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Public Interest Research and Development: *Electricity Sector Reforms and their Effects in Energy R&D Activities*

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Foreword

The **Energy Discussion Paper** series is intended to disseminate pre-prints and research reports organized or authored by members of the **International Energy Initiative** (Latin American Office) and its associates with the purpose to stimulate the debate on current energy topics and sustainable development.

Any comments or suggestions are welcome and should be addressed to the authors for consideration.

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Apresentação

A série **Energy Discussion Paper** tem o objetivo de disseminar os artigos e relatórios preparados pelos membros ou associados do escritório regional da **International Energy Initiative**. A intenção é estimular o debate sobre temas correntes na área de energia e desenvolvimento sustentável.

Comentários e sugestões são bem-vindos e devem ser encaminhados diretamente aos autores, para consideração e eventuais revisões.

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1. Introduction

Radical change is required in the current energy system worldwide if sustainability is to be effectively pursued and incorporated in policy decisions and future technological choices. Developing countries, in particular, are facing additional and significant challenges with regards to continuing their economic development and the need to increase access and the level of energy services to their populations. More efficient and clean technologies, and economic strategies to commercialise them can help provide the solution to these challenges both to industrialised and developing countries (Williams 2001, Patterson *et al.* 2002).

Power sector reforms have posed new challenges and opportunities to enhance energy R&D activities in some developing countries but may also have aggravated the capability to innovate and promote domestically conceived solutions.

Developing countries have little tradition in investing in R&D in general and in energy R&D in particular. Often R&D efforts are adaptive following externally developed technologies (see for example Intarakumnerd *et al., 2002*). Total national expenditures in R&D in developing countries hardly represent a significant share of their GDPs. In 1994 the average was about 0.65% in developing countries and 3% in industrialized countries (Hadjimanolis and Dickson, 2001). India and Brazil, for example, dedicate a little over 0.5% of their GDP to R&D activities[1] (Figure 1), much less than South Korea and several industrialised countries (Runci, 1999). In percapita terms total Brazilian R&D expenditure in year 2000 were US$ 80.40, more than ten times smaller than the US per capita expenditure and five times less than South Korea (MCT, 2002)[2]. In Thailand only 0.26% of GDP (NSTDA, 2002) is accounted for R&D activities and in South Africa the figure is approximately 0.7% in 2002 (Paton, 2002). Nevertheless, several developing countries have over the years created and supported research institutions with the purpose of providing technical (and in fewer cases, scientific) assistance to the existing electricity utilities.

Introduction of power sector reforms had immediate implications on the support for R&D, the purpose of the research institutions and a re-definition of the role of the public sector, which was, in many instances, the major and only supporter of research establishments and responsible for the research agenda being carried out. The pursuit of greater competition, the creation of smaller and unbundled utilities and, in some cases, foreign private ownership, may cause developing countries to rely on internationalised markets for R&D to provide solutions to their particular problems. The obvious implications of this usually high dependence on first world technologies, or solutions tailored for global markets, are that problems or opportunities specific to developing countries may not receive appropriate and adequate R&D attention.

