FOSTERING BIOSCIENCE INNOVATION: LESSONS FROM BIO-EARN

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Synthesis Chapter of a Study on

INNOVATION SYSTEMS FOR BIOTECHNOLOGY IN KENYA, TANZANIA AND UGANDA

undertaken in the context of the BIO-EARN programme

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CONTENTS

ABSTRACT

This paper synthesises the findings of, and distils lessons from a study which has sought to illuminate the process of bioscience innovation in three East African countries: Kenya, Tanzania and Uganda. More specifically, we attempt to trace specific efforts to foster biotechnology innovations in those countries and to determine in what ways and to what extent the innovation system in place impinges on the final outcome of those innovations. The paper concludes with a set of policy recommendations that may enhance bioscience innovations in East Africa.

In all three countries covered by the study, science, technology and innovation are central to recent policy discussions and policy development. However, despite these policy objectives, current government expenditure on research is relatively low, and still very much dependent on external donor funding. Promising steps are made in setting up new institutions and national funding mechanisms to encourage research and innovation.

The study underpinning this paper has reviewed the national innovations systems in place in the three countries, conducted a survey of research institutions and analysed the trajectories of specific biotechnology innovations. These include, in the case of Kenya, biotic and abiotic stress tolerant sorghum varieties, and, cassava genetic improvement and clean seed production; in the case of Uganda, "epuripur" (sorghum) production and production of clean sweet potato planting materials; and, in the case of Tanzania, bioenergy from sisal waste and wastewater treatment through constructed wetlands. In terms of progress achieved in the innovation cycle, three of the cases (epuripur, bioenergy from sisal waste and constructed wetlands) have been successfully transferred from research, through product development to a final biotechnology innovation adopted by clients. In the other three cases, while strong advances have been made in collaborative research and in product development, the potential innovations are still in the testing / pilot phase. All cases point to the crucial role of an individual research scientist acting as "product champion", and close (though informal) linkages between the R&D organizations and technology customers.

There is no single, one-fits-all solution to successful technological innovation. Indeed, there may be a number of possible pathways to success. What is important in current and future bioscience programs is to identify demand for a specific technology, and to plot the essential links as early as possible in the research, development, dissemination process. The question of demand is crucial in making an assessment as to whether a particular innovation may have commercial prospects and can therefore be distributed in a market context, through commercial channels, or whether it has no immediate market prospects but, because it is considered important for environmental or social reasons (and therefore a "public good" technology) needs to be developed and disseminated in a non-market context, through public authorities, community groups, farmers' groups, or NGOs.

I. INTRODUCTION

This paper synthesises the findings of a study which has sought to illuminate the process of bioscience innovation in three East African countries: Kenya, Tanzania and Uganda. More specifically, it has attempted to trace specific efforts to foster biotechnology innovations in those countries and to determine in what ways and to what extent the innovation system in place impinges on the final outcome of those innovations.

