigns have reduced the spread of the epidemic.

But the high prevalence rates in a large number of countries imply that even extraordinary success on the prevention front will only gradually reduce the human toll. Moreover, preventive efforts promoting condom use and focusing on education rely essentially on changes in individual behaviour—and may therefore take a long time, with no guarantee of effectiveness on a large scale. The HIV/AIDS pandemic in Africa calls for an emergency response. One such response is the exploration and early adoption of new treatments and technologies.

Even extraordinary success on the prevention front will only gradually reduce the human toll

New technologies to fight HIV/AIDS

Since HIV was identified as the cause of AIDS in 1983–84, medical science has moved quickly to develop several products that treat, though do not cure, those who are infected. These treatments are called halfway technologies: they are aimed at postponing the onset of illness in HIV-infected individuals or the death of those already ill with AIDS. There are currently three main treatment strategies (Panos Institute 2000). First, antiretroviral drugs are used to reduce the amount of virus in the body and even increase CD4 cell counts. Second, prophylaxis using other anti-infective agents is used to prevent opportunistic infections. Third, painkillers and other symptomatic drugs are used to relieve suffering in a comprehensive approach to care and support. Among all these, antiretroviral drugs are the key treatments—if they were highly efficient, there would be little or no need for prophylaxis or painkillers.

Although no definitive technology exists to prevent or cure the disease, remarkable progress is being made in antiretroviral drug development, microbicide technology, and vaccine research.

Antiretroviral drugs. The development of antiretroviral (ARV) drugs to treat HIV is one of the major achievements of modern biomedical research in the past decade. ARV drugs do not kill the virus. Instead, they block steps in the process through which the virus reproduces (box 4.2). In this way ARV drugs slow damage to the immune system and allow people infected with HIV to feel better and lead more normal lives.

Box 4.2
HIV life cycle

The HIV life cycle involves several steps:

1. Free virus circulates in the bloodstream.
2. HIV attaches to a cell.
3. HIV empties its contents into (infects) the cell.
4. The HIV genetic code (ribonucleic acid, or RNA) is changed into DNA by the reverse transcriptase enzyme.
5. The HIV DNA is built into the infected cell's DNA by the integrase enzyme.
6. When the infected cell reproduces, it activates the HIV DNA, which makes the raw material for new HIV viruses.
7. Packets of material for a new virus come together.
8. The immature virus pushes out of the infected cell in a process called budding.
9. The immature virus breaks free of the infected cell.
10. The new virus matures: raw materials are cut by the protease enzyme and assembled into a functioning virus.

Source: *New Mexico AIDS Infonet 2002.*

Remarkable progress is being made in antiretroviral drug development, microbicide technology, and vaccine research

Today there are three main categories of ARV drugs. The first is nucleoside reverse transcriptase inhibitors, also called "nukes." These drugs work by blocking step 4 of the HIV life cycle by providing faulty DNA building blocks to halt the DNA chain that the virus uses to make copies of itself. The second category of drugs, non-nucleoside reverse transcriptase inhibitors, block the same step of the HIV life cycle but in a different way—by binding the enzyme called reverse transcriptase so that the virus cannot carry out its copying function. Drugs in the third category, the protease inhibitors, block step 7 of the HIV life cycle, where the raw material for new HIV virus is cut into specific pieces. In other words, it blocks the protease enzyme that HIV uses to produce infectious viral particles (Panos Institute 2000; New Mexico AIDS Infonet 2002).

The introduction of ARV drugs, many of which became available only in the mid- to late 1990s, has revolutionized the treatment of HIV. Continuous treatment with ARV drugs can substantially restore the immune system, reducing vulnerability to secondary infections and prolonging life. ARV drugs have extended the interval between infection and the onset of disease. They may also reduce the transmission of the virus because they reduce the viral load in the body.

ARV drugs have been particularly effective in reducing mother to child transmission of HIV. The drug nevirapine—a non-nucleoside reverse transcriptase inhibitor—has been clinically shown to decrease the risk of vertical HIV transmission by up to 50% in low-income countries (AVERT 2001b). The full nevirapine regimen is as simple as a single dose to the mother during labour and a single dose to the newborn within 72 hours of delivery.

A study using data from South Africa shows that providing antiretroviral prophylaxis to 25% of all pregnant women testing positive for HIV-1 and their babies would prevent nearly 28,000 HIV-positive births a year in that country (Wood and others 2000). Indeed, in industrial countries the use of antiretroviral prophylaxis among HIV-positive pregnant women has almost eliminated perinatal transmission (Dabis and others 1999; Saba 1999 as cited in Wood and others 2000).

The success and low cost of drugs to prevent mother to child transmission of HIV in Africa

The success and low cost of drugs to prevent mother to child transmission of HIV have led to wide adoption of this treatment in Africa. Uganda announced in July 2001 that it would provide free AIDS drugs to prevent mother to child transmission of HIV along with a programme of voluntary counselling and testing (AVERT 2001b). The indicative cost of nevirapine per treatment is $4 when purchased from the patent holder, Boehringer Ingelheim, though the company also announced that it would make the product available free of charge to least developed and low-income developing countries with specific programmes for prevention of mother to child transmission (UNICEF and others 2001).

The use of antiretroviral prophylaxis among HIV-positive pregnant women has almost eliminated perinatal transmission in industrial countries

Since HIV can become resistant to any one drug, treating a patient with a combination of ARV drugs can prolong their impact. There are also efforts to simplify treatment by developing drugs that combine several ARV drugs into a single pill. One example is Trizivir, which needs to be taken only twice a day (CMH 2001).

Highly active antiretroviral therapy (HAART), the most effective therapy today, combines three or more ARV drugs and has a much stronger effect than one or two ARV drugs alone. Complete treatment using HAART maintains the health status of HIV patients remarkably. But there is a fear that in the long run the widespread use of HAART, especially if it is not properly monitored, will increase the resistance of the virus to triple combinations of drugs as well (CMH 2001).

Besides improving the physical condition of HIV patients, ARV treatments such as HAART have supported the social and psychological struggle against the disease. The ARV treatment regime normally complements the distribution of drugs with care and counselling. Moreover, because ARV treatments have shown that HIV is treatable, they have helped to reduce the social stigma associated with it and to integrate people living with it into society. And when ARV drugs are available, people are more willing to take an HIV test and take action to fight the virus if they test positive.

Microbicides. Another potential new technology in the fight against HIV is microbicides (box 4.3; WHO and UNAIDS 1998). Products that kill or deactivate dangerous microbes, microbicides could block infection by creating a barrier between the pathogen and the body, kill or immobilize pathogens, or prevent a virus from replicating once it has infected the cells of the body. Vaginal and rectal microbicides will be produced in many forms—gels, creams, films, sponges, suppositories. More than 60 vaginal microbicide products are in various stages of development, though none has been approved yet for human use.

Box 4.3

Microbicides—empowering women to protect themselves

Of the 25.3 million Africans infected with HIV in 2000, more than half (14 million) were women. Besides being biologically more vulnerable to HIV infection, women in Africa often face social factors that make it difficult to protect themselves against the virus, including the common practice of sexual relations between girls as young as 13 and much older men, the unequal power relations within the household, and employment of girls as sex workers from a young age. Thus the development of female-controlled mechanisms to protect against HIV infection is vital.

One technology offering enormous potential for protecting against the transmission of HIV and other sexually transmitted infections is the use of microbicides. Because microbicides come mainly in the form of a gel or cream, women could use them without the knowledge of their male partner. Another advantage of microbicides is that they would allow a couple to conceive a baby while being protected against sexually transmitted infections. Microbicides could also reduce mother to child transmission of HIV if used before delivery, and prevent the transmission of HIV from women to their partners.

Although microbicides are still under clinical development and not yet on the market, a consensus exists on their scientific feasibility and potential profitability. But the research has been slowed by limited funding. Large pharmaceutical companies fear that poor nations, those hit hardest by the epidemic, lack the economic capacity to buy microbicide products. Survey results do not bear out these concerns. A survey by the Allan Guttmacher Institute revealed that in Côte d'Ivoire and Kenya 60% of women would pay five times the price of condoms for microbicide products. And in Brazil the potential annual sales of microbicides could be as high as $800 million. What's more, the survey found that 12.6 million women in the United States are interested in using microbicide products, and 7.7 million of them would be willing to buy them for twice the price of male condoms.

