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# ENERGY AND THE ENVIRONMENT

## INTRODUCTION

This issue of the UNU/INTECH Technology Policy Brief series focuses on energy and the environment. The articles explore the nexus of energy and the environment by analysing the effects of distinct types of pollutants, global warming, and current international and national rules in dealing with them. The roles of energy in alleviating poverty and concerns with institutional restructuring of the energy system within the context of liberalisation complete this issue.

*A. P. Mitra* (page 2) provides a valuable and compelling analysis of the environmental and health impact of three distinct categories of pollutants with implications for the Kyoto Protocol. He reports on the substantial concentration of the sunlight-absorbing haze over the Indian Ocean. The article also provides empirical confirmation of the transnational impact of climate warming. The sources of the pollutants are not different, deriving largely from fossil fuels with coal as the most important source of carbon dioxide emission. The relative distribution of emissions from the fossil fuels burning therefore constitutes an important concern for policy.

*A. Brew-Hammond* (page 4) uses a rural energy project, the multi-functional platform (MFP), to illustrate the ways in which sustainable livelihood could be built among the very poor in Africa. Poverty reduction and environmental sustainability provide bases for promoting the project. This requires an environment for adopting such projects and mainstreaming them in policy-making. At the regional level, the New Partnership for Africa's Development (NEPAD) as well as the global Millenium Development Goals (MDGs) set great store on poverty alleviation in a sustainable manner. Women who bear the brunt of poverty among the rural poor need special support.

*J. Adeoti* (page 7) surveys alternative but largely untapped energy forms in Africa such as wind, solar, and biomass (e.g. wood) including their differential environmental impacts on the environment. The low energy use and the poor state of African infrastructure could be remedied through partnership and international co-operation, and increased investment in the energy sector. He suggests that countries promote policies that enable industrial firms to benefit from global environmental funding mechanisms.

*A. T. Furtado* (page 10) reviews on-going liberalisation and the accompanying institutional changes in the Brazilian energy sector to stem the decline of research and development (R&D) expenditure. His article highlights implications for the national systems of developing countries. He observed that R&D declined in areas with the most profound reform efforts. Where national oil companies carry out the most innovations, reform could predictably affect innovation in very significant ways. In Brazil, institutional change was conducted in anticipation of sharp drops in R&D expenditure. Interaction with actors within the national system, the universities, and collaborating firms was crucial, but commitment of the state to maintain R&D spending was equally important. Reforms in poorer countries often lead to a hollowing-out of the state with deep budget cuts that not only incapacitate institutions but destroy the limited extant technological capacity pre-reform.

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# ENERGY AND ENVIRONMENT: SCIENCE AND PUBLIC POLICY FOR SOUTH AND SOUTH-EAST ASIA

This article explores the policy implications of a recent study, the Indian Ocean Experiment (INDOEX). The study shows the presence of a huge sunlight-absorbing haze layer extending over some 10 million square kilometers across the Asian and the northern Indian Ocean region.[1] This international effort throws up new perspectives on pollutants such as aerosol. Aerosols are tiny particles, of about a millionth of a centimeter or smaller in diameter, that scatter sunlight back to space and cause a regional pooling effect. This paper raises new policy questions on the interface of air quality and global warming, the potential effects of Asian pollution in other regions, and emphasizes the gaps in existing protocols.

Two special aspects are notable: one, that the pollutants are of three distinct categories: the long-lived gases, the short-lived gases and the particulate materials of different sizes and composition, including climatically important soot carbon. These have increased rapidly, with growth rates in some cases 3-5 times larger than in most industrialised countries. However, emphasis has been on the long-lived gases. Second are the tools to predict impacts of regional pollution. Presumably, regional models, such as those under development for tropical monsoons, will be useful.

Besides INDOEX, there is the Asian Least-Cost Greenhouse Gas Abatement Strategy (ALGAS), a 2-year programme covering 11 countries in the Asian region: Bangladesh, China, India, Indonesia, Republic of Korea, Mongolia, Myanmar, Pakistan, Philippines, Thailand and Vietnam. These countries represent 51 per cent of the global population. The objective was to generate an inventory of long-lived greenhouse gases for the year 1990, following internationally-set guidelines, provide baseline projections for 2020, identify mitigation strategies, and define least-cost options. Three countries stand out for special attention: China, India, and Indonesia. China and India because together they contribute some 83 per cent of carbon dioxide emission and depend primarily on coal. Indonesia, because it is a major emitter of greenhouse gases from large-scale deforestation and extensive forest fires.

In addition to the primary objective of both programmes, we now have new information to underpin policy formulation on health hazards, food security, and water balance – three key areas of concern.