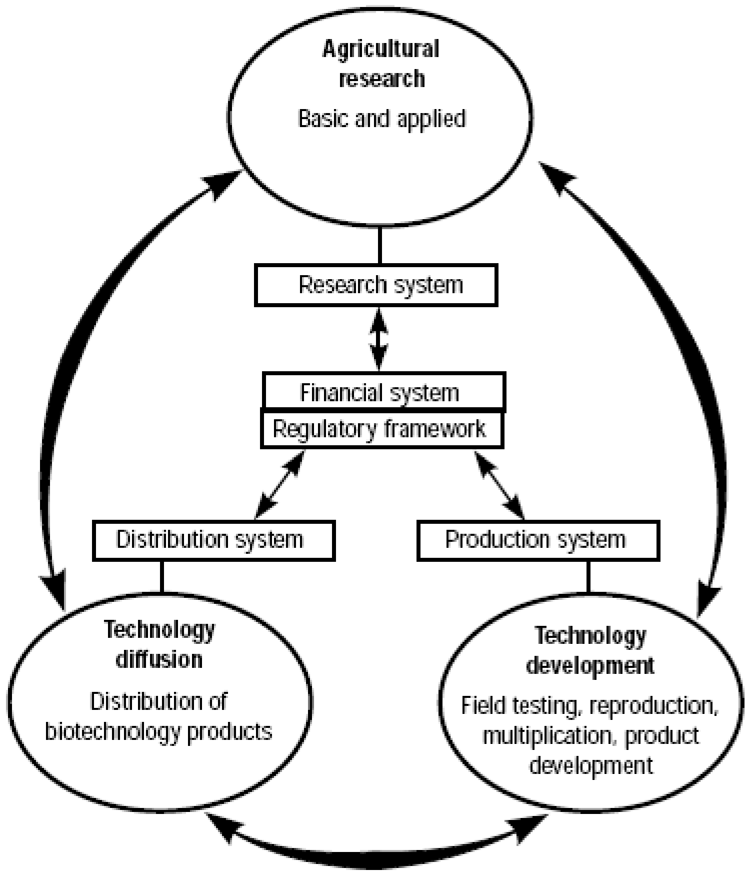
Supported by and focused in part on elements of the BIO-EARN[1] programme, the study reviewed the national innovations systems in place in the three countries, conducted a survey of research institutions and analysed the trajectories of specific biotechnology innovations. These include, in the case of Kenya, biotic and abiotic stress tolerant sorghum varieties and cassava genetic improvement and clean seed production: in the case of Uganda, *Epuripur* and sweet potato vines: and, in the case of Tanzania, bioenergy from sisal waste and constructed wetlands. Thus, the case studies relate to both environmental/industrial and agricultural biotechnology innovations.

For the purposes of this study, an innovation is conceived as knowledge produced formally through research and development and knowledge which may originate from informal and indigenous sources, combined to produce value. The value created is realised through the introduction of a new product (a good or a service) to the market, the introduction of a new process that produces products for the market, or delivers them; the use of new organizational structures or business practices; or the development of new markets, or the capturing of a greater share of existing markets. The concept of the innovation system is based on the premise that the flow of information, knowledge and technology among people, institutions and enterprises is key to the innovative process. It encompasses the interaction (or links) between the different actors who are needed in order to turn an idea or successful research results into a process, product or service which has economic value (Brenner, 1997). These interactions are schematically presented in Figure 1 below; while specifically focused on agricultural biotechnology innovations, this figure applies to other types of bioscience innovations as well.

This chapter attempts to distil overall lessons from the country studies contributed by Kenya, Tanzania and Uganda. In Section II the national innovation frameworks are reviewed as they relate to policies, institutions and financial and human resources. In Section III the case studies are briefly presented followed by overall findings from these experiences. Finally, in Section IV, conclusions are drawn, recommendations made and implications outlined for future bioscience innovation initiatives.

[1] BIO-EARN: Eastern Africa Regional Programme and Research Network for Biotechnology, Biosafety and Biotechnology Policy Development. URL: www.bio-earn.org

Figure 1. Biotechnology in a National System of Innovation



Source: Brenner, C. 1997. Biotechnology Policy for Developing Country Agriculture. Policy Brief No.14. Paris: OECD Development Centre.

II. BIOSCIENCE INNOVATION FRAMEWORKS: POLICIES, INSTITUTIONS, RESOURCES

With growing acknowledgment of the strategic importance of science, technology and innovation in national economic development and in competitiveness, innovation is currently at the forefront of policy preoccupations in all three countries.

Kenya has a National Science and Technology Act (1977) and is in the process to draft a science, technology and innovation (STI) policy which proposes, *inter alia*, the creation of science and technology parks. Reorganisation of the National Council for Science and Technology is also planned, as is the creation of two new institutions, a National Science Foundation and a National Innovation Agency. An Innovation Fund, established in 2006, disbursed funding of 450 million Kenya shillings (approximately US$ 6.42 million) between 2007 and 2009. In parallel with the proposed institutional changes, indicators to evaluate research funding and national STI capacities are also being developed.

Within the broader national STI context, biotechnology has been targeted as a strategic priority. The National Biotechnology Development Policy (2006) provides a clear framework and vision for biotechnology application in Kenya, while the Biosafety Act of 2009 provides the framework for biotechnology regulations. The Act has established a National Biosafety Authority, which is now functional.