Today 38 small biopharmaceutical companies, 28 non-profit research entities, and 6 public sector agencies are working to develop microbicides—up from the handful interested in 1996. Sixty-four products are at various stages of development, with 7 at later stages of clinical trials by mid-2001 and around 30 still in pre-clinical testing. With sufficient investment, microbicide products could reach the market within five years.

Source: *Population Council and International Family Health 2001; Lerner 2001; Topping-Coun 2001; World Bank 2001a.*

Microbicides have an important advantage. Unlike other barrier methods, a microbicide could be used without the co-operation or even the knowledge of one's sexual partner. In Sub-Saharan Africa, where many women lack the bargaining power in relationships to ensure the use of condoms, microbicides could thus empower women to protect themselves. Female condoms are another new technology that empower women to take the initiative in practicing safe sex. By contrast, with male condoms, the ultimate decision-making power in most cases lies with the male partner.

Vaccine technology. An effective, widely available vaccine offers the best long-term hope of bringing the HIV/AIDS epidemic under control. Such a vaccine could be preventive, protecting non-infected people from becoming infected, or therapeutic, stopping or retarding the

Box 4.4

Approaches to HIV vaccines under development in 2001

Thanks to new innovations in biotechnology, vaccine development has progressed enormously since HIV was identified

Several concepts or approaches to HIV vaccines are under development or in clinical trials.

Recombinant subunit vaccines introduce a genetically engineered, harmless part of HIV into the body. This is the approach used in Gp 120 protein, the only vaccine in phase 3 clinical trials at the moment. Most candidate HIV vaccines use this approach.

DNA vaccine, or naked DNA vaccine, introduces into the body actual genes of HIV (rather than the antigens) that have been genetically engineered to become avirulent. When the HIV genes are introduced into skin or muscle, the cells of the body take up the genetic material and produce viral antigens (HIV proteins) through normal cellular mechanisms. While some HIV vaccines produce a humoral response (antibodies), DNA vaccine has been shown to also trigger cell-mediated immune responses. This vaccine is in phase 1 clinical trials.

Live viral or bacterial recombinant vector vaccines are created by inserting HIV genes into a live virus or bacterium that is infectious but does not cause disease to the human body. The engineered virus or bacteria are used to transport the desired HIV antigens to the body. When they enter the cell, they cause the HIV protein to be generated inside the cell, producing both humoral and cellular immune responses. Viral types of the vaccine include canary pox, in phase 2 of clinical trials, and vaccinia, in phase 1. Bacterial types include salmonella, in phase 1 of trials. Bacterial types could have two advantages: they could be given orally and produced cheaply.

Live-attenuated virus vaccines are made of live but weakened HIV that is unable to cause disease. When the body responds to the weakened virus, it has the experience of an infection and is thus prepared to react to the full-strength virus. Today this is the most commonly used system for other vaccines, such as those for polio and measles. But the risk that HIV may not be adequately attenuated and could have long-term consequences leading to litigation has held back investigations of this approach in HIV vaccine research and development. At the moment no vaccine of this type is being tried in humans.

Whole-inactivated virus vaccines use the entire HIV, rendered non-infectious through inactivation by chemicals, irradiation, or other means. This approach, also widely used for other vaccines, such as those for polio and hepatitis A, is said to be safer than live-attenuated vaccines. But no form of this vaccine has reached clinical trials in HIV-negative volunteers.

Combination vaccines combine two or more of the above approaches. For example, the prime-boost strategy first uses a recombinant vector vaccine to induce cell-mediated immune response and then a subunit vaccine to stimulate the production of antibodies.

Synthetic peptide vaccines focus on very small pieces of HIV proteins (peptides) that are the most potent parts of the proteins stimulating immunity. Three of these vaccines (lipopeptides, p17, and V3-based) are in phase 1 of clinical trials.

Other types being developed are virus-like particle vaccines (pseudovirion vaccines). When tested in the laboratory, most of these vaccines are generally well tolerated. But concerns about unexpected side-effects have arisen recently, pointing to a need for intensified research.

Source: *IAVI 2002a; NIAID 2002; Hug a Nurse Training Centre 2001.*

progression from HIV infection to AIDS for people already infected (ICASO 2000). Research is progressing on both fronts, though therapeutic vaccines are still in the very early stages of development.

Developing a vaccine for HIV is particularly challenging because HIV is one of the most mutable viruses known—thus the prevalence of a wide variety of strains. No HIV vaccine exists at the moment. But thanks to new innovations in biotechnology, vaccine development has progressed enormously since HIV was identified as the cause of AIDS.

First-generation HIV vaccines could become available within the next two to six years

HIV vaccine development is moving from conventional methods to new approaches. The classical approach used for most viral vaccines today is based on the use of whole but inactivated or live-attenuated viruses. But for ethical and safety reasons, this approach has not been aggressively pursued in HIV vaccine research. The nature of HIV adds another complication to the development of a vaccine: the vaccine must be capable of stimulating the immune system to destroy a virus whose prime characteristic is to destroy that same immune system.

Several forms of vaccines have been identified as potential candidates (box 4.4). All have to be subjected to long laboratory, animal, and human trials before being approved for human use. The test on humans alone is a long process consisting of three main phases:

Phase 1 trials obtain initial information on the safety and immunogenicity (ability to produce an immune response). Phase 2 trials obtain additional safety and immunogenicity data, as well as information about different populations. Phase 3 trials assess the efficacy of the candidate vaccine in preventing infection or disease.

Since 1987, when the first human trial of a candidate HIV vaccine was carried out, more than 30 candidate vaccines have been shown to trigger an immune response and to be safe in phase 1 trials, including the first vaccine developed specifically to fight the HIV-1A strain common in Africa. Two vaccine concepts have reached phase 2 trials, and one vaccine, for HIV-1 subtypes B and E, has progressed to phase 3 trials. The trials are being carried out in Thailand and the United States, and the results should be available in early 2003 (ICASO 2000; Mwau 2001).

Depending on the results of the phase 3 trials, first-generation HIV vaccines could become available within the next two to six years (Esparza 2001). In the meantime human trials of HIV candidate vaccines have provided important information that have permitted the design of improved generations of vaccines. First-generation vaccines might not be highly effective, but with moderate efficacy of 50% could still play a significant role in preventing new infections, especially in populations with a high incidence of HIV infection and for which other prevention interventions are not having the expected effects (Esparza 2001). Although most candidate vaccines in clinical trials still focus on strains of HIV circulating in industrial rather than developing countries, the past two years have yielded significant advances for products oriented towards developing countries (box 4.5; U.K. Performance and Innovation Unit 2001).

Box 4.5

Clinical trials for the first HIV candidate vaccines for Africa

Since the first HIV vaccine trial in Africa, conducted in 1998–99 in Uganda, trials have expanded to other countries on the continent, such as Kenya and South Africa. One set of candidate vaccines that has recently moved from the research laboratory to clinical trials—the first HIV candidate vaccines for Africa—is being developed by a team of Kenyan researchers at the University of Nairobi and British researchers at the University of Oxford. Funded by the International AIDS Vaccine Initiative, the vaccine project began human trials in Nairobi in 2001. The candidates being tested include both the DNA component (to "prime" the immune response) and MVA (modified vaccinia Ankara, to "boost" the initial response) vaccines.

The clinical testing started phase 1 with the enrolment of 18 volunteers, completing a full course of vaccinations and follow-up visits and clinical evaluation. After two intramuscular inoculations, results indicated that the vaccine was well tolerated and had no serious side-effects; robust outcomes were obtained for low doses of DNA vaccine. These results compare favourably with those for other HIV candidate vaccines under development. Participants in the trial are awaiting the second phase.

The next step is to study the combined DNA-MVA prime-boost to assess the optimal dose and frequency of the two injections and the optimal interval between the prime and boost inoculations. In addition, before these candidates are recognized as vaccines, several more trials will be needed. To accelerate phases 1 and 2 and improve the efficiency of phase 3 trials, additional venues for the trial will be assessed in East Africa, including Kenya, Tanzania, and Uganda, as well as potential future sites in Côte d'Ivoire, Gambia, and Thailand.