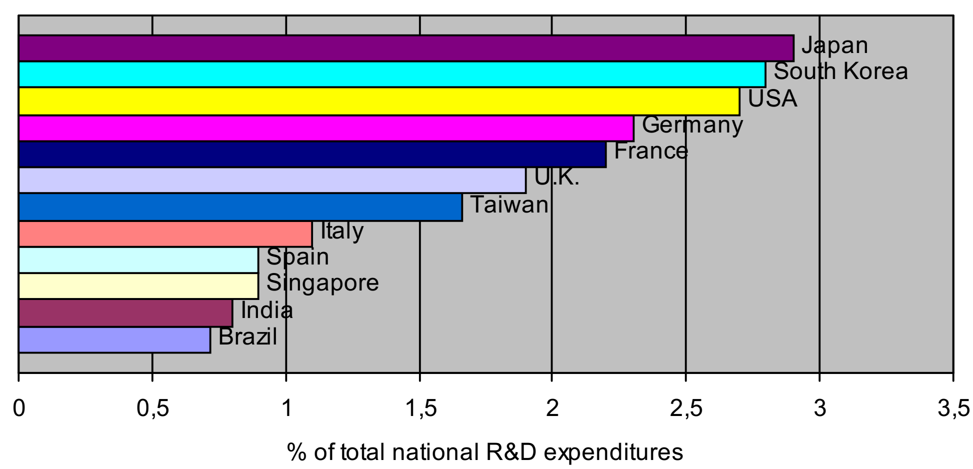
In order to be able to address these issues in the new power sector context and at the same time show their commitment to sustainable development, developing countries need to define a coherent R&D agenda and their priorities in R&D, establish new institutional structures, re-examine (and probably re-define) the role of public agents, develop criteria for allocating funds (both public and private), deal with intellectual property rights, develop indigenous innovative capacity, establish evaluation methods and monitor the progress on their R&D efforts. All these

[1] In year 2000, Brazil's total R&D expenditure (public and private) represented 1.05% of GDP (MCT, 2002)
[2] Per capita figures are in 2000 US $, corrected by local purchasing power parities (PPP).

issues require that energy policy makers in developing countries understand the innovation process in the supply and demand side of the energy system and create mechanisms to support this process.

Developing countries are in different stages of power sector reforms and present significantly different approaches to the insertion of R&D initiatives in the process. Some countries such as Brazil have passed part of the stages of reforms but most of them are beginning implementation of the reform processes. In this chapter, experiences from some countries already at more advanced stages of the reforms have been highly used. Its is hoped that experienced gained in these countries will provide useful input to the reform processes in other developing countries.

Figure 1: Total National R&D expenditures in select countries (1997)



Source: OECD (2001)

1.1 Chapter structure

It is the objective of the chapter to make policy recommendations for advancing public benefits resulting from energy R&D efforts by providing a rationale for supporting PIER&D in a restructured electricity industry in developing countries.

Firstly the chapter presents the overall scope of activities considered for the concept of PIER&D used in the chapter and how some of them may be more relevant to some developing countries than others. The following sections present an overview of the status of PIER&D prior to reforms and the main impacts observed since power reforms were introduced in energy R&D efforts. We then analyse possible contributions and barriers promoting energy R&D in developing countries. We also discuss the need and purposes of creating evaluation procedures for PIER&D.

1.2 Scope of energy R&D

Energy R&D includes a complex and diverse set of activities, some of them time consuming, very expensive and with uncertain outcomes. It includes not only efforts to develop new technologies; but also adaptation and introduction of incremental innovations in existing ones. It includes the creation and maintenance of research facilities and related infra-structure; the establishment of codes, standards and technology certification; development of methods for operating and planning energy systems (including policy-making and regulation); training of personnel at all levels (from technical to scientific); capacity building in areas relevant to the improvement current and future energy technologies and services. The socio-economic use of the results of these activities, which is one of the main objectives of R&D efforts, involves coordinated actions from public and specially private sector actors, both at the domestic and international level.

The broader definition of energy R&D adopted here is more comprehensive when compared to the ones found in the literature, e.g. PCAST (1997) and Dooley (2000) [3], but include several aspects of R&D efforts already mentioned that require attention and are relevant for developing countries, specially the creation and maintenance of research facilities, industrial base, technological and human capacity building.