Tanzania is in the final stages of revising its STI policy, which commits government to promote innovations. In addition, a National Biotechnology Policy was passed in May 2009. This policy has a vision to develop a viable and competitive biotechnology industry in Tanzania. The Ministry of Communication, Science and Technology (MCST) is responsible for matter of science and technology, with the Commission of Science and Technology (COSTECH) as one of its semi-autonomous agencies. COSTECH is the secretariat of the National Biotechnology Advisory Committee (NBAC) which advises the government on matters relating to research and the safe application of biotechnology. Biosafety regulation is coordinated by the National Biosafety Committee under the Division of Environment in the Office of the Vice President.

In Uganda, a national S&T policy was first proposed in 1991. However, it was not until 2008 that the proposal was submitted and until August 2009 that the national STI policy was finally approved. The National Agricultural Research Policy was adopted in 2005. As in the other two countries, biotechnology has been targeted as a strategic area in Uganda and a National Biotechnology and Biosafety Policy was approved by government in April 2008. It is also anticipated that a National Biosafety Bill will be approved in the near future.

The Uganda National Council for Science and Technology (UNCST), a semi-autonomous agency under the aegis of the Ministry of Finance, Planning and Economic Development and the Parliamentary Committee on Science and Technology (PCS&T), established in 2003 to oversee matters of STI in Parliament, are the bodies responsible for STI governance.

Despite recent stated policy objectives, current government expenditure on research is relatively low in the three countries. Comparative data on R&D expenditures are scarce, but a number of initiatives are under way to remedy that situation. For example, the NEPAD African Science Technology & Innovation Indicators Initiative (ASTII) initiative is currently under way to develop comparative STI indicators for 19 countries, including Kenya, Tanzania and Uganda. The ASTII data will be collected and stored by the African Observatory for Science, Technology and Innovation, which is being set up in Equatorial Guinea by the African Union.

Compared with levels in industrialised countries, expenditure on R&D is currently low in the three countries. For example, between 1995 and 2004, expenditure was as low as <0.1 per cent of its gross domestic product (GDP) in Tanzania. Of this, 14 per cent was contributed by government, 51 per cent by foreign sources, 31 per cent from income generation and 4 per cent by local donors. Recently the Tanzanian government has announced its intention of increasing R&D expenditures to 1 per cent of GDP.

In Uganda, total expenditure on R&D as a percentage of GDP averaged 0.3 per cent between 2003/04 and 2007/8. This is low compared with between 0.8 and 1 per cent in South Africa and 4 per cent in Sweden.

New financing mechanisms for stimulating innovation are, however, emerging. In Kenya, the ministries of Higher Education, Science and Technology (MoHEST) and the Ministry of Agriculture (MoA) have both had innovation funds operating since 2007. In Uganda, the government's Millennium Science Initiative (MSI), co-financed by the government and the World Bank, is implemented by the UNCST. By the end of 2008, a total of 27 competitive grants had been awarded, the largest being US$0.8 million for a period of three years, and US$1.25 million for creating new and/or upgrading undergraduate science and engineering degree programmes.

There is limited data available on private sector investment in R&D in the three countries but it is generally accepted that it is even less than public sector investment.

Similarly, limited comparative quantitative data is available on both the human and financial resources devoted to science in general and biotechnology in particular in the three countries. The country studies have, however, contributed valuable data on the scientific capacities of the major institutions conducting biotechnology research. These are presented in the individual country study reports.

A large share of funding for biotechnology research is contributed by external sources in all three countries. With respect to the BIO-EARN supported activities which are the subject of this study, funding has been provided since 1998 by the Swedish International Development Agency (SIDA). Other bilateral donor organisations contributing to biotechnology research in Kenya, Tanzania and Uganda include USAID, DFID (UK), DANIDA and GTZ. The European Union, the World Bank, the Rockefeller Foundation, the Bill & Melinda Gates Foundation and AATF[2] are among the growing number of organisations which provide financial contributions. ASARECA[3] is a regional organisations concerned with STI in general and agricultural biotechnology in particular.