Source: *IAVI 2002b.*

Tuberculosis

Tuberculosis, an ancient disease caused by a bacterium (*Mycobacterium tuberculosis*), is another leading cause of death in Africa. It commonly attacks the lungs, but it can also spread to other parts of the body. The infection is usually transmitted from people with pulmonary tuberculosis to other people, particularly through coughing or sneezing. Clinical disease occurs within two years after the primary infection (Jamison and others 1993).

Epidemiology and status

Tuberculosis is closely associated with poor socio-economic conditions, including poverty, overcrowding, and poor housing (Borgdorff, Floyd, and Broekmans 2001). It is also more likely to occur in people with poorly functioning immune systems, such as those infected with HIV. Once considered vanquished, especially in the West, tuberculosis has been on the rebound since 1993, when the World Health Organization declared it a "global emergency" (WHO 1996).

Two characteristics distinguish today's tuberculosis from that of years past. The first is close association with HIV/AIDS infection, in what is called the dual epidemic. Tuberculosis is the biggest AIDS-related killer, causing the deaths of nearly 40% of

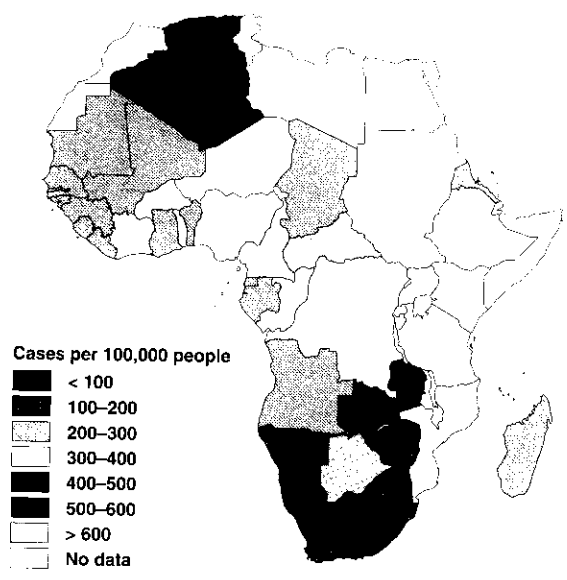
HIV/AIDS patients (Robertfroid 2000). According to the WHO, about 1.8 billion people are infected with the bacterium that causes tuberculosis. But only about 8 million go on to develop active tuberculosis each year. Of these, 2 million die from the disease. HIV infection is the strongest known risk factor for progressing from tuberculosis infection to disease. The second characteristic of the new tuberculosis epidemic is the increasing resistance to the drugs used.

In 1997–99 Sub-Saharan Africa experienced a staggering 20% annual growth in new tuberculosis infections (WHO 2000a). The incidence of tuberculosis varies across the region, with Botswana having the highest rate (map 4.2). Evidence strongly suggests that the epidemic is still growing worldwide, particularly in developing countries. Around 95% of tuberculosis cases and 98% of tuberculosis deaths occur in the developing world.

In 1997–99 Sub-Saharan Africa experienced a staggering 20% annual growth in new tuberculosis infections

In industrial countries the fall in the incidence of tuberculosis in the past hundred years was led by improvements in social and economic conditions—and in the past 40 years by antituberculosis chemotherapy. There are now direct means to treat the infection faster and more efficiently. The current regimen pursued, the Directly Observed Treatment Short course (DOTS) strategy, has had significant success in curing and controlling the spread of the disease. A six-to eight-month course of cheap generic drugs, the regimen leads to a cure rate of more than 90% if the recommended schedule is followed (Borgdorff, Floyd, and Brockmans 2001). According to the WHO, only one in four of the world's tuberculosis sufferers receives DOTS treatment, and among those who do, the poor are underrepresented (WHO 2002c). DOTS requires strict adherence to the treatment regimen and frequent visits to a health cen-

Map 4.2
Estimated incidence of tuberculosis in Africa, 2001



Source: WHO 2002a.

tre. Patients often do not adhere to the regimen. Once they start to feel better, many stop taking the medicines. Long distances to a health centre, lack of resources, and seasonal agricultural work also hinder compliance with the full treatment programme. Non-compliance not only makes the treatment ineffective but also increases the resistance to drugs.

Socio-economic burden

The treatment of multi-drug-resistant tuberculosis has been progressing

Those suffering from tuberculosis are unable to work for an average of three to four months a year, losing up to 30% of annual household income as a result (WHO 2002c). Moreover, other family members are likely to become infected, and children may be withdrawn from school. All this means an unhealthy labour force, lower productivity, and greater stress on health systems. The macroeconomic implications can be substantial: in developing countries 75% of tuberculosis cases occur among the economically active. In countries with a high burden of tuberculosis, annual productivity losses due to the disease are estimated at 4–7% of GDP (Stop TB Initiative 2002).

Of even greater concern is the cost of inaction or inadequate action. Inadequate treatment services and incorrect self-treatment for tuberculosis can substantially increase resistance to multiple drugs, raising the cost of future treatment. Multi-drug-resistant tuberculosis is estimated to be at least 100 times as expensive to cure (Stop TB Initiative 2002).

New innovations in treatment, diagnosis, and prevention

Treatment and diagnostic technology. Ongoing scientific improvements are strengthening drugs and improving the efficiency of treatment programmes for tuberculosis. New technologies aimed at shortening the duration of treatment and allowing less frequent treatment are becoming more accessible and easier to use. Much of the progress has been achieved through longer-acting rifamycins, a family of antibiotic drugs that includes such compounds as rifapentine, rifabutin, and rifampin. The most promising work has been on rifapentine, approved in the United States in 1998. Rifabutin has been recommended for those who are also infected with HIV and unable to receive rifampin because of interactions with antiretroviral agents.

The treatment of multi-drug-resistant tuberculosis has been progressing through development of the broad-spectrum fluoroquinolone antibiotics, now among the preferred second-line medicines and reported to be effective. Newer compounds in this class, such as moxifloxacin and gatifloxacin, appear to be much more active against multi-drug-resistant tuberculosis than any of the currently available agents (O'Brien and Nunn 2001). In addition, promising diagnostic technologies are being developed for rapid field use. Those based on the dip-stick technology and using body fluids, for example, allow prompt identification of the disease (Borgdorff, Floyd, and Broekmans 2001).

Prevention technology. Existing drugs are generally effective only after the bacterium causing tuberculosis activates in the body. Fully successful control of tuberculosis would require an efficient vaccine to prevent infection. Bacillus Calmette-Guérin (BCG), the most widely used vaccine for tuberculosis, is cheap to produce. But its effects on the global epidemic have been minimal. BCG gives good protection against childhood tuberculosis (75–80%) but little protection to adults. It is estimated to prevent only 5% of all potentially vaccine-preventable deaths due to tuberculosis (Borgdorff, Floyd, and Broekmans 2001). Moreover, it is believed to offer low protection to people with immunodeficiency and even to lead to disease in HIV/AIDS patients (Dreher and others 2000). The aim of research using modern biotechnology is to find an efficient substitute for BCG.

After decades of unsuccessful research, advances in immunobiology, molecular biology, and gene therapy bring new hope for a better tuberculosis vaccine. A major breakthrough came when the complete genomic sequence of *M. tuberculosis* was mapped in 1998. Researchers are now exploring that genome to extract the specific information that will permit the identification of new drug targets, novel methods to speed diagnosis and treatment, and vaccine candidates. The work on a vaccine has been further advanced by research providing new information on the human body's immune response to the infection, particularly on the balance between humoral and cellular response.[2] This information will make it possible to enhance the response to the disease (Dreher and others 2000).

In addition, such revolutionary approaches as DNA vaccination have been recently applied to tuberculosis, with excellent results in small animals and more reserved results in big animals (Dreher and others 2000). Recombinant gene vectors with vaccinia viruses are also being researched and have shown success in the mouse model. Other potential vaccine candidates are being developed and screened in small animal models, including subunit vaccines and non-pathogenic mycobacteria (Rochon Ford 2000).

Malaria

Malaria ranks among the major health challenges for Africa. Worldwide, acute malaria affects more than 300 million people each year and kills more than one million a year—about 3,000 a day—most of them children (Global Partnership to Roll Back Malaria 2002). About 90% of malaria cases occur in Sub-Saharan Africa (figure 4.2). Most vulnerable are those in rural areas with difficult access to health services, especially to well-equipped centres with skilled staff.