## The Indian Subcontinent

INDOEX coverage was limited to the Indian subcontinent and the surrounding ocean, which has a total land area of about 3 per cent of the world. The population in 1990 was 21.3 per cent of the global population and projected to reach 23.6 per cent in 2025. This is one of the most densely populated regions of the world with the present population density ranging between 100-500 persons /sq km. Forest degradation has been particularly serious in this region. Differences in rainfall rather than temperature define the climate regimes within the area. The summer monsoon accounts for 70-90 per cent of the annual rainfall over a major part of South Asia, while there is a large variability in the monsoon rainfall on both space and time scales.

There are several unusual aspects of the oceans surrounding the landmass that require attention. Apart from its dominant role on the unique monsoonal regime, the two arms of the northern Indian Ocean – the Arabian Sea and the Bay of Bengal – behave differently. These need differential treatments.

The third component of the Earth System – the atmosphere – also holds some unusual features. Although the total emission from this region is only 3 per cent of the global emission, its growth rate is high for most of the countries. Emissions from agricultural sources in terms of carbon dioxide equivalent are 50 per cent of emissions from energy and industry for India, 126 per cent for Bangladesh, 62 per cent for Pakistan and 325 per cent for Sri Lanka. For the subcontinent as a whole the ratio is 55 per cent. The INDOEX study confirms much of what we already know about the nexus of energy and the environmental pollution.

## Scenarios of Emissions

Table 1 provides the emission scenario for India, South Asia, and China in the context of global emission and emissions from the USA for the reference year 1990. We can see that until recently the emissions were substantially lower than in the USA and a small fraction of global emissions. Emissions from India and China, for example, were half that of the USA while the 1990 populations were about 10 times larger.

**Table 1: A Comparitive Scenario (tg/yr) for 1990**

| | $CO_2$ | $CH_4$ | $N_2O$ | $CO_2EQ$ | CO | $NO_x$ | $SO_2$ | EC | OC |
|---|---|---|---|---|---|---|---|---|---|
| Global | 26400 | 375* | 5.7* | 37050 | 1800 | 103 | 75 | 6.4 | 10.1 |
| India | 585 (2.2%) | 18.5 | 0.26 | 1005 -4.5 | 50-60 | 3 | 3.5 | 0.45 | 1.9 |
| South Asia* | 715 (2.7%) | 24 | 0.26 | 1278 | 70-100 | 4 | 3-5 | | |
| China | 1770 (6.7%) | 25-33 | 0.2-0.5 | 2440 | - | - | 22 | 1.46 | 2.23 |
| China+ India | 2355 (9%) | 47 | 0.62 | 3448 | | | 25-27 | | |
| USA | 4521 (17%) | 27 | 0.4 | | 83 | 21 | 22 | | |

Source: INDOEX International Project Office
* Excluding India

For South Asia, with one quarter of the world's population, the emission of $CO_2$ was less than 3 per cent. Per capita emissions show large inequalities while cumulative emissions for the last 50 years show even larger variations. High growth rates of emissions pose a definite danger. It is therefore unrealistic to formulate strategies for mitigation based on energy sources alone. The high emissions of aerosols – the main thrust of the INDOEX program – the very high rate of growth of these emissions, the dominance of black carbon and organic carbon, and the flow of pollutants across boundaries, constitute important factors.

## Policy Lessons for Developing Countries

Policy issues are complex because we are dealing with three distinct categories of pollutants: the long-lived category with global implications and of central concern for the Kyoto Protocol; the short-lived gases responsible for tropospheric ozone production; and finally the particulate material – the aerosols – which we now find can no longer be considered as local. For the second and third categories there is no international forum, nor has the Kyoto Protocol recognized their climatic effects. Also, the nature of INDOEX findings requires transnational treatment. In addition, the three categories are not totally independent – the sources are identical.

Several issues emerge. The first concerns the mechanisms and the need for national and international initiatives to address these new questions. The second issue involves the relative contributions from fossil fuel and biomass burning, particularly the relative roles of coal-fired power stations, diesel-driven trucks, and traditional biomass burning, and defines priorities for action. The third issue concerns the movement of large pollution plumes from one region to another, the so-called trans-boundary problem. The fourth relates to issues about new and additional impact effects arising from increasing aerosol loading, especially respiratory hazards, productivity loss from decreased sunlight, and changes in evaporation from ocean surface.

The Kyoto Protocol does not include the question of aerosol emissions or its mitigation strategies. Nor does it adequately include the short-lived gases, which are responsible for photochemical production of ozone and are thus contributors to the formation of smog. The Protocol does include three new gases which have long lifetimes and also very large global warming potentials. However, emission of these gases from developing countries is rather insignificant, therefore these countries have little interest.

The extensive nature of the aerosol haze suggests strongly the need for sensitising United Nations Framework Convention on Climate Change (UNFCCC) member countries of this additional hazard. The nature and sources of the aerosols influence the policy implications. Secondly, national communications from all countries, including those in the developing world, may include, on a voluntary basis, information on emissions of the short-lived gases and aerosols and national efforts to control these emissions.