[2] AATF: African Agricultural Technology Foundation
[3] ASARECA: Association for Agricultural Research in East and Central Africa

III. CASE STUDIES

Two case studies were selected for analysis from each country. They include:

Case 1.Kenya: biotic and abiotic stress tolerant sorghum varieties
Case 2.Kenya: cassava genetic improvement and clean seed production

Case 3.Uganda: *Epuripur:* production of sweet sorghum for brewing industries
Case 4.Uganda: micropropagation of virus-free sweet potato

Case 5.Tanzania:bioenergy from sisal waste
Case 6.Tanzania:constructed wetlands for wastewater treatment

The cases thus include not only agricultural biotechnology, but also environmental and industrial biotechnology, which was a unique feature of the 10-year BIO-EARN programme.

As the case studies are analysed and presented in detail in individual country studies, this chapter focuses on synthesizing overall lessons.

III.a Overall findings from case studies

It is useful to keep in mind that, in four of the six cases, research has been supported under the BIO-EARN programme for the past 10 years.

In terms of overall progress and the "distance" achieved in the innovation cycle, three of the cases (*epuripur*, bioenergy from sisal waste and constructed wetlands) have been successfully transferred from research, through product development to a final biotechnology innovation. In the other three cases, while advances have been made in collaborative research and in product development, the potential innovations have not yet been disseminated.

Case 1: Biotic and abiotic stress tolerant sorghum varieties

Research efforts to develop biotic and abiotic stress tolerant sorghum varieties have been underway since the third phase of the BIO-EARN programme was initiated in 2005, with 10 institutions in 5 different countries (4 African + Sweden) collaborating in the research. Moi University in Kenya is the lead institution. Multiplication of material is conducted both at Moi University and at KARI centres at Kibos and Kiboko, as well as in farmers' fields, managed under a Memorandum of Understanding (MoU) between Moi University and KARI.

Despite interest expressed by the agrochemical industry for the extraction of juice from sweet sorghum varieties for brewing, this innovation has yet not moved beyond the research and product development phase. The project has been running for three years and therefore needs more time to complete the cycle from the laboratory to performance trials and commercialisation. Delays in project execution were, among other things, caused by procurement issues.

Case 2: Cassava genetic improvement and clean seed production

It is stated that “a model for production and delivery of virus free planting materials has been proposed but is yet to be piloted on station”. A quality management protocol (QMP) has also been developed for use by the multipliers and plant health inspectors. In all four countries involved in this project, a clean seed delivery system has also been developed in collaboration with national agriculture research systems, farmers and private sector.

Case 3: Epuripur: sweet sorghum for breweries

The case of *Epuripur* was not in any way supported by the BIO-EARN programme. Originally, the initiative came from a private company, Nile Breweries Uganda Limited (NBL), which sought to replace imported barley with local material in brewing its lager beer. This led to a relationship between NBL and a public research institution, the National Semi Arid Resources Research Institute (NaSARRI), whereby NaSARRI supplied NBL with six sorghum lines it had developed, one of which was *Epuripur*, found to be eminently suitable for NBL’s purposes, with acceptable limits of fat, protein and starch, less tannins, and no fungal contamination.

The relationship between NBL and NSARRI did not endure, however, which was regrettable given that NSARRI, apart from distributing seed (free to farmers at the time), ensured good agronomic practices, pest control and clean seed. NBL subsequently engaged a seed company, AFRO-KAI Uganda Limited, as its agent to distribute seed to farmers, buy *Epuripur* from farmers and supply NBL. AFRO-KAI’s role, unlike that of NaSARRI, was a purely commercial one.

Case 4: Virus-free sweet potato vines

In this instance, the role of an individual scientist has been the essential driving force in efforts to develop and disseminate the innovation. The objective was to establish a propagation and distribution system for the clean sweet potato materials to farmers. This was in any event a complicated undertaking. First, the virus was to be eliminated through various *in vitro* techniques. Second, virus-free materials were to be micropropagated using tissue culture techniques. Third, nucleus seed was to be produced on farm. Fourth, and finally, clean seed was to be distributed to farmers.