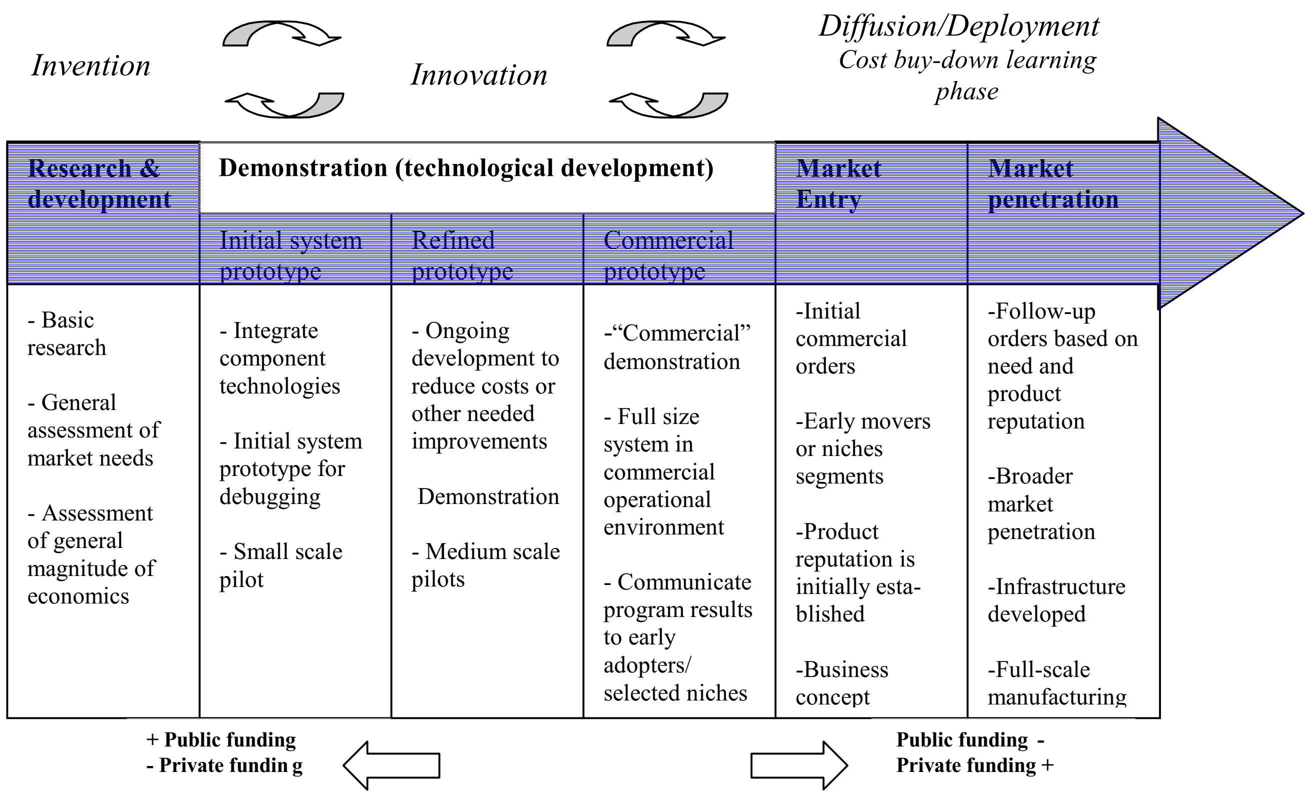
For purposes of this chapter, "energy R&D" includes not only basic and applied research, technology development and small scale demonstration, but it goes all the way to commercial demonstration, technology transfer, scaling-up to commercial production, and market transformation mechanisms. As noted by Sagar and Holdren (2002) , a narrow focus on energy R&D misses important aspects of innovation, namely the process of deployment and diffusion of the new technologies and processes, which are included in here. We consider this view relevant to developing countries since financial and human resources are crucial an any R&D effort compete with more visible and short-run objectives. It is important to ensure that investments made in R&D effectively achieve results that can be commercialized and yield the intended socio-economic objectives.