Policy implications have to be different for the rural residential and urban industrial sectors. With low availability of commercial energy and an inadequate supply of energy for schools, hospitals, and roads, the low energy consumption is at the cost of human welfare. Policy approaches should keep this in view and have different pathways. One pathway is the gradual substitution of non-commercial energy (fuelwood cow dung, agricultural residues) by commercial energy. Another pathway is the increasing introduction of renewable energy sources.

In contrast, the problem of urban consumption and of power, steel, and industrial requirements can be primarily classified into two categories: problems which arise from the transport sector; and those which arise from coal, the latter being a key problem. Thus, coal along with transport and rural energy use (keeping in mind that here social welfare cannot continue to be a casualty) should form the core of policy initiatives.

Transport to long distances of pollutant plumes originating in this region bring in a new parameter: the question of trans-boundary pollutant transport. This is, however, not unique to the region. The trans-boundary aspect requires recognition of the regional nature of aerosols and regional agreements.

Reasons for climate changes are still not clear for a situation in which both scattering and absorption of radiation from aerosols are involved. It is thus strange that this critical factor at the moment is not included in the international framework convention.

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**Endnote**

1 This study, co-ordinated by the Center for Clouds, Chemistry and Climate, The National Science Foundation (NSF), and Science and Technology Center (STC), concentrated on aerosols covering the western part of the ALGAS region. In addition, there were measurements of carbon monoxide and nitrogen oxides and ozone. Information provided by the two studies are complementary. For details and full references, please contact the author.

# RURAL ENERGY POVERTY AND THE ENVIRONMENT: A CASE FOR BIOFUELED MULTI-FUNCTIONAL PLATFORMS

This article examines the role of energy in alleviating poverty in the context of two of the UN's Millennium Development Goals (MDGs). The first aims to eradicate extreme poverty and hunger (MDG1), while the other aims to ensure environmental sustainability (MDG7).

One objective of NEPAD is to increase access to reliable and affordable commercial energy supplies for productive activities. Specifically, under NEPAD's Infrastructure Initiative, the target is to achieve increased access to modern, affordable commercial energy supply from 10 per cent to 35 per cent or more of Africa's overall population.

The multi-functional platform (MFP) is a proven energy-based concept that could be a tool for achieving the NEPAD energy objective and the MDGs. This article suggests a framework for analysing energy-based poverty-reduction interventions in rural areas of the developing world. It then discusses experiences and impacts of the MFP approach and the efforts to ensure that the MFP addresses not only MDG1 but also MDG7. Policy issues and options are presented at the end.

## Conceptual Framework

Despite their central role in the food chain, women in rural areas of sub-Saharan Africa are at the bottom rung of the "energy ladder", while cleaner, more efficient fuels are associated with corresponding higher levels of income. They rely on traditional biomass – such as wood, plant residues and dung – as energy sources for cooking. This is equally so for motive force, mainly in food preparation (peeling, pounding, grinding, mashing) and in the extraction, transportation, and distribution of foodstuffs and traditional biomass fuels. They lack alternative resources such as animal power, or mechanical or electrical devices for energy transformations. These have important implications for survival and development, as food preparation is critical to agrarian societies relying largely on human and animal energy.

Poor women pay a disproportionately high price for inefficient energy services with associated health costs. Long hours spent collecting water and firewood for food and agro processing, to sustain rural livelihoods, deprive them of time for childcare, education, rest, social and cultural activities, and recreation. As water and traditional fuelwood sources become increasingly scarce, the costs in terms of women's time and energy become higher.

The rural energy poverty framework suggests that sustaining affordable energy services for the poor requires that such services be designed as directly productive and income generating. Near the surface of the rural energy poverty problem lie various manifestations of social deprivation that may be called "dirty" fuels, signifying non-renewable energy in the form of kerosene, other petroleum fuels, and harvested woodfuels.

Central to rural energy poverty is the use of human energy for a wide range of activities. Thus, interventions such as solar photovoltaic (PV) lighting programmes, providing electricity for lighting and entertainment, tend to scratch only the surface of the problem. Efforts to improve woodfuels supply, while important in improving productivity of labour, do not fully address what is widely acknowledged as the key issue, namely, the productive uses of energy and income generation to alleviate poverty.

## Experience of the MFP from Mali

The MFP consists of a source of energy provided by a diesel engine mounted on a chassis to which end-use equipment can be added, such as grinding mills, oil presses, battery chargers, and electric water pumps. The MFP is a community-based approach being implemented in four West African countries – Mali, Burkina Faso, Guinea, and Senegal – with support from the United Nations Development Programme (UNDP), the United Nations Industrial Development Organisation (UNIDO), and others since the early 1990s. Currently a MFP Shell Foundation Program is underway to support the development of private business models in Burkina Faso, as is a proposal for an expanded program, in 12 African countries, under the auspices of UNDP and UNIDO.