An informal partnership was established between the Makerere University Agricultural Research Institute at Kabanyolo (MUARIK), a field station of the Department of Crop Science, and a private company, AgroGenetics Technologies Limited (AGT) as it was envisaged that AGT would multiply and distribute the clean sweetpotato materials to farmers. However, as the research progressed, it was realised that sweet potato is a bulky crop and that large areas of land would be required to grow and propagate the planting materials. Moreover, sweetpotato is a low value commodity and so cost recovery was not assured. As a consequence, AGT became reluctant to participate actively in the project and an effective distribution system has therefore not yet been set up.

Case 5: Bioenergy from sisal waste

The case study of bioenergy from sisal waste is also a case where the initiative stems from a local private company, Katani Limited, which owns 10 sisal decorticating factories in five sisal estates acquired in 1998 following the privatisation of the former parastatal, the Tanzania Sisal Authority.

In 2001 Katani Ltd initiated a project known as "Cleaner integral utilization of sisal waste for biogas production and bio-fertilizer" after examining results from research on anerobic digestion undertaken from 1992 by the Department of Molecular Biotechnology and Biotechnology (DMBB) atthe University of Dar es Salaam (UDSM), the Centre for Agricultural Mechnization and Rural Technology (CAMARTEC) in Arusha and the Danish Technological Institute in Denmark. This project was implemented following visits to China which provided opportunities to become familiar with large-scale biogas plants, gasification and mini-hydro power plants. Officials from the Tanzania Sisal Board and employees of Katani Ltd underwent biogas training at the Biogas Research Training Centre in China. Chinese and German engineers were contracted to construct, in cooperation with local company engineers, the biogas plant at Hale – Tanga, which was launched by the President of Tanzania in August 2008. The Katani bio-energy plant produces electricity which is sold to the Tanzania Electricity Supply Company to be fed into the national grid.

If Katani is to increase sisal fiber production and bio-energy production it is estimated that some 24 million sisal plantlets will be required, compared to the current capacity of 600,000 plantlets. The Agricultural Research Institute (ARI) at Mlingano, Tanga, currently produces clean and improved plantlets for sisal growers using tissue culture for meristemic propagation. However, the figure of 24 million plantlets totally outweighs the overall capacity of ARI Mlingano. Without substantial increases in its capacity, an appreciable increase in bio-energy production from sisal waste is therefore not assured.

In the meantime, DMBB continues its research on the enhancement of anaerobic digestion, but its research results have not yet been carried further in the innovation process.

Case 6: Constructed wetlands for wastewater treatment

The constructed wetlands technological innovation has been developed by the Department of Chemical and Process Engineering (DCPE) at the College of Engineering and Technology, University of Dar es Salaam, in its research efforts to solve problems of urban domestic and industrial waste water disposal in a more affordable and environmentally friendly way.

The Department was able to finance product development in the form of a pilot plant through a grant from the BIO-EARN Innovation Fund. Subsequently, the innovation has been successfully diffused for waste water treatment in one school, one college, four municipalities and four prisons in Tanzania.

UDSM is currently implementing a project aimed at imparting the skills of construction of the CWs for waste water treatment in other parts of Tanzania and beyond the borders into Uganda, Kenya and Madagascar.

In this case, much of the successful dissemination of the innovation has been due to the efforts of a product “champion”, the principal researcher. No IPRs have been taken out on the technology, however, and neither the university nor the champion have benefited financially from its success.

III.b Case-study analysis

Of the 6 cases analysed, three have successfully completed the innovation cycle in the sense that successful research results have led to the development and diffusion of a specific innovation. The other three have not yet completed the innovation cycle but have, as a result of successful collaborative research effort, reached the product development stage.

Of the three success stories, one, *Epuripur*, was developed in response to clear demand on the part of a private brewing company. In the case of bioenergy from sisal waste, Katani was stimulated to pursue development of the utilization of sisal waste for biogas production by encouraging research results (produced, *inter alia*, by UDSM) and by the support of the Tanzania Sisal Board. The other environmental innovation, constructed wetlands, has been developed and successfully transferred to final users not as the result of perceived economic demand, but as the result of the perceived need to alleviate environmental pollution. It can therefore be termed a “public good” technology and, as such, has not been transferred through market mechanisms.