Figure 2 presents an illustration of the range of activities that are included in energy R&D. Similar concepts and diagrams have been the focus of several studies in the area of theory of innovation and technical change (for example, Lundvall *et al, 2002*). In the energy literature context, PCAST (1997) refers to a similar sequence of efforts as "technology innovation pipeline" and Turkenburg (2002) as "the innovation chain". The sequence of activities presented in the figure does not necessarily proceed in a linear or in the sequential order displayed. In fact, this is a more complex model with interations, stages of learning processes and accumulation of knowledge along all the way. Depending on the technology some stages take longer and/or are developed simultaneously, i.e. there are overlaps and feedbacks between the various phases (Turkenburg, 2002). The chain of activities presented is relevant to differentiate the roles of

[3] "*Energy R&D* is the linked process by which energy supply, energy end use, or carbon management technology moves from its conception in theory (including necessary enabling basic research) to its feasibility testing and small scale deployment. It encompasses activities such as basic and applied research as well as technology development and demonstration in all aspects of resource extraction and production (e.g., mining, drilling, refining, exploration); power generation (e.g., nuclear fission and fusion, fossil, and renewable energy); transmission, distribution and energy storage; energy efficiency; and carbon management technologies. *Carbon management technologies* include but are not limited to advanced agro-forestry practices intended to enhance the absorptive capacity of soils to hold atmospheric carbon dioxide and engineered carbon capture (pre- and post-combustion) and engineered carbon storage (e.g., in depleted gas and oil wells, coal-bed methane seams, deep saline reservoirs, and in the ocean)"(Dooley 2000) .

public and private sector funding along the process, as it will be discussed in a later section[4] (Figure 8).

Figure 2: Research, Development, Demonstration and Commercialization chain



Source: Based on Little (2001) , PCAST (1997), Turkenburg (2002), and Ahman (2003)

It is relevant to note that particular energy R&D programs do not need to include necessarily all the above-mentioned steps, nor need to have an exclusive technology-oriented engineering approach. As mentioned earlier, we also include any activities concerning the development of domestic capability and expertise in adaptation of technologies[5], management practices that leads to the improvement and lowering final costs of energy services or reduction of local environmental impacts. These aspects are especially relevant to governments and industries in developing countries, which, in many situations, are not be able to undertake the entire span of activities from basic research to demonstration and commercialisation of products/appliances, nor can afford the time and expenses in setting-up a specific and dedicated R&D infrastructure. These countries may present small markets, poor industrial base, lack of technical capacity or expertise,

[4] Public funding is important in areas which offer greater risks and long lead-times for attaining results it may require a stronger participation of public funds. In the commercialization phase private funds and efforts are dominant, but governments may play an important role in regulation (standards and codes, for example) and market transformation initiatives.
[5] This may include the basic understanding of the technology, the capability of operate and maintain it.

and my limit there actions to the later stages of the R&D (Figure 2), i.e. demonstration and deployment.

Finally, it is relevant to state that energy R&D is not restricted to innovation in the supply side, i.e. the conventional generation, transmission and distribution of electricity system; one key aspect of efforts with important implications for environmental protection, frequently overlooked, is innovation in end-use devices and systems.

2. Defining Public Interest Energy R&D

Power sector reforms introduced new actors[6] with different purposes and motivation for promoting energy R&D. In this section we present the concept of PIER&D employed in a way that helps to establish a rationale for maximising the public benefits and supporting PIER&D in a restructured electricity industry in developing countries.

2.1 Public Benefits and Energy R&D efforts

Broadly speaking, *public benefits* are certain characteristics of energy services that bring about social welfare improvements, as presented in Chapter One. *Public benefits* associated with R&D efforts in general and energy R&D in particular, are very difficult to categorise precisely. This task requires discussions and consensus building amongst energy planners, government officials, energy companies, regulators, academics, scientists and even public consultation. The literature shows that the discussion hardly reaches a definitive conclusion and, more importantly, that these concepts are socially constructed over time and undergo continuing change and revision (Blumestein *el al.* 1998, Bruce *el al.* 1995, Harmon 1969, Schubert 1961, Sorauf 1957).

Bruce *et al.* (1995) presents a list of what they call "public policy responsibilities" associated with the power sector in the USA. This list is in fact a compilation of desired public benefits[7] for several activities related to the power sector, including R&D, resulting from a debate with representatives from electric utilities, NGOs, academics, PUCs, State Energy Commissions, and IPPs. These discussions were held at the time power sector reforms were being introduced in that country and the debate concerned the maintenance and protection of the *public benefits*.