By June 2001 there were about 149 village MFPs installed, 862 rural women trained in functional literacy, and 98 rural artisans trained in various technical and income generation activities associated with the MFP project in Mali. More recent data suggests that the number of village MFPs installed in Mali has risen to 200.

## Impacts of MFPs

The MFP has been proven effective in helping the very poor who do not benefit from development initiatives (particularly energy). Reports on poverty-reduction impacts of MFPs show positive effects on women's energy and time, modern energy services, social relationships, entrepreneurship, education, nutrition, and health. The MFP concept is flexible enough to satisfy both the current and expanding energy needs of a village in the medium and long term. Access to MFP services is free for two to six hours per day for each woman, depending on the platform services. The MFP energy services lead to added income through associated enterprises that use energy services from the MFPs. Services provided include grinding, oil pressing, and battery charging.

While we still lack empirical evidence, experience from the limited research in West Africa suggests that the MFP is capable of breaking the energy and income poverty trap, which confronts women and girls more acutely, as well as men and boys in rural areas. Many rural folks now generate income for modern energy services to save time and relieve drudgery. The MFP is also being used as a decentralised rural energy source to generate electricity for water pumping and lighting, depending on energy choices and preferences, and what they can and are willing to pay for. Increased and diversified income for women and men arises from greater productivity in agro-processing and services like welding and battery charging. From our interviews we found that additional income is used to purchase food, and cover schooling costs, resulting in increased school enrolment, especially for girls, as the MFP substitutes for child labour.

## Jatropha-Fueled MFP Initiatives

The MFP program in West Africa aims to encourage the substitution of diesel fuel with jatropha oil, a biomass fuel derived from the seed of the Jatropha Curcas plant. By 2004, 15 per cent of the Malian platforms are to be run on jatropha oil; only one MFP currently does so. Malifolkecenter, an NGO based in Bamako, recently undertook a targeted intervention under UNEP's Sustainable Energy Advisory Facility (SEAF) resulting in two fully functional jatropha-fueled MFPs.

Jatropha curcas, a shrub originating from South America, is drought-resistant and grows in different parts of Africa. It is locally well-known and used as living hedges against wind erosion, for vegetable garden protection, and as livestock pens. Depending on the variety, most parts of the shrub can be used: the leaves as vegetables and for medicinal purposes, latex for medical use, the whole fruit as a combustible, and the whole seeds as pesticides. The most important by-products are oil and cake; the oil can be used as a medicine and vegetable fuel while the base is used for a very much-appreciated soap. The cake can also be used as organic matter against erosion and declining fertility in soils.

Research to evaluate jatropha oil as a fuel carried out in Mali in the late 1980s and early 1990s, supported by Gesellschaft für Technische Zusammenarbeit (GTZ) and UNDP, showed positive results. When the GTZ project was stopped, no major research was undertaken until Malifolkecenter showed renewed interest. Malifolkecenter has gone on with help from UNEP and UNEP Collaborating Centre on Energy and the Environment, based in Denmark, to adapt a press imported from Nepal, and now has a Malian press which is much cheaper than the original Nepali press.

## Policy Implications for Developing Countries

Poverty reduction is high up on the development agendas of sub-Saharan African countries. Gender imperatives are also clearly identified as key to reducing poverty and accelerating national development. What is required is a favourable policy environment for implementing the MFP concept – to tackle the challenge of the energy-poverty trap – across the region.

The results obtained so far, even for the diesel-fueled MFP, call for specific policy instruments like education and awareness raising, and fiscal incentives (explicit tax rebates for MFP enterprises, etc.) to facilitate the adoption of MFPs in rural areas. Further research, development and demonstration (RD&D), especially on jatropha oil use as fuel and other biomass resource use for different agro-climatic zones, should be explored. Other biomass resources include Oil Palm (Elaeis guineensis), Babassu Palm (Orbigniya speciosa), Coconut Palm (Cocos nucifera), Shear nut tree (Butryospermum parkii), Castor Oil Plant (Ricinus communics) and Neem Tree (Azadirachata indica).

The MFP has proved to be a formidable tool for rural transformation. It is imperative to mainstream the MFP approach into policy frameworks at regional, national, and local levels. The strategic focus for policy mainstreaming at the regional level is the achievement of the NEPAD energy objective. At the national level, the poverty reduction strategies require allocation of substantial sums of money for MFP project implementation. The establishment and integration of MFP enterprises into villages and local level initiatives will help to demonstrate the socio-economic benefits of reducing energy poverty and build capacity to sustain and replicate MFP initiative in rural areas.