It is striking to note that, except in the case of *Epuripur*, no mention is made and, apparently, no effort has so been made to assess development and/or dissemination costs of the proposed innovations. It would seem important, particularly in circumstances where farmers are not in the habit of purchasing seed or planting material, at least to have an estimation of what these costs might be. Similarly, it would seem important to be able to provide reasonably accurate figures regarding the costs of constructing wetlands.

The question of **demand** is crucial in making an assessment as to whether a particular innovation may have commercial prospects and can therefore be distributed in a market context, through commercial channels, or whether it has no immediate market prospects but, because it is considered important for environmental or social reasons (and therefore a “public good” technology) needs to be developed and disseminated in a non-market context, through public authorities, community groups, farmers’ groups, or NGOs. Whether an innovation is distributed in a market or non-market context, costs are in any event involved and the costs will need to be met one way or another. Without an early assessment of market prospects, which would include an effort to estimate such costs, obstacles are likely to occur in moving beyond research.

One apparent shortcoming in the cases of the innovations which are still at the product development phase is that insufficient effort was made in the original design of the project to identify and plot the links in the innovation chain which would need to be connected to complete the process. Clearly, these links will differ according to the nature of the innovation, for example, whether an agricultural technology or an environmental technology. They will also differ according to whether or not it is anticipated the innovation will be developed and diffused within a market or a non-market context.

Not only is it important to identify potential and necessary partners, it is also important that the roles of the different partners involved in the innovation process be clearly defined and their roles and responsibilities clearly understood and agreed. This will avoid misunderstanding or disappointment.

Public research institutions are often ill-equipped to move an innovation beyond research. This applies in particular to the universities whose original vocation was confined exclusively to research and training. That vocation remains, but universities are now under growing pressure to deliver tangible products from research results. In contrast, the vocation of the public agricultural research organisations was, from their establishment, applied research with emphasis on agricultural innovation. For that reason, there is an established tradition of links with other public institutions such as experimental stations, phytosanitary authorities, seeds certification agencies, extension services. When it comes to environmental/ industrial innovations, where there is no such tradition, the links may be less obvious.

Certainly in the past, when budgets have been fixed and allocated they have focussed essentially on research and allocations for product development have been neglected. Particularly if it is envisaged that an innovation will be developed and disseminated in a market context and therefore by a private company, it is important to be able to demonstrate the relevance and economic viability of a given technology. This implies, in addition to scientific evidence, a minimum of economic and/or marketing analysis.

In the case studies analysed, both the research institutions themselves and the scientists who have been instrumental not only in generating successful research outcomes but have also played an active role in promoting the development of innovations stemming from their research, have not been financially rewarded in the course of the dissemination of their innovations. In the case of the constructed wetlands innovation, the innovation "champion" presumably has the moral satisfaction of seeing the innovation installed in a number of sites.

It is not obvious whether the public research institutions reap rewards from their successful research outcomes, particularly with respect to "public good" technologies. For example, in the case of the constructed wetlands technology, the participating universities have no framework to license technologies. In any event, the public research institutions are confronted with the need to decide to what extent it is appropriate to become involved in product development and diffusion, and what, if any, institutional mechanism would be appropriate for that purpose. Some public research institutions have established technology transfer offices or created commercial units for the purpose of seeking appropriate partners and fostering product development and diffusion. This is the case with Moi University and the University of Nairobi in Kenya, and the University of Dar es Salaam in Tanzania. What is important is that the research institutions devise institutional strategies to ensure that successful research outcomes can be further developed. An institutional IPR policy would be an important aspect of any such strategy.

The case studies suggest that perceptions of the time-frames required to translate successful research results into an innovation have been over-optimistic. And in some instances, it is not possible to accelerate the time required. For instance, while plant-breeding can be accelerated by marker-assisted selection, the time taken for small- and large-scale field-testing, to produce and multiply seed and for the seed certification process, usually carried out by public bodies, cannot be shortened.

In the case of environmental/industrial technology, the setting up of a pilot plant can be a lengthy operation as can the period required to demonstrate its effectiveness to potential customers.