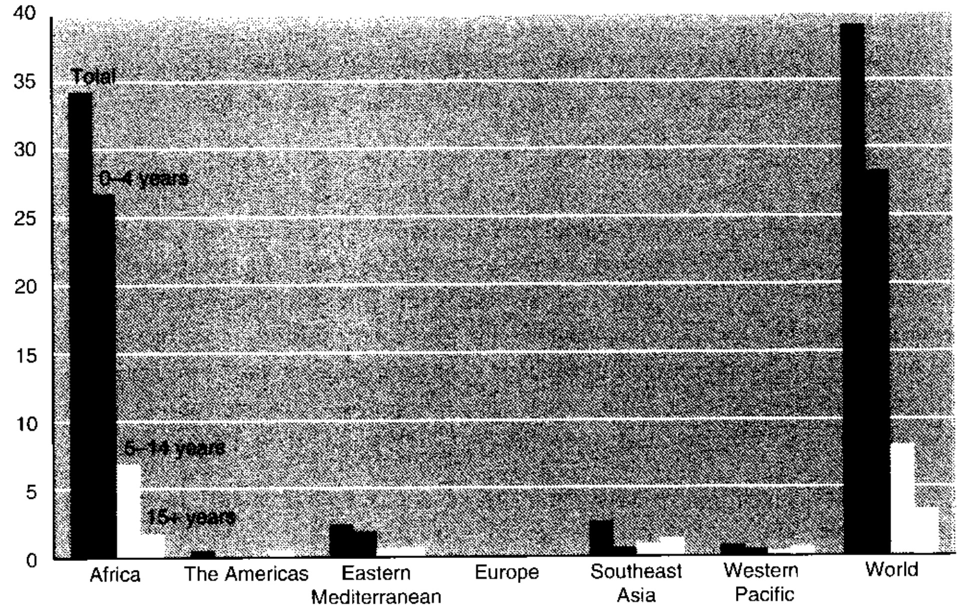
Epidemiology and status

Malaria is caused by four kinds of *Plasmodium* parasites that can be transmitted to people when they are bitten by female anopheline (malaria transmitting) mosquitoes.[3] The infected person may also pass the parasite to a biting mosquito. Severe illness is usually caused by *P. falciparum*, widespread in Africa but less so in Asia and Latin America. Transmission occurs mainly in the tropics, boosted by warm temperature and high humidity.

Malaria is curable if diagnosed and treated promptly

Malaria is curable if diagnosed and treated promptly. But without effective treatment, cerebral malaria, severe anaemia, or multiple organ failure can rapidly ensue, leading to fatality rates of 10–30%. Where people receive hundreds of infective bites a year, illness is frequent. People in highly endemic areas may develop some immunity, however, which

Figure 4.2
Burden of malaria by region and age group, 1998



***Note:** Disability-adjusted life years (DALYs) reflect the loss of healthy life years because of premature mortality and disability resulting from disease. The total loss of DALYs is the global burden of disease.*
***Source:** WHO 1999.*

prevents them from developing the severe form of the disease. Pregnant women (and their foetuses) are at particularly high risk because of lower immunity. Young children and travellers from areas of lower transmission are also at high risk.

In several areas of Asia and Latin America, deaths from malaria have been reduced considerably in the past century. But in Sub-Saharan Africa the number of deaths is growing. The main reasons are increasing drug resistance, large and mobile populations, deteriorating health systems, and climate change. A major concern is the growing resistance of the malaria parasite *P. falciparum* to such drugs as chloroquine, the mainstay of treatment for decades. Insecticide-treated mosquito nets and repellents have been efficient in local prevention efforts, reducing mortality rates (CMH 2001). But these interventions have more limited success when implemented on a large scale.

Socio-economic burden of malaria

Malaria kills mainly children and also adversely affects their education through illness and absenteeism. It has a substantial impact on the economically active population through illness and lost workdays. And it renders large tracts of land uninhabitable and jeopardizes tourism and foreign investment. In Nigeria it has been estimated that subsistence farmers devote as much as 13% of household spending to malaria treatment. In Africa 20–40% of out-patient visits and 10–15% of hospital admissions are attributed to malaria. The provision of prevention and treatment services strains government resources.

Malaria deepens poverty in endemic areas through the loss of workdays and the cost of treatment for frequent episodes of illness, a substantial burden for the poorest families. Estimates suggest that economic losses due to malaria in Africa amount to about $12 billion a year—far more than the resources needed for malaria control, estimated at about $3 billion. Differences between countries with high and low prevalence of malaria illustrate the economic losses. One study suggests that bringing malaria under control in Africa could increase its annual economic growth rate by three percentage points (U.K. Performance and Innovation Unit 2001).

One of the most promising cures for malaria comes from a traditional medicinal herb called sweet wormwood

Scientific breakthroughs in combating malaria

Treatment. For many years the cheapest and most widely used drug for treating malaria was chloroquine, a generic, non-patented drug. Although very safe and still in use in some countries, chloroquine has become ineffective in most endemic countries because the malaria parasite has developed resistance to it. The main reasons are poor patient adherence to dosage regimens and the production of low-quality drugs by some manufacturers. Resistance to other malaria treatments (such as sulfadoxine-pyrimethamine) is increasing rapidly in East and Southern Africa (Meek, Webster, and Hill 2001). The most resistant strains of malaria require more expensive drugs or a combination of drugs, increasing the cost of treatment. And some strains have developed resistance to all leading antimalarial drugs, making the development of new drugs and combinations a priority for research and development.

One of the most promising cures for malaria comes from China. Based on a derivative from a traditional medicinal herb called *qinghao*—or sweet wormwood—artemisinin is highly effective because the malaria parasite has yet to build resistance to it. The drug is a rapidly reacting agent that reduces the number of parasites in the blood to very small numbers. At least four treatment drugs are now being developed, with one already available. Most important, these drugs are likely to be affordable for the poor.

Prevention. Fascinating new discoveries and new knowledge are renewing hopes of containing and ultimately eradicating malaria. Research on vector biology and control provides new tools for better understanding the biology of malaria parasite transmission. This knowledge is being used in two streams of research. One is working to produce mosquitoes that can replace existing disease-carrying insect populations. The other is seeking to genetically engineer female mosquitoes to vaccinate animal disease reservoirs, livestock, and humans against particular diseases.

Under way since 1991, the first stream of research has been aimed at transforming the malaria-transmitting mosquito into a harmless insect that does not carry the parasite (TDR 2001). The goal is to create genetically modified mosquitoes equipped with the genes required for manufacturing antibodies to malaria parasites. These antibodies would stop the movement of malaria parasites from an infected blood meal into the mosquito, creating an "incompetent mosquito," one unable to transmit malaria. The hope is that once released into the wild, these genetically modified mosquitoes would eventually make all mosquitoes resistant to the parasite, wiping out malaria. But the science is not there yet. It is estimated that another 10 years are needed for this research to come to fruition. Even so, there has been tremendous progress. In 2000 scientists successfully inserted a functional gene into malaria-transmitting mosquitoes. This gene, it is hoped, can eventually be replaced with one that inhibits development of the malaria parasite.

Also proceeding at a tremendous pace is research using mosquitoes to deliver a treatment or vaccine to the victim, and thus to prevent the transmission of the malaria parasite in the first place. This "altruistic" malaria vaccine has already been created at Imperial College, London, and was registered under InSecta Ltd. in October 2000 (Research Intelligence 2001). In the medium term this research is expected to help provide a significant supply of "refractors" (engineered, non-sterile males and females designed to replace existing disease-carrying insect populations) and "angels" (engineered females designed to vaccinate animal disease reservoirs, livestock, and humans; Research Intelligence 2001). The mapping of the malaria genome sequence soon to be done will generate valuable new information.

The mapping of the malaria genome sequence will generate valuable new information

Challenges in the application of biotechnology

The diseases of poverty—HIV/AIDS, malaria, and tuberculosis—are taking a huge toll on Africa. But new innovations in biotechnology are opening avenues to strengthen the response to them. A major challenge for Africa is to take advantage of these advances and to make high-impact interventions widely available to tackle the many epidemics affecting its people.