## Conclusions and Recommendations

MFPs are enabling poor women and men to get out of the energy-poverty trap and gain access to affordable and sustainable modern energy services. This is in line with poverty reduction (and women empowerment) targets under MDGs, and the NEPAD objectives to increase access to low-cost, reliable commercial energy for productive activities. Nevertheless, diesel fuel use in MFPs is an obstacle for environmental management and sectoral programmes, which favour renewable energy technologies. Further work is needed to promote the use of environmentally sustainable biofuels in MFPs. Education and awareness raising, fiscal incentives and further RD&D will be required. Mainstreaming the MFP approach into policy frameworks at local, national, and regional levels will also be critical for the achievement of national poverty reduction strategies as well as the development goals and targets of the international community as reflected in NEPAD and the MDGs.

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# THE ENVIRONMENT AND UNEXPLORED TECHNOLOGICAL OPTIONS FOR ENERGY SUPPLY IN SUB-SAHARAN AFRICA

Energy supply could satisfy economic needs with substantially less adverse effect on the natural environment. This article discusses a number of currently available technological options for energy generation in sub-Saharan Africa and policy options to promote a balance in ecology and economy in energy generation. Africa is endowed with abundant natural resources. The benefits of these resources are mostly obtained only when they have been unlocked from their naturally existing states. The processes of extraction, which range from crude mining to industrial processes that transform raw materials into a diverse range of intermediate and consumer products, require energy. However, energy consumption comprises largely non-renewable natural resources such as wood, coal, gas, various types and grades of oils, and radioactive materials. The use of non-renewable resources for energy generation and the pollution effects of emissions from power plants have been major concerns of the contemporary debates on protecting the environment.

While Africa has considerable energy resources, the relative underdevelopment of the continent is, however a potential threat to energy conservation and environmental protection. Stories of how industrial economies arrived at their current levels of development are laden with examples of non-renewable and heavily polluting sources of energy. An important challenge in international development co-operation is the balancing of ecology and economic development without diminishing the ability of developing countries to embark on development trajectories that suit their particuliar socio-economic circumstances. It is non-controversial that technology plays an important role in strategies that are aimed at achieving this balance. This contribution accordingly highlights some existing and/or new technological developments in energy sources and the prospects of employing them for development objectives, especially in sub-Saharan Africa. The illustrations are largely drawn from Nigeria.

Nigeria is an African country endowed with large deposits of hydrocarbons. Other sub-Saharan African countries with proven substantial reserves of non-renewable energy sources include Angola (petroleum and natural gas); Gabon (petroleum); Equatorial Guinea (petroleum and natural gas); Sao Tome and Principe (petroleum); Sudan (petroleum); Mali (uranium); and Chad (uranium). These energy fuels have been explored for exports with little or no value added. The development of alternative energy sources has been largely abandoned for a number of reasons, e.g. poor management, lack of adequate technical capabilities, obsolete or non-competitive technologies, and lack of capital for the development of energy infrastructure.

## Hydropower

Hydroelectricity potential in Africa is facilitated by an abundance of large free-flowing water resources and impressive natural formations (e.g. falls and gorges) that create opportunities for harnessing waterpower to roll turbines that generate electricity. The Inga hydropower station in the Democratic Republic of Congo currently under construction would be a notable supplier of hydroelectricity to some North African countries, and even Nigeria has been reported to be exploring the possibility of sourcing for electricity from Congo. Power generation in Congo is at 1 cent/kW, about the cheapest in the world. In Nigeria, the most important source of electricity is a hydro station at Kainji on the Niger River. This energy is shared with Niger Republic. Presently most of the turbines at Kainji are relatively old and poorly maintained. Recent attempts to refurbish and reactivate them nonetheless leave performance largely below expectation. While the economic consequences are apparent in the higher cost of power generation through diesel or petrol powered industrial heavy duty and smaller engines, ecological impacts are less quantifiable due to relatively lax environmental regulation. In Nigeria, there are effluent limits for industrial emissions of carbon dioxide and related gases that may emanate from diesel generators. However, a survey of the impact of the Nigerian environmental regulation on industrial firms showed that regulators have limited capacity to monitor industrial gaseous emissions.[1]

Though there are strong arguments against large dams on ecological grounds, hydroelectricity remains one of the most important environmentally benign sources of electrical energy. The potential for its development is still enormous in sub-Saharan Africa. For instance, there are several waterfalls that could be harnessed to this effect. In Nigeria, potentially undeveloped hydroelectricity sources exist at Goroye, in northern Nigeria.