While innovation may be a long-term process, public funding is generally short-term. This is certainly the case with respect to the bilateral aid agencies. It is unrealistic to expect that much of what can be a lengthy and tortuous innovation process is likely to be achieved within a three-year period, which is often the period for which funds are allocated, unless plans have been carefully laid, with all the necessary links in place and connected.

One of the problems posed by the relative importance of short-term, external funding is that it obviates the need for the public research institutions and their scientists to elaborate a longer-term, more strategic research strategy and agenda, clearly linked to sectoral or national priorities.

In the case studies analysed, the relationship between the national innovation environment (in terms of policies, institutions and resources) and innovation outcomes is not obvious. In the case of bioenergy from sisal waste, Katani has benefited – and indeed continues to benefit – from the support of the Tanzania Sisal Board which fulfils a promotion role at trade fairs, etc. The country's electricity Act of 2008 allows private generation of electricity and sell to the national grid. Prices of such sales are determined by the Tanzania Energy and Water Utility Regulatory Authority for small energy providers. However, the extent to which it has benefited from specific innovation policy initiatives is not clear. Similarly, in the case of constructed wetlands, personal initiatives from researchers have encouraged clients to install the innovation, rather than specific policy initiatives.

Whether or not the public research institutions profit financially from successful research effort, and whether or not the scientists within those institutions are rewarded, it is important that the achievements of the scientific community and the scientific capabilities embedded within the public research system be made known to policy-makers, as well as to local entrepreneurs.

IV. CONCLUSIONS, POLICY RECOMMENDATIONS AND IMPLICATIONS FOR FUTURE BIOSCIENCE INITIATIVES

IV.a Conclusions

This study has been conducted at a time of transition, when innovation is at the centre of policy preoccupations in an increasing number of African countries and, more specifically, in the three countries which have contributed. At the same time, it has to be acknowledged that it has been conducted at a time when African markets for technological innovation, with the exception of South Africa, are still relatively undeveloped. The challenge is then, in the light of the BIO-EARN and other experiences, to reflect on ways in which innovation can best be fostered.

Innovation is a complex process and the path to success is a function of policies institutions, financial and human resources. The key to success lies in forging the links among key actors at the appropriate time in the innovation cycle and, more particularly, in the life of the innovation in question. And these links will differ according to the type of technological innovation (agricultural, environmental, and industrial) and according to whether the innovation will be disseminated through commercial (market) or, as in the case of "public good" technologies, non-market channels.

Whatever the channels, and whether disseminated through commercial channels or as a "public good" innovation , there are indispensable phases in the innovation process if it originates with research, that is, research, development and diffusion (or final transfer). Ideally, the final consumers of an innovation be they farmers, individual consumers, public or private organisations, will become an integral part of the innovation cycle, providing feedback into research so that the innovation process becomes a virtuous circle.

If the innovation process is complex, it is also time-consuming. Research can be a lengthy process, spanning several years, but research is often the shortest part of the research, product development and diffusion cycle. This time frame, particularly the research and product development components, is often under-estimated, creating unrealistic expectations and giving rise to unsubstantiated claims.

The question of **demand** for a given innovation is often either ignored or neglected in the design of research project proposals, as is the consequent need to decide whether market or non-market avenues will be appropriate for technology development and diffusion.

There is no single, one-fits-all solution to successful technological innovation. Indeed, there may be a number of possible pathways to success. What is important is to identify and to plot the essential links as early as possible in the research, development, dissemination process.

The current heavy reliance on external funding has both positive and negative implications. Even though the funding is inevitably short-term, it enables scientists to continue to work on research which would otherwise not be funded through national sources, exposes them to international collaboration and enables them to keep in touch with the state-of-the art in their particular fields. At the same time, it creates a situation where scientists may be competing rather than collaborating within a given institution, and where the external funding may insulate the institution from facing the realities of a changing national environment where, increasingly, public research institutions are expected, if not to be self-sufficient, at least to generate some income.

The new emphasis on the importance of STI and government initiatives taken in that direction point to an evolving, more prominent role for public research institutions, where they would need to be more outward-looking, more competitive, and engage more with policy-makers. This enhanced role would also imply innovative partnering (with the private sector, farmers' organisations, CBOs, as relevant) and a more strategic, longer-term research agenda.