Table 1 presents an illustration of desired public benefits associated with energy R&D activities that should be maximised with public investments as it was discussed in Brazil during the implementation of the National Energy R&D Fund (CTEnerg[8]). The parameters displayed show an understanding of the relevant issues that should be considered in evaluating the public benefits accruing from energy R&D programs which were categorised into four dimensions: techno-economical, environmental, social and strategic. The choice of parameters such as these

[6] In many developing countries the new actors are the private electric utilities, energy commercialization companies and the regulatory agencies established as part of the reform process. In addition, government agencies, universities, research establishments (public and private) are other participant actors in energy R&D.
[7] The authors summarise the contributions of a wide range of efforts that help to advance economic development, social equity and environmental protection.
[8] The Brazilian Energy R&D Fund CTEnerg will be presented in more detail in a later section.

presented here and the different weights that can be assigned to them are highly dependent on socio-economic context and perceptions from energy R&D decision-makers.

It is important to note that *public benefits* of energy R&D efforts can be achieved not only by means of public funding but also when private companies introduce, for example, innovative solutions that make possible the improvement of their services and lower costs to consumers.

Table 1: An illustration of Public Benefits associated to Energy R&D efforts

Dimension	Public Benefits
Techno-Economical	Improvement of industrial competitiveness
	Reduction of the electricity intensity of the national economy
	Technological and services exports
	National economic growth
	Economic Efficiency
Environmental	Optimal Use of Hydro Resources
	Climate Change
	Air quality
	Biodiversity
	Sustainable development
Social	Access to electricity
	Employment creation
	Equity issues related to energy services
	Reduce energy costs to consumers
Strategic	System reliability, loss reduction, quality of energy
	Regional Development
	Domestic Technology Capacity Building
	Diversification of the electricity mix
	Security of energy supply
	Improve the technological services balance of trade
	Create industrial base for energy technologies

Source: Based on CTEnerg White Paper (MCT 2002) (Brazilian Ministry of Science and Technology)

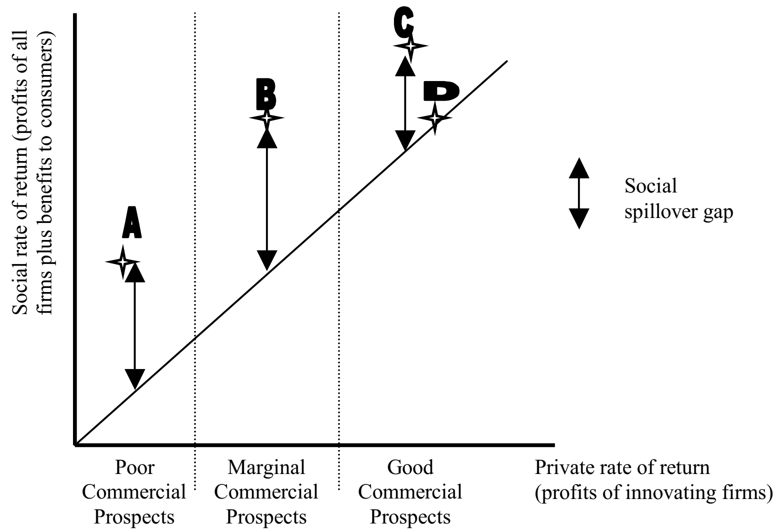
2.2 A definition of PIER&D

Blumstein *et al*. (1998) define as public interest R&D activities as those that are not adequately conceived and financed by competitive markets since some or all of its benefits are widely distributed and cannot be captured entirely by the firms in order to justify their investments. Examples of public interest energy R&D include, for example, those related to basic research in combustion systems that can provide better emissions standards and positive environmental externalities. Basic research in Fluid Dynamics can be useful in improving the performance of wind generators and also of oil flow in pipelines. Other examples can include the development of renewable technologies that can create local or regional employment opportunities; the development of technologies that enhance the operation, reliability and performance of the whole electrical system and not necessarily of one individual firm. In general, technologies that help consumers to save energy, or that have other social and/or environmental externalities that cannot be captured exclusively by firms, or present long-term benefits may not be amongst immediate concerns of company board members and shareholders and, therefore may not receive enough attention from energy corporations.