From Nigeria's experience, it appears that the main obstacle to the development of these hydropower sources is the lack of relevant industrial policy that can attract private investment in energy supply. Besides corruption and economic mismanagement, the view that natural resources are national heritage to be owned and used by all has retarded the speed of liberalisation and privatisation of the energy sector. Because the ecological consequences of alternative sources of electricity (gaseous emissions) have trans-border impacts, issues of harnessing hydropower sources should be an important concern in multilateral fora which seek to limit ecological consequences of economic activities. Moreover, like the case of the Kainji power station that serves both Nigeria and Niger Republic, hydropower sources on trans-border rivers signify the importance of regional energy policies that will serve as frameworks to which national policies must conform. This is in order to prevent international disputes on hydropower generation and to assure private investors of the security of their investment. Regional policy frameworks that address energy and other economic and ecological issues should form an important aspect of the new initiative on African development, NEPAD. Regional frameworks can cover technical training schemes on hydropower management for existing hydropower stations, whether or not they are being privatised.

## Wind Energy

Wind is also an important source of renewable energy. It is, however, largely undeveloped in Africa, and the reason for this is presently unclear. Research on socio-economic implications of harnessing wind as an energy resource in Africa is currently needed. While there may be a paucity of the required technical knowledge, policies at national and regional levels can promote the acquisition of necessary technological knowledge. In Nigeria, there are two streams of prevailing winds each year: the south-west trade-wind, predominant during the raining season and which spans approximately April to October; and the north-east trade-wind, prevalent during the dry season and which spans roughly November to March. From a technical point of view, this may present an important opportunity for a clean and perhaps reasonably cheap energy source by employing wind turbines.

## Coal Energy

The employment of petroleum-based fuels for domestic and industrial uses has led to the decline of coal as an energy resource. However, large deposits of high-quality coals still exist in many parts of sub-Saharan Africa and the development of clean coal technology portends continued use of coal as a significant energy resource. Apart from the fact that coal is a non-renewable resource, the environmental impact of coal burning is the emission of greenhouse gases.[2] It is thus not encouraging to promote coal as fuel for power plants in sub-Saharan Africa except where capacity and resources for clean coal technology exist. However, since coal may be a relatively cheaper fuel for Africa, it should at least serve as a bargaining instrument during discussions that relate to international conventions on global warming. In addition, African governments should also promote policies that enable industrial firms to benefit from global environmental funding mechanisms such as the Global Environment Fund (GEF) and the Clean Development Mechanism (CDM) of the UNFCCC.

## Hydrocarbons

Hydrocarbon sources of energy available in sub-Saharan Africa include petroleum and gas. Petroleum sources relate to the earlier mentioned alternative sources like diesel power engines used for both industrial and domestic supply where hydropower or gas turbine sources are lacking or non-existent. Smaller power engines that use petrol or kerosene also exist. In Africa, such engines are largely employed for small-scale business operations and for household uses. The exhaust from these alternative power sources includes large amounts of greenhouse gases. Moreover, the relatively poor economic environment has resulted in the importation of used power engines into sub-Saharan Africa. The very slow rate of economic growth and poor performance of hydro and gas energy sources have promoted the market for used power engines. The implication for the environment is an apparent transfer of emission sources from the countries of the North to the less affluent or poor countries of the South.

Gas as an energy resource is currently being promoted in Africa especially in countries or regions with large deposits of natural gas. The West African Gas Pipeline (WAGP) Project financed by some Economic Community Of West African States (ECOWAS) countries, multinational oil corporations, and the African Development Bank, is an example of this. If successfully executed, this regional clean energy development project is obviously an important and potent tool of rapid regional industrialisation with less environmental consequences in terms of gaseous emissions.

Automobile use continues to increase all over the world, Africa not excluded. The bane of automobiles in sub-Saharan Africa is particularly related to the high and prohibitive costs of new vehicles in relation to the earning capacities of most Africans. Except in a few countries in southern Africa (e.g. Botswana and South Africa) where there exists a relatively higher concentration of the affluent African elite, the vast majority of vehicles are used or scrapped vehicles imported from advanced countries. Thus the vehicles on African roads are perhaps more polluting than anywhere in the world. Policies that economically empower Africans to buy new vehicles or those that encourage public transport systems that use new vehicles (or even electric vehicles) would reduce energy consumption and at the same time produce less obnoxious emissions.

Furthermore, the state of African railways is very backward. For example, the moribund Nigerian railway system remains the colonial heritage constructed nearly a century ago. The system is narrow gauge and all engines in use are diesel locomotives. Such archaic systems could be replaced with relatively modern electrically powered railway systems. This could be another focus of international partnerships for African development. Development co-operation should be broadened to embrace infrastructural improvements in the poorer regions directly or by rich countries providing incentives for the private sector initiatives aimed at upgrading infrastructures that have potentials of yielding gainful economic returns.

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**Endnotes**

1 Adeoti, J.O. 2002. *Technology and the Environment in Sub-Saharan Africa*. Aldershot: Ashgate Publishing.

2 Though advanced industrial societies benefited from coal burning and have thereby contributed irredeemably to global warming, African countries need not follow the same path, but rather use this fact as bargaining power to argue for Marshal-like transfers to the South in aid of clean sources of energy in general.