IV.b Policy recommendations

It is unlikely that, in the short term, major changes can be anticipated in the current pattern of investment in research. While governments may have announced plans to increase research expenditures, these intentions have not been paralleled by major new incentives to stimulate private sector investment in research. While the preponderance of public and donor funding continues, more innovative approaches are required for "public good" innovations. This would imply, first and foremost, a greater concentration of effort on forging links between the public research institutions and other public and private actors who might play the role of "technology brokers" or "intermediaries". It would also imply greater efforts to exploit opportunities for complementarities among a growing number of private non-profit or philanthropic actors.

At present, funding remains concentrated in the research phase of the innovation cycle, with inadequate provision made for product development. Particularly in the case of "public good" technologies, funding may be required not only for product development, but also for initial dissemination through non-market channels and should therefore be more evenly distributed throughout the innovation cycle. Dissemination through non-market channels also provides opportunities for a "demonstration effect" which in turn stimulates demand and enhances opportunities for the creation of *local* enterprises.

Research funding depends heavily at present on external funding, by bilateral and multilateral donors and philanthropic foundations. To correct this bias, it would be necessary for governments either to increase their own funding or, alternatively or in parallel, to provide incentives for private investment in research. At the same time, it would be necessary to provide incentives to stimulate the development of technology markets and, in particular, the creation of *local* enterprises. These might include: the provision of matching funds for product development, innovation funds, "bridging finance" mechanisms, and the provision of micro-credit in support of local entrepreneurs and local farmers, particularly when they may be purchasing improved seed or planting material for the first time.

Dependence on external funding, as suggested earlier, can be a double-edged sword in the sense of enabling researchers to pursue personal interests which may be at variance with national research priorities. Similarly, donor priorities may differ from national priorities. One way of minimising inherent conflict would be for governments to provide clear policies and guidance with respect to national R&D priorities and strategies.

In this transitional period, when governments are designing policies in support of STI but when public funding for research is only one of many urgent priorities and when there is as yet little private funding, the public research institutions have a crucial role to play. That role would imply a change of mind-set, a need to be more outward-looking, to form innovative partnerships and to seek opportunities to generate income and enhance their independence. It would imply more open research and innovation teams in the sense of promoting interdisciplinarity, encompassing not only science, but also economics, marketing and policy.

Finally, it would also imply the need to play an active role in communicating with decision-makers to enhance awareness of the capacities of the local scientific community and, at the same time, to elicit support for that community.

During its lifetime, the BIO-EARN programme has played a significant role in this regard. It has also been instrumental in facilitating policy developments relating to biotechnology and biosafety.

The regional dimension of research and innovation programmes such as BIO-EARN adds complexity to the innovation process and its policy environment. It raises the question of the prospects for **regional** policies, **regional** harmonization of regulations, **regional** procurement, and **regional** markets.

IV.c Implications for future bioscience initiatives

The foregoing suggests some important implications for the design and implementation of the future bioscience initiatives, including the newly established Bio-Innovate programme that will partially succeed the BIO-EARN programme. These include:

- The need to think beyond science and scientific enquiry in project design and to take into account the question of **demand** in both an economic and social sense. This is essential to be able to make realistic assumptions regarding the prospects of translating research into an innovation in the farmer’s field or in the hands of end-users and to plot realistic innovation pathways.

- The need for disciplines other than science in project teams. African scientists and public research institutions in African countries do not in general benefit from the well-established infrastructure and innovation environment which characterises similar institutions in industrialised countries. As emphasized earlier, technology markets in most African countries are still relatively undeveloped. It is all the more important, therefore, that they are able to add economic, market and/or social perspectives to their research efforts if they are intended to result in a technological innovation

- Whether or not it is envisaged that research will lead to an innovation to be developed and disseminated in a market or non-market context, funds will be required for product development. Provision should therefore be made to allocate adequate funds to product development and/or to facilitate the innovation process.

- The BIO-EARN programme was unique in that it had a policy component. Lessons from the BIO-EARN experience strongly suggest that, rather than be designed as a separate component within a scientific programme, it would be more effective for policy issues to be included as an integral part of individual projects.