The optimistic tone of this chapter should not be interpreted as suggesting that the exploitation of these new technologies by African countries faces no obstacles. Two major sets of obstacles can be identified: those inherent in the scientific research process and application and those emanating from circumstances in Africa that limit its capacity to absorb the new technologies.

The first set of challenges relates to red biotechnology research and application. Ethical concerns arise from the manipulation of genetic material and the need to ensure safe procedures and the accountability of science to humanity. Moreover, there is a long time lag between research and the development of new products. And global investment in health research is biased towards non-communicable diseases, an issue that needs to be addressed by the international community.

The second set of challenges has to do with the inability of African countries to benefit substantially from the scientific and technological innovations leading to new generations of treatment and drugs that are cheaper, more effective, and easier to adapt. These African challenges include the inadequate health infrastructure, the extremely high cost of drugs, the bias of medical research towards high-profit products, and the lack of coordination between existing programmes and stakeholders.

Ethical issues in red biotechnology

Ethical concerns surrounding genetic manipulation are so important that many countries, industrial and developing, have set up bioethics committees to determine general principles of research and application and monitor compliance with them. The potential effects of human gene manipulation on research strategy and the enormous power conferred on the scientific community raise questions about rights to information and civil society participation. Major ethical questions also arise about equity and what is considered the common heritage of mankind. In particular, questions are raised about whether the ownership and economic benefits of gene discoveries can be privatized. Also raising concern are the contradictions between the recognized right of intellectual property protection and the recognized universal ownership of genetic material, based on the principle that the DNA structure of human beings is the heritage of all and should be registered as the property of all.

Long lag time between discovery and application

Drug discovery takes many years of dedicated research to convert new ideas into new chemical entities and then new drugs

Drug discovery is a long and complex process. It takes many years of dedicated research in biology combined with cutting-edge medicinal chemistry to convert new ideas into new chemical entities and then new drugs. The procedure is tightly governed by national and international rules. The clinical compounds have to be designed not only to inhibit the molecular target against which they are directed, but also to be stable, non-toxic, and able to be absorbed into the bloodstream and to cross from the blood plasma into the infected blood cell. To fulfil all these requirements, new chemical entities have to pass through laboratory and animal testing before clinical trials and before approval as a drug. The clinical trials consist of three phases, each long. The time required for clinical testing, along with the cost, can determine access to such research.

International rules and regulations governing research involving genetic manipulation are even more stringent because of the uncertainty about the long-term effect of this type of research on the human body. This adds to the cost of the research at all stages, from basic research to application.

In Africa the time and cost requirements are a serious obstacle to participating in research and deriving benefits from the results. Despite the optimism about the development of an HIV vaccine, in some African countries the approval process for clinical trials can be long and mired in controversy and red tape. In Uganda it took two years and nine committees to approve HIV vaccine trials.

Disequilibrium in research priorities

Worldwide, there is a huge disequilibrium between research devoted to the diseases of the poor and that focusing on the diseases of the rich: less than 10% of global spending on health research is directed to the health problems accounting for 90% of the world's disease burden—the 10/90 disequilibrium (Global Forum for Health Research 1999). As measured by disability-adjusted life years (DALYs), the global burden of communicable diseases, concentrated in low-and middle-income countries, is 13 times the global burden of non-communicable diseases, the main health concern of the developed world. Yet non-communicable diseases receive by far the most research attention, while communicable diseases are neglected. For example, malaria accounted for 2.7% of the global disease burden in 2000, with 90% of cases in Africa, but for only 0.17% of the $60 billion spent globally on biomedical research that year (CMH 2001; Global Forum for Health Research 2002).

This inequality in research is also reflected in medical products. Of the 1,233 drugs that reached the market between 1975 and 1997, only 13 were for tropical diseases (Global Forum for Health Research 2002). Among the medicines being developed through biotechnology research, a far smaller share are directed to HIV/AIDS than to cancer.

Low investment and absorption capacity for technology transfer

African countries face constraints on the development and use of new innovations in biotechnology as well as on the adoption of those developed outside the continent. What constrains African countries? Their low technical capacity in research, their low financial resources, and their enormous burden of disease.

The investments in health research by African countries are much lower than would be expected given the scale of the epidemics they face. The risks and uncertainties characteristic of investments in expensive clinical trials are not matched by the expected willingness to pay of the potential beneficiaries. This is especially so for treatments for HIV/AIDS, malaria, and tuberculosis, which mostly affect the poor. While the pharmaceutical market for HIV/AIDS drugs has been expanding rapidly in Europe and North America, that has not been the case in developing countries, even though most HIV-infected people live in Africa and Asia.

What constrains African countries? Their low technical capacity in research, their low financial resources, and their enormous burden of disease

The transfer and adaptation of technologies developed in high-income countries is also limited by several factors. African countries have low technology bases and individually may not be able to finance either the purchase of these new technologies or the research to adapt them to local circumstances.

Lack of effective demand

Fewer than 1% of Africans infected with HIV/AIDS can obtain antiretroviral therapy today (UNICEF and others 2001). Many African countries, with annual per capita health spending as low as $10, have difficulty purchasing vaccines and drugs. And because existing treatments for HIV/AIDS and tuberculosis do not cure the infections, but only strengthen the immunological system, treatment must be continuous, adding up to very high costs over the patient's lifetime.

Although the prices of antiretroviral drugs have declined substantially as a result of competition from generic drugs and pressure on pharmaceutical companies, they have not yet fallen to a level that would make the drugs easily affordable to the millions of HIV-infected Africans living on less than $1 a day. Moreover, the non-drug costs associated with antiretroviral treatment, such as tests and counselling, are also considerable.

Complicating the problem of the high cost of drugs are the generally weak health systems in Africa. Even if pharmaceutical companies were to drop drug prices to nearly zero, African countries would still need to meet the costs of delivering care, and the treatment of HIV/AIDS and tuberculosis requires strong health care delivery systems. Highly trained doctors, nurses, and clinic staff are required to identify those who need the drugs, to counsel and support them, and to ensure that they comply with the complicated drug regimens. But health systems in Africa are often poorly equipped to serve as effective conduits for care. About 95%

of Africans infected with HIV/AIDS have no access even to basic health care, and only 20% of those infected with tuberculosis receive effective treatment.

The provision of care is further constrained by the poor integration of HIV/AIDS programmes into existing health systems. As earlier malaria and immunization programmes showed, vertical disease-specific programmes are unsustainable if they are not integrated into national health systems.

Gaps in information and knowledge

The results and products of red biotechnology research, and the increasing knowledge intensity of such research, pose serious challenges to African countries. Even for countries with access to information, the rapid flow of information on ongoing research and new drugs overwhelms their processing capacity. And in the many countries that lack such access, information is received and processed with considerable lags.

Without systematic access to the most recent information, it is extremely difficult for any African country to plan a strategy for combating disease. Another problem is the complexity of information and the language in which it is couched. The software and statistical approaches used to disseminate research results are becoming more sophisticated. Take gene sequencing, which requires a high level of bioinformatics to decipher the advances in the field. That makes it difficult for Africans to follow modern research work and transmit new knowledge to the public.

It is extremely difficult for any African country to plan a strategy for combating disease

Despite the challenges, the continent cannot afford to allow the emerging innovations in red biotechnology to pass it by. The devastating social and economic impact of communicable diseases on the continent demands an all-out effort to find ways to overcome the challenges and gain the full benefits of these advances. African leaders and policy-makers have a large role to play in this.

Benefiting from red biotechnology—policy recommendations

There is increasing awareness in Africa of the gravity of the health problems its population faces and their socio-economic consequences—and African leaders have recently taken important steps. In the Abuja Declaration on HIV/AIDS, TB, and Other Related Infectious Diseases, and in the enabling Framework Plan of Action, African leaders declared HIV/AIDS the continent's most important development challenge, resolving to set aside no less than 15% of annual budgets to strengthen the health sector (box 4.6). And the New Partnership for Africa's Development (NEPAD), adopted by African heads of state in their 2001 summit in Lusaka, Zambia, established a number of goals for health (box 4.7).