R&D investments have important spillover effects and these determine the level of participation of private agents. Jaffe (1996) using the conventional economist view on (social and private) rates of return, discusses the effects of investments made on R&D activities. Since decision-making by private firms is mostly based on private rate of return on the investments, this limits the scope of topics that are economically interesting to them, meaning that some projects that are socially desired will be under-invested by private companies.

Figure 3, based on Jaffe (1996), shows some hypothetical projects that present net social returns (A, B and C). From the private sector point of view, projects to the right (higher private return) are more likely to be funded by private firms, all else being equal. Project D is the most attractive to the private firm but yields less social spillover (public benefits) than project C and also projects A and B. The public sector seeks to maximize the expected social return, whilst the private sector seeks to maximize the expected private return. Projects A, B and C could be candidates for receiving public funding. Although C presents higher social rate of return, projects A and B have higher social spillover gaps.

Figure 3: The social spillover gaps (public benefits) of projects. The relationship between social and private rates of return



Source: Based on Jaffe (1996)

The definition of PIER&D, however, does not appear to be straightforward or consensual in the literature. The definition may vary substantially according to economic development context, political organization, existing industrial base and R&D human resources and infra-structure. As Blumstein *et al*. (1998) observes that the main characteristic of public interest energy R&D is its coherence with other guidelines established by public policy makers in areas of socio-economic development, environment and health, areas that are not in the main scope of activities and concerns of private companies. In particular, the central underlining issue that will guide the establishment of a precise definition of PIER&D is the strategic view of public policy makers about the future with regards to the role of energy, environment and development. Therefore, governments and public authorities are the ones that should define priorities and agenda for investments in public interest R&D.

2.2.1 Conclusion

We define PIER&D *as those energy R&D programs aligned with broad public developmental plans that yield relatively high social spillovers (public benefits) and low private returns, and therefore require public funding in order to take place.* These programs, as stated, must be aligned with the objectives of national governmental policies and address areas that fill gaps between what society needs and what the private sector does. These "market failures" are explained by inadequate information, excessive concentration or fragmentation in markets, for example. There are other factors that prevent much of PIER&D taking place and are presented in a following section on barriers.

This chapter therefore focuses on a *sub-set* of energy R&D efforts that are relevant to *public funding*[9], which we call Public Interest Energy R&D (PIER&D). PIER&D will try to maximise those *public benefits* of R&D efforts which are unlikely to receive priority or to be pursued by competitive (or private) utilities and need *public funding* to support them.

2.3 Corporate (or commercial) energy R&D

Power sector reforms have altered the structure of utilities and their internal decision-making process with impacts in the organisation of energy R&D activities, in particular its agenda and priorities. In a competitive electricity industry context, risk is borne not by captive customers and government, as before reforms, but by shareholders and/or bankers, as well. R&D efforts will reflect corporate investments perceived as strategic by energy companies and have the purpose of better positioning the energy corporation in the competitive market.

Therefore, it is possible to distinguish a category of energy R&D in a re-structured power sector that will be more aligned with the objectives of the new electric utilities. This category named "corporate (or commercial) energy R&D" contrasts with the purposes of PIER&D as presented in the previous section.

These investments will mainly try to implement innovations that help reduce costs in energy production, transmission, distribution and commercialisation. Private and competitive utilities will seek R&D activities that present lower risks and shorter expected time to yield commercial results. In addition, they will try to target projects that help them promote differentiation of products and services as opportunities to enhance the company's participation in energy markets.