# INSTITUTIONAL CHANGE AND INNOVATION IN THE BRAZILIAN OIL INDUSTRY

The Brazilian national oil company Petrobras has acquired considerable technological and R&D capabilities particularly in deep-water technology. This company, which competes with global leaders, had been engaged in important R&D efforts since before the reforms of the 1980s and 1990s. Petrobras created several post-graduate oil-related technology programs in Brazilian universities by allocating substantial funds for research conducted by universities and research centres. In addition, since the 1950s, Petrobras had developed a procurement policy to improve supplies industries' technological and productive capabilities. This paper examines the implications of institutional reforms on national R&D programmes, and the lessons for other developing countries.[1]

Beginning some 20 years ago developed and developing countries alike reformed their energy sectors through privatisation of public monopolies and the opening of energy markets to competition. The impact of these reforms on R&D expenditures were largely negative, contrary to assumptions that increased competition would improve innovation efforts. There was sharp decline in R&D spending, which was quite significant in countries that engaged more deeply in reforms. Firms and governments neglected investment in long-term research in energy in an attempt to generate more profit.

In the USA and UK, R&D expenditures decreased in the electric power sector after privatisation, while competition intensified. More recent figures show that R&D expenditures were halved in 9 of the 18 countries surveyed by the World Energy Council, and most of them were in developed countries. In the USA that accounts for 40 per cent of world R&D; expenditures fell by 70 per cent between 1995 and 1999, due mostly to the decline in private sector expenditure.

Two prominent sectors, electricity and petroleum, received the greatest policy attention. However, reforms in developing countries were more far-reaching in electricity than in the fossil fuel industry. This might be because oil companies, being important sources of tax revenues for exporting and importing countries, put on greater resistance to reform. Privatisation would mean the loss of an important source of revenue. While a small group of developing countries privatised their national oil companies in order to attract foreign investment, others did so to increase the management autonomy of national companies to allow them to survive competition.

National oil companies in some developing countries are responsible for a significant portion of total R&D efforts and do have an important influence on the national system of innovation (NSI), i.e. universities, research centres, and national supplies industry. For example, in Mexico, Pemex and the Mexican Petroleum Institute (IMP) were responsible for 77 per cent of public expenditures in energy R&D. Thus we presume deeper impact of institutional change in countries where state companies are central actors of NSI, as the increase in competition will conduce these actors to reduce their own R&D efforts.

## Institutional Change in Brazil

The Oil Law 9,478 of 1997 provoked important changes in the Brazilian oil and gas sector. The Law ended the monopoly of Petrobras by allowing new private companies, most of them foreign, to compete with Petrobras in the upstream and downstream of the industry. The internal market was opened to imports of crude and refined products and a new institutional actor, the Petroleum National Agency (ANP), was created to regulate competition.

However, anticipating the negative outcomes of increased competition in the research system, particularly within universities, research centres, and national suppliers, the Law created new sources of funds for R&D projects. These included additional royalty payments for oil extraction, part of which was allocated to science and technology. The Ministry of Science and Technology (MCT) created CTPetro, which manages the funds. A Co-ordination Committee, consisting of civil servants both at federal and state level, was created and executive functions are undertaken by the Federal Technology Agency (Finep), which is in charge of the highest share of the CTPetro resources.

The main form of application of the fund is the university-industry partnership. Universities or research centres in co-operation with industry conduct approved technological projects.

This institutional change allowed Petrobras to maintain its R&D and enlarge previous Science and Technology (S&T) efforts in the face of falling R&D expenditure at the global level. However, there were significant changes in the strategy of the main S&T actors.

## Changes in the Brazilian Oil Industry Innovation System

The oil and gas sectoral innovation system comprises specialised firms, universities, research centres managing training programs, and sectoral funds. In the petroleum industry, the production sector has two main actors: oil companies and the oil supplies firms. The oil companies control different stages of the oil and gas production process, while oil supplies firms are in charge of sets of products and services for the oil companies. At the global level, oil companies control important shares of R&D efforts. In developing countries, like Brazil, these efforts are concentrated in the national oil companies.

The roles and functions of actors are depicted in Table 1. Phase I corresponds to the previous institutional arrangement where Petrobras monopolised oil and gas activities in Brazil, while Phase II shows the new institutional arrangement.

In Phase II, the network became multi-polar and co-ordination was weaker. The rules of competition changed, and Petrobras abandoned some of the missions that guided its actions during the previous phase, such as promoting domestic universities, research centres, and oil supplies firms. CTPetro could not substitute for the roles played by Petrobras before the reform for reasons beyond the scope of this article. It is sufficient to note that the creation of the important new fund generated tensions in the co-ordination function of the system.