NEPAD is the crystallization of a common vision shared by African leaders to eradicate poverty. It recognizes the role of new technologies in achieving socio-economic recovery and in closing the gap with the rest of the world in health, education, and general well-being. NEPAD also recognizes that African countries will find it difficult to commit

Box 4.6

African leaders' response to HIV/AIDS

High-level meetings have been convened in recent years to focus attention on the enormous burden of HIV/AIDS, malaria, and tuberculosis on Africa. The African Development Forum 2000 was convened by the Economic Commission for Africa to address the theme "HIV/AIDS: The Greatest Leadership Challenge." Participants emphasized the need for commitment by leadership at all levels to combat HIV/AIDS. And they called for an international partnership to mobilize $3–10 billion annually to provide a wide range of treatments and interventions, including antiretroviral treatment for people infected with HIV (Economic Commission for Africa 2000a). The meeting led to a concrete outcome—the African Consensus and Plan of Action: Leadership to Overcome HIV/AIDS.

The African Development Forum was followed by a special summit of African heads of state in Abuja, Nigeria, in April 2001. At the summit African leaders adopted the Abuja Declaration on HIV/AIDS, TB, and Other Related Infectious Diseases, calling on African countries to allocate 15% of their annual budget to health and to lift all barriers to health funding. They called on donor countries to pledge 0.7% of their GNP as development assistance and pushed for the creation of a global AIDS fund of $5–10 million. The Abuja Declaration was endorsed by the assembly of African heads of state and government in Lusaka, Zambia, in July 2001.

Internationally, the Group of Eight (G-8) summits in Okinawa, Japan, in 2000 and in Genoa, Italy, in 2001 endorsed the international development targets for HIV/AIDS, tuberculosis, and malaria and recognized the need for urgent action. The United Nations convened a special session of the General Assembly in June 2001 to address HIV/AIDS as an appalling challenge to humanity.

The repeated calls for sustainable resources to stem the deaths from HIV/AIDS, malaria, and tuberculosis—up to 6 million a year—led to the creation of the Global Fund to Fight AIDS, Tuberculosis, and Malaria. The G-8 summit in Okinawa first endorsed the fund, followed by the United Nations Special Session on HIV/AIDS in June 2001 and then the G-8 summit in Genoa. An independent, public-private partnership, the fund provides grants for proposals from countries hit hard by HIV/AIDS, malaria, and tuberculosis. So far, donors have pledged $2.1 billion. The fund began disbursing funds in April 2002, with $616 million (of $1.6 billion in approved grants) to be disbursed in the first two years. The second call for proposals has already been issued.

Source: *Organization of African Unity 2001a; Economic Commission for Africa 2000a, b; World Bank 2001a; Global Fund to Fight AIDS, Tuberculosis and Malaria 2002; United Nations 2001c.*

substantial resources for technology initiatives when their people lack food, education, and adequate health services. So it emphasizes the need for Africa to put in place strategic policies and programmes for scientific and technological development in health, agriculture, and other areas. This emphasis is well placed: evidence shows that new technologies explain substantial reductions in mortality across the world, especially in industrial countries.

The start up costs for the innovative new health technologies and products are high

Invest strategically in red biotechnology research and development

African countries invest much less in research on HIV/AIDS, malaria, and tuberculosis than would be expected given the enormous costs of these epidemics to the continent. But the start-up production costs for the innovative new health technologies and products are high, and countries are unlikely to be able to afford them on their own. So, African coun-

Box 4.7
New Partnership for Africa's Development—setting goals for health

The New Partnership for Africa's Development is premised on African ownership of the development process. It represents a pledge by African leaders to eradicate poverty and to place their countries—individually and collectively—on the path of sustained growth and development while also participating actively in the world economy and political body.

As part of the effort to achieve these goals, NEPAD seeks to significantly improve the health of Africans so as to build a strong base of human capital. Broadly, NEPAD aims to:

- Strengthen programmes for containing communicable diseases, to ensure that they do not fall short of what is needed to reduce the burden of disease.
- Build a secure health system that meets needs and effectively supports disease control.
- Ensure the support capacity needed for sustainable development of an effective health care delivery system.
- Empower the people of Africa to improve their own health and to achieve health literacy.
- Encourage cooperation between medical doctors and traditional practitioners.

NEPAD also set specific goals:

- To diminish the burden of communicable diseases in Africa by reducing HIV prevalence in young people by 25% by 2010; reducing the prevalence of and deaths from malaria and tuberculosis by 50% by 2010; reducing infant and child mortality rates by 67%, and maternal mortality ratios by 75%, by 2015; and providing effective prevention of other major diseases by 2015.
- To have a secure health system that meets needs and effectively supports disease control in place by 2015.
- To achieve health literacy in Africa by 2007.
- To reduce the disease burden of the poorest in Africa.
- To ensure the necessary support for sustainable development of an effective health system.

These goals are not mutually exclusive but mutually reinforcing. And a strong, secure, stable, and efficient health system is essential to achieve all the other goals.

Source: *Organization of African Unity 2001b.*

tries need to pool resources for research and development on health—pursuing efforts based on mutual support at the regional level, in partnership with diverse stakeholders, and directed towards the most cost-effective R&D activities. Africa's R&D investment strategy should follow three main directions:

- *Promoting African R&D centres, particularly for red biotechnology.* Red biotechnology research is extremely costly and beyond the reach of many African countries on their own. Moreover, benefits from the control of diseases spill over national borders. So, there is ample reason to pool resources, both financial and human. African countries should promote regional and subregional research centres through shared efforts, using strong incentives to encourage collaborative research between the regional research centres and the research institutes of industrial countries. This investment would promote research on the diseases and strains that most affect Africa. And it would create critical knowledge and capacity for adopting cutting-edge biological and pharmaceutical research while building and retaining capacity on the continent. A good example of regional cooperation is the recently established Africa AIDS Vaccine Programme, in which 15 African countries are collaborating on finding an HIV vaccine. Similar initiatives should be undertaken for other diseases prevalent in Africa.

- *Focusing on applied research, not basic research.* Pure research, such as that on gene sequencing or protein isolation, is extremely costly, and the results and duration of the research are uncertain. Given the scarce resources of African countries, participating in this phase of research is not very cost-effective. Applying the results of such research to particular areas of interest, such as in field clinical trials of HIV vaccines, is more cost-effective—for several reasons. First, the clinical stage requires fewer resources than the pure research stage. Second, clinical trials enhance local technical capacity through learning by doing. Third, clinical trials allow the targeting of specific areas and social groups, and their results could contribute to the development of the drug or vaccine. Several African countries are conducting field trials of HIV vaccines, among them Kenya, South Africa, and Uganda.
- *Adopting new advances in biotechnology openly but cautiously.* Africa should incorporate the new advances in biotechnology gradually, to avoid dangerous diversions of funds from current health care delivery and to ensure sustainability. As with any technological discovery, the more the science advances, the easier and cheaper it becomes to use the new technologies widely. But new technologies may not be a cure for all ills. Thus the adoption of new biotechnology products should be preceded by careful cost-benefit analyses of the competing products and technologies available, to provide a rationale for initiating large-scale treatments in resource-limited settings.

Make the prices of emerging drugs affordable

African governments can take several measures to make drugs affordable to those who need them

The unaffordably high prices of emerging drugs limit African countries' ability to benefit from more effective treatments. But several recent developments have brought prices down. Much cheaper generic drugs are becoming widely available, and several patent holders have agreed to provide their drugs at prices near marginal production costs (box 4.8).

African governments can take several measures to make drugs affordable to those who need them. First, they can produce drugs directly through compulsory or voluntary licensing under the World Trade Organization (WTO) Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS). Second, they can collaborate with other developing countries, such as Brazil, India, and Thailand, all of which now have the capability to produce generic HIV/AIDS drugs. Third, they can enter joint ventures with pharmaceutical firms, individually or through common initiatives such as the Accelerating Access Initiative (see box 4.8). In one possible model for such a joint venture, an African government could grant extended life to patents in exchange for substantial price reductions for the drugs they cover.