Another characteristic of this type of R&D is the pursuit of patents, or intellectual and commercial proprietary rights over any type of results accrued. Therefore, projects done under this category will also have characteristics of confidentiality that also needs to be considered under power sector reforms (Vine 1997) .

This does not mean, however, that investments conceived as corporate energy R&D cannot yield public benefits. In fact, if the innovation introduced to reduce the utility's cost to produce electricity, for example, when passed on to the tariff, have the benefits to lower energy costs of all consumers. However, as explained in the previous section, corporate investments in energy R&D will prioritize the maximization of utility's economic returns (Figure 3). The argument for supporting "green pricing" is another example where some private investors contribute for the enhancement of public energy benefits and are prone to pay more for renewable energy (see, for example Wiser *et. al.* 2001).

It is important to policy makers to understand the logic and strategies of energy corporations when designing PIER&D programs, as to avoid duplication of efforts or funding un-necessarily efforts that can be undertaken by competitive energy-companies. PIER&D can complement commercial R&D in areas that present desired *public benefits*, especially in areas that present greater risk to private companies.

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[9] In this chapter we understand public funding of R&D activities as direct governmental spending (taxpayers' funds) or activities supported by funds collected through levies (or other mechanisms) from energy consumers or utilities.

3. Electricity R&D prior to power sector reform in developing countries

Most developing countries had public research institutions or R&D departments within their main utilities. In many instances these institutions were the only place to carry out and support domestic PIER&D. This is the situation in countries such as India and South Africa, where the states still maintain high proportion of ownership of their power sector. Different from South Africa and India, Brazil created a Power Sector Research Centre in the seventies and the recent changes illustrates clearly the impacts of power sector reforms on this type of set-up.

Importance of utility's sponsored R&D activities can be seen in South Africa, where its main public utility, Eskom, indicated to be carrying out R&D activities which were contributions not only towards the sector's needs, but also to the national interest. The following paragraph illustrates Eskom´s support for PIER&D:

"Whilst the entire research programme [i.e. Eskom's] *may be viewed as a contribution to national technological development there are specific areas which are heavily weighted towards generic national interest. This work is undertaken in the absence of alternative national lead agencies or due to lack of national research funding, where the information generated is critical to Eskom's business. Areas with such as national contribution are the Integrated Energy Systems and Environmental Research categories"* (Eskom, 1998).

In 2001, Eskom invested about 1.1% of its total revenue in R&D and Demonstration (Eskom, 2000), and it is the country's leading energy R&D agency. During its monopoly regime, large and risky projects such as the controversial (Thomas, 2002) Modular Pebble Bed Nuclear were conceived and implemented (Eskom 2001, Eskom 1999). Prior to around 1999, Eskon had been funding university research for many years. Currently, Eskom is forced to put its business under a competitive environment and many changes have occurred to its R&D activities as will be seen in the coming sections.

India has a much more diversified range of institutions devoted to energy R&D, and most are government agencies or public sector institutions. The major electric power R&D organisation is the Bharat Heavy Electricals, which operates under the Ministry of Heavy Industries and Public Enterprises. In India only 10% of the installed capacity is privately owned and very little R&D activities takes place in these corporations. The amount of public interest R&D investments made by public enterprises in India is several times higher than the amounts spent by Indian subsidiaries of multinationals like Siemens, ABB, Cummins and Thermax. R&D activities for renewable energy sources are taken care of by the Ministry of Non-Conventional Energy Sources, which funds a number of academic and other research institutions (Sagar, 2002).

CEPEL, the Brazilian Centre for Electrical Energy R&D, was created in 1974 and has had the support from several state owned utilities since then. CEPEL operates under the federally owned utility Eletrobras, which also provided most of its core funding until power sector reforms started in the country in mid nineties. After 1995 CEPEL had to increasingly rely on external contracted services to complement its budget (Table 2). One of the main activities of CEPEL was to carry out applied research for its members and helped to solve common technical obstacles facing the industry, especially with regards to transmission of electricity over large distances. It also provided technical assistance and advice for individual state utilities and technical support for the government, as an agency of the Ministry of Mines and Energy (through Eletrobras) in the tasks of providing inputs for long term energy planning and advice on many issues concerning national decisions over technology choices. CEPEL played role in providing both short-term solutions and long-term strategic thinking and direction for the role electricity sector until the mid-nineties (Brown and Lewis, 1997), when power sector reforms were initiated.