**Table 1: Functions and Roles of the Main Institutional Actors of the Brazilian Innovation System**

| Functions/Roles | Phase I: Monopoly | Phase II: Competition |
|---|---|---|
| R&D Planning and Co-ordination | - Petrobras | - Petrobras<br>- CTPetro |
| R&D Funding | - Petrobras | - Petrobras (70%)<br>- CTPetro (30%) |
| R&D Execution | - Petrobras (mainly)<br>- Universities and Research Centres (few) | - Petrobras<br>- Universities and Research Centres (large number) |
| Human Resources Training Funding | - Petrobras (mainly)<br>- Federal Government | - Petrobras<br>- CTPetro<br>- ANP<br>- Federal Government |
| Human Resources Formation | - Petrobras (mainly)<br>- Universities and Technical Schools | - Universities and Technical School (mainly)<br>- Petrobras |
| New Knowledge Users | - Petrobras<br>- Oil Supplies Firms | - Petrobras<br>- Oil Supplies Firms<br>- Other Oil Companies |
| Clients of the New Knowledge Users | - Petrobras | - Petrobras<br>- Other Oil Companies |
| Final Consumers | - Society | - Society |

Again, the co-ordination function was weakened with the entrance of the CTPetro as a main actor largely because co-operative projects require a firm's co-founding. There is also a lack of capacity to define the scope of the programmes. Lastly, specification of regional spending rules[2] reduced programming co-ordination since poor regions had less technological capabilities in universities and research centres.

Overall, CTPetro promoted technological variety involving a larger number of actors by mobilising existing technological capabilities to create new knowledge bases.

While Petrobras maintained its R&D efforts, there was a reduced co-ordination in national R&D efforts due to CTPetro's tendency to disperse resources. The otherwise negative outcome was mitigated by the general improvement in R&D expenditure, including funding of deep-water technology.

Local oil supplies firms remain the weakest component of the Brazilian system. It is a well-established industry, which originated from Petrobras efforts to reduce equipment and services imports. At the end of the 1980s, Brazilian suppliers were responsible for more than 90 per cent of Petrobras' equipment and materials purchases. However, few firms engaged in R&D efforts in the era of monopoly (Phase I in Table 1). These firms tended to be passive, adopting foreign technology chosen by Petrobras.

## Policy Lessons for Developing Countries

Brazil proactively introduced institutional reforms in order to mitigate the anticipated drop in R&D expenditure that would have resulted from reforms. One important reform was the creation of a co-funding mechanism intended to induce university-industry partnerships. It, however, seems to have encouraged externalisation of R&D efforts that benefit only large firms such as Petrobras. The co-funding requirement could be one of the reasons why oil supplies firms did not fully engage CTPetro, the main co-ordinator of the R&D fund. However, there seems to be several other reasons. First, firms lacking in research tradition had no information on the nature of the program. Second, while CTPetro encouraged new entrants, this was outweighed by the lack of interest of well-established suppliers. Third, local supplier's indifference could be a result of limited scope of R&D, which is restricted only to strategic areas, where appropriability matters leave little room for co-operation.

While the liberal reforms – privatisation and the end of national monopolies – initiated important changes in energy innovation systems world-wide, there was a decline in R&D efforts. In the oil sector, reforms in developing countries were limited to the opening of internal markets to competition while keeping national oil companies under state control. However, anticipating the negative impacts of institutional change demanded attenuating laws and programmes.

While the mechanism described could be appropriate for large firms like Petrobras, with its own internal R&D capacity, and the more advanced system as found in Brazil, the general principles contain lessons for developing countries.

In sum, there are a few key lessons. The first is that to support the innovation efforts of local firms there is a need to initiate, concurrently with reforms, institutional changes, such as a special fund and the organisation to manage it. Secondly, R&D is costly, but it is not the only requirement to improve competitiveness. Developing countries which are less advanced than Brazil may well require other forms of innovation support. All actors should carefully arrive at these requirements through consensus in the national system. Lastly, despite severe expenditure reductions, developing countries need continuing explicit investment in innovation and human capital development to remain competitive.

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1 A complete version of the arguments presented in this article, including full references, could be obtained from the author.

2 40% of CTPetro funds has to be allocated in the north, north-east and center-west Brazilian macro-regions.

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## FUTURE TECHNOLOGY POLICY BRIEFS

Future UNU/INTECH Technology Policy Briefs will address issues in transnational corporations and innovation, and information and communication technologies.

The next TPB will address transnational corporations, learning and innovation. The issue will examine the World Trade Organisation's (WTO) Trade-Related Investment Measures (TRIMs) Agreement and its potential impact on the role of transnational corporations and technological capability building in developing economies.

Comments, criticisms, and suggestions on this Brief are welcome. Please contact Banji Oyeyinka at: oyeyinka@intech.unu.edu

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