Box 4.8

Falling prices for antiretroviral drugs

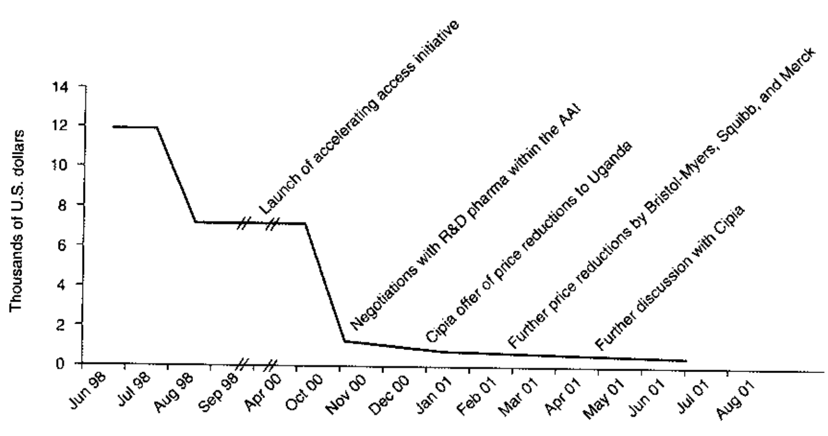
The price of antiretroviral (ARV) drugs have fallen dramatically, driven mainly by competition from generic drugs. Several firms n Brazil, India, and Thailand have developed low-cost formulations of ARV drugs. In 2001, for example, the Indian drug company Cipla offered to sell an AIDS cocktail normally costing $10,000–15,000 a year per patient to Médicines San Frontières for only $350 as long as it agreed to distribute the drug at no cost (*Times of India 2001*).

These low-cost drugs are enabling African countries to broaden access to treatment. In September 2001 Nigeria launched a pilot programme to treat HIV-positive people with generic ARV drugs produced in India, and in early 2002 expanded it to a larger joint programme with the United Nations aimed at treating thousands of people. Nigeria is to pay $350 a person a year for the drugs—drugs that in industrial countries would cost an estimated $10,000–20,000 (AVERT 2001a).

In South Africa in January 2002, humanitarian aid groups started to import three generic ARV drugs: zidovudine (AZT), lamivudine, and nevirapine. Use of these generic drugs has reduced the daily cost per patient from $3.20 to $1.50 (CNN 2002). This initiative will greatly expand access to the drugs—critical in a country where about 20% of adults were infected with HIV in 1999 (UNAIDS 2000c).

Public opinion has played a big part in increasing access to HIV/AIDS drugs. So have such collaborative efforts as the Accelerating Access Initiative (AAI), started by five UN organizations—the United Nations Population Fund, United Nations Children's Fund, World Health Organization, World Bank, and Joint United Nations Programme on HIV/AIDS (UNAIDS)—in partnership with five pharmaceutical companies. The AAI provides policy guidance on HIV and its treatment—and fast-track support for developing countries wanting to expand access to ARV drugs. Through this initiative 18 African countries have signed agreements with manufacturers reducing the prices of some ARV drugs by as much as 85%. Uganda is one of the success stories (see figure). The prices of ARV drugs in that country have fallen sharply since the launch of the AAI and continue to fall through price reductions agreed to with pharmaceutical companies (UNAIDS 2002b).

Annual cost of a first-line antiretroviral regimen in Uganda, 1998–2001



Source: *WHO and UNAIDS 2002b.*

Through arrangements like these, some African countries have greatly improved the accessibility and affordability of ARV drugs in the past few years. In 2001 Botswana became the first country to provide ARV drugs through the public health system, in an initiative made possible by price reductions negotiated with pharmaceutical companies. And in early 2002 Nigeria introduced the largest ARV drug programme in Africa, in collaboration with the United Nations and generic drug producers in India.

Strengthen health systems to deliver emerging treatments

Effective treatment of HIV/AIDS, malaria, and tuberculosis requires strong health care delivery systems with sophisticated infrastructure. So does the use of new innovations in red biotechnology, which is highly knowledge-intensive.

International community is sharpening its focus on the diseases of poverty and contributing more resources to address them

Although Africa's health care delivery systems generally fall short of these needs, there are some positive developments. First, new technologies are improving treatment techniques and simplifying procedures. Second, the international community is sharpening its focus on the diseases of poverty and contributing more resources to address them. Third, and perhaps most important, developing countries are coming up with innovative approaches to providing complex treatments, even with limited resources. Haiti and Malawi have successfully experimented with the technically demanding highly active antiretroviral therapy, using the infrastructure for tuberculosis therapy (DOTS). The results so far show that some of the most demanding therapies can be viable even in resource-limited settings (Harries and others 2001).

Governments need to create awareness of these new possibilities and strengthen the capacity of health care systems to systematically obtain the most recent information, evaluate it, and disseminate it. If physicians are unaware of treatment protocols for new drugs, for example, those drugs will remain unavailable to most Africans. Knowledge is also needed on the prices for similar drugs, so that governments can make the right choices. For this, governments need access to studies that compile and compare price lists, such as through regular distribution of medical bulletins, through the Web, and through regional centres of expertise. The regional research centres would be best placed to serve as clearinghouses for information on new medical advances and best practices.

Governments also need to ensure that disease-specific programmes, particularly those for HIV/AIDS and tuberculosis, are well integrated into existing health systems, to avoid the sustainability problems in earlier disease-specific initiatives that were poorly integrated. In addition, experience with malaria control shows that prevention and treatment need to be delivered together, through a strong health system. Also essential in strengthening the capacity to manage widespread diseases is to improve the delivery of health services—by removing barriers to access for the poor, improving preventive care, and ensuring quality treatment.

Foster an enabling environment through regulatory policies and international legislation

Most African countries have a lax regulatory environment in the health sector. But the need to deal with emerging innovations in biotechnology has made having appropriate regulatory policies all the more important. Regulatory policies are needed to ensure the human safety of new products emanating from red biotechnology research, particularly when it involves genetic manipulation. At the same time, regulatory institutions need to be strengthened to speed the approval and licensing of new products—to make essential medicines quickly available and promote competition. Countries should harmonize regulatory practices across borders and work closely with international regulatory bodies that monitor research and application.

Regulatory policies for intellectual property rights are the most complex and controversial issue relating to new technologies. Protecting intellectual property rights is important to promote research, but it may preclude countries from using cheaper generic drugs. Very few African countries have patent laws protecting pharmaceuticals. Under the TRIPS Agreement, most have until 2006 to provide such protection.

There is now recognition that intellectual property rights might constrain the ability of poor countries to take advantage of new medical technologies. The WTO meeting in Doha, Qatar, in November 2001, recognized the right to health—putting health needs ahead of intellectual property rights. Member countries agreed that developing countries could override patent protections to produce drugs during public health emergencies (box 4.9). The challenge now is to build on this commitment and convert it into sustained action. This can be achieved if governments, international donor agencies, pharmaceutical companies, non-governmental organizations, and communities join efforts.

Harness international biotechnology research to the diseases of poverty

Targeted public and international support is needed to strengthen the incentives for research on the diseases of poverty—to equalize the 10/90 disequilibrium in global health research. Frontier research in health is skewed towards non-communicable diseases. So, African countries must undertake a major effort, in collaboration with the international community and non-governmental organizations, to push forward criteria for research priorities based not on private sector incentives but on the "public good" nature of health research. These criteria should reflect equity concerns—leading to research on diseases that account for the largest burden—rather than the demands of those who can pay (the industrial countries). On present estimates, such criteria would mean allocating at least $3 billion a year to research and development for the diseases of poverty (Global Forum for Health Research 2002).

Pharmaceutical and medical research is driven primarily by the expected return on investment, leaving little incentive for pharmaceutical companies to invest in research on the diseases of poverty because the poor do not create enough demand. So, one approach to increasing research on these diseases would be to identify ways of increasing Africa's effective demand for medical research and products. For example, African governments could provide incentives to speed the development of an HIV or AIDS vaccine by participating actively in and contributing effectively to international programmes that evaluate

Box 4.9

Access to treatment for all—the Brazilian experience

Donors should support the efforts of African countries to harness new technologies and health products to the diseases of poverty

A catastrophic forecast of HIV/AIDS infection rates in Brazil by a World Bank model in 1992 prompted a rapid reaction by the Brazilian government. The government enabled local firms, public and private, to produce antiretroviral (ARV) drugs and several of the particularly expensive drugs for fighting opportunistic infections. The result was drastically lower drug prices and, more important, a 50% reduction in the number of people dying of HIV/AIDS-related causes.

A key part of Brazil's fight against HIV/AIDS is the free distribution of ARV drugs, many manufactured by local companies. The government set up a pharmaceutical company, FarManguinhos, which researches generic versions of ARV and other HIV/AIDS drugs and manufactures the drugs using raw materials produced by other companies.

This arrangement brought an angry response from large pharmaceutical companies, which accused the Brazilian government of violating the World Trade Organization (WTO) Agreement on Trade-Related Aspects of Intellectual Property Rights (TRIPS). But the government responded that its actions, backed by a national law, were fully consistent with the TRIPS Agreement, which allows compulsory licensing of a patent without the authorization of the patent holder in cases of national emergency or extreme urgency or to correct anticompetitive behaviour. The TRIPS Agreement also stipulates that patents may be used in this way only if efforts to obtain authorization from the patent holder on reasonable commercial terms fail. This was the case for Brazil.

Brazil's HIV/AIDS programme spends about $300 million a year to purchase 12 HIV/AIDS drugs, 8 of which are produced by the local pharmaceutical industry. At the end of 2001 nearly 105,000 Brazilians were receiving ARV treatment thanks to the programme. Indeed, half the patients in developing countries with access to ARV treatment are in Brazil.

Pharmaceutical companies continued to lobby against the production of generic versions of HIV/AIDS drugs and for protection of their monopoly. But compelled by the HIV/AIDS crisis, Brazil and other developing countries argued that generics must be produced—and that no poor country should suffer "economic blackmail" or face the threat of litigation nationally or before the WTO. That argument won the day at the WTO meeting in Doha, Qatar, in November 2001. As a result governments attempting to apply bilateral trade sanctions or pressure poor countries seeking to promote access to HIV/AIDS drugs will expose themselves to the condemnation of WTO member states and the rest of the international community.

Source: *UNAIDS 2002b.*

candidate vaccines. By doing so, they would ensure that their citizens will get these vaccines—if and when they become available—at affordable prices.

Donors should support the efforts of African countries to harness new technologies and health products to the diseases of poverty. They can fund collaborative research between industrial and developing countries, contribute to global initiatives, and support African countries in their negotiations with multinational pharmaceutical firms. They can also maintain research guidelines and ethics to ensure that human trials of potential new drugs are not carried out on Africans without due consent.

Box 4.10
Global initiatives to fight the diseases of poverty

- *The Global Fund to Fight AIDS, Tuberculosis, and Malaria* was established by an alliance of private donors, non-governmental organizations, foundations, national governments, and intergovernmental organizations. The fund's mission is to attract, manage, and disburse additional resources for reducing the impact of HIV/AIDS, tuberculosis, and malaria in countries in need. Industrial and developing countries, corporations, foundations, and individuals have pledged some $1.9 billion to the fund, which awarded its first round of grants in April 2002 (http://www.globalfundatm.org/html).
- *UNAIDS*, the Joint United Nations Programme on HIV/AIDS, is the leading advocate for worldwide action against HIV/AIDS. It leads, strengthens, and supports an expanded response to the epidemic to prevent the spread of HIV, provide care and support for those infected and affected by the disease, reduce the vulnerability of individuals and communities to HIV/AIDS, and alleviate the socio-economic and human impact of the epidemic (http://www.unaids.org).
- The *International AIDS Vaccine Initiative* works to speed the development and distribution of AIDS vaccines, particularly those that could be used in developing countries. It focuses on mobilizing support through advocacy and education, accelerating scientific progress, encouraging industrial participation in AIDS vaccine development, and ensuring global access (http://www.iavi.org).
- The *Global Partnership to Roll Back Malaria* was jointly founded by the World Health Organization, United Nations Children's Fund, World Bank, and United Nations Development Programme in 1998 with the objective of halving the malaria burden worldwide by 2010 (http://www.rbm.who.int/).
- The *Medicines for Malaria Venture* aims to discover, develop, and commercialize antimalaria drugs at prices affordable to the populations most affected by the disease, at a rate of one new product every five years (http://www.mmv.org).
- The *Malaria Vaccine Initiative* works to accelerate the clinical development of malaria vaccine candidates, identifying the most promising vaccines and technologies and implementing targeted partnerships with scientists and development projects (http://www.malariavaccine.org).
- The *Multilateral Initiative on Malaria in Africa* works to strengthen and sustain, through collaborative research and training, the capability of malaria-endemic countries in Africa to carry out the research needed to develop and improve tools for malaria control.
- The *Global Alliance for TB Drug Development* works to accelerate the discovery and development of cost-effective, affordable drugs that will shorten or simplify treatment for tuberculosis—and to provide more effective treatment of multi-drug-resistant tuberculosis.
- The *Stop TB Partnership* works to protect vulnerable populations from tuberculosis and its multi-drug-resistant strains. Its aim is to ensure that every person with tuberculosis has all the necessary information and access to treatment and cure. It recently launched the Global Plan to Stop TB (http://www.stoptb.org/home.html).
- The *Global Alliance for Vaccines and Immunizations* and its financing arm, the *Global Fund for Children's Vaccines*, focus on purchasing new vaccines for poor countries. They consider applications to fund new vaccines from countries with a population of less than 150 million and per capita GNP of less than $1,000.

Enhance public-private partnerships

Public-private partnerships need to be strengthened to pool resources and increase the bargaining power of developing countries. Greater bargaining power would be particularly useful in the WTO, where efforts should continue to seek relaxation of WTO rules on licensing.

There has been a demonstrable increase in the number of public-private partnerships dedicated to the fight against AIDS, malaria, and tuberculosis

Governments also need to develop new models of collaboration with the private sector—domestic and international. The private sector—indeed, all stakeholders—should be involved in determining the future of disease-specific research, the technologies to be adopted, and the nature of incentives to be provided. Public-private partnerships would be particularly useful when governments enter bulk purchase arrangements with pharmaceutical companies and other suppliers. Such partnerships would strengthen the bargaining power of the governments and enable them to exploit economies of scale.

At the urging of the United Nations, there has been a demonstrable increase in the number of public-private partnerships dedicated to the fight against AIDS, malaria, and tuberculosis (box 4.10). The UN General Assembly, in its special session on HIV/AIDS in June 2001, committed leadership and financial resources. And it established the Global Fund to Fight AIDS, Tuberculosis, and Malaria to bring additional resources to bear in countries in need through a new public-private partnership. Such partnerships aim to bolster collaborative efforts and encourage more efficient ways of scaling up resources. They also send a signal to the private sector that all countries are committed to fighting these diseases.

Conclusion

Biotechnology advances in health offer important opportunities to improve the health of Africans, offering much-improved diagnostic, treatment, preventive, and curative technologies. Given the scale of the HIV/AIDS, tuberculosis, and malaria pandemics and their enormous socio-economic costs, the exploration and early adoption of new treatments and technologies should be a priority. But biotechnology is not a panacea for Africa: its countries still need to develop the capacity to absorb these new technologies. Still, success stories abound—showing that despite resource constraints, some countries have managed to devise innovative approaches to adopting and using new technologies.

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Economic Commission for Africa

New and emerging technologies can yield a high payoff in catalyzing Africa's transition to sustainable development. Where effective, the new technologies can lower the incidence of disease, reduce food insecurity, and reduce vulnerability to environmental damage by allowing more flexible crop management systems.

These are some of the conclusions in *Harnessing Technologies for Sustainable Development*. The report also tracks the progress of African countries towards sustainable development. The indicators reveal sobering challenges—while some countries have made good progress, many have slipped down the rankings.

The Report identifies medical and agricultural biotechnologies as key missing ingredients often overlooked as a basis for sustainable development. These exciting new technologies range from genetically engineered mosquitoes that have the potential to eradicate malaria, to vitamin A enriched rice that can reduce blindness in children. And many more are on the horizon.

But the new technologies are no panacea or silver bullet. Producing them and spreading their benefits will not happen automatically. That will require critical analysis and planning—by regional and international organizations and governments, private sectors, and civil societies—to take full advantage of the technological revolution. It will also require coordinated actions and strategic partnerships in fostering first-rate intellectual public goods, including scientific research and public policy analysis, nationally and regionally.

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