Table 2: Funding sources of the Brazilian National Power Sector Research Centre C EPEL as % of total annual budget (1990 -95)

Funding Sources	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Eletrobrás	86%	81%	92%	89%	53%	47%	53%	54%	55%	50%	50%	46%
Founding members	11%	13%	4%	6%	35%	31%	35%	28%	31%	22%	23%	18%
Own funding sources	3%	4%	2%	2%	7%	6%	10%	15%	13%	21%	22%	27%
Others	0%	2%	2%	3%	5%	16%	1%	3%	0%	7%	5%	10%
Total (million US$)	33.60	28.30	25.00	29.40	37.63	45.76	42.09	43.81	40.55	30.54	35.14	29.20

Source: Soares (1997). CEPEL (2000), CEPEL (2001) Notes: Founding members are CHESF, FURNAS, ELETRONORTE, ELETROSUL (federal generating and transmission utilities); "own funding sources" and "others" include contracted services.

The performance on R&D activities of the power sector research establishments and the energy research agenda in developing countries during pre-reform period must be viewed critically. The main question is which have been effective contributions of energy R&D activities prior to reforms to meet the country's energy demands by providing environmentally sustainable solutions. The contributions, albeit relevant, in the Brazilian case seems to be limited for the most part as they could not help to reduce the country's net dependence on external power sector technologies.

There are some evident mismatches between energy R&D expenditures and the pattern of energy supply and demand in India, where an insignificant share of the country's R&D expenditure is dedicated to coal, in spite of its importance in India's energy system, accounting for over two thirds of commercial energy supply. Also, non commercial sources of energy, which in India supply the majority of the population energy needs have not received adequate support form R&D activities (Sagar, 2002). Sagar (2002) also notes that much of energy R&D efforts done so far could be characterized as development or technology acquisition and upgrading.

4. Electricity sector reforms and its impacts on R&D in developing countries

This section first presents some impacts brought by that power sector reforms in industrialized countries with regards to funding energy R&D and finally analyzes the main consequences of the reforms in developing countries.

4.1 Energy R&D situation in industrialised countries

Overwhelming majority of energy R&D activities are concentrated in industrialized countries. Public and private expenditure on energy R&D in OECD[10] countries represents 80% of global R&D investments (Chesshire, 1999). The concentration is even more disturbing to note that only nine countries[11] account for 95% of OECD R&D expenditures globally (IEA, 2002).

However, there has been sharp decline in public funding and overall activities of energy R&D in industrialised countries as a result of power sector reforms (Williams, 2001, Dooley *et al*, 1998). In the US, for example, there has been a declining trend in public sector support for energy R&D both as a percentage of GDP and in absolute terms. . In the early stages of the reform process, R&D was one of the first activities to be cut back. The main reasons are due to the pressures to reduce costs in the increasingly competitive energy industry and also to free-rider effects in certain areas of energy R&D, where private energy corporations perceive greater risks in promoting innovation without adequate guarantees of economic returns and commercial properties rights.

4.1.1 Decrease in public funding for energy R&D

Public funding, in particular, for energy R&D suffered cutbacks worldwide (Margolis and Kammen 2001, Dooley *et. al.* 1998), because de-regulation, and privatisation in some cases, transferred responsibilities to the competitive utilities, which, in the new context, had strong desire and incentives to promote innovation. Therefore, greater participation of private sector investments in energy R&D was expected.

In the European Union the overall share of public R&D spending dedicated to energy declined steadly from nearly 50% (period 1984-87) to only 14% (1998-2002), but showed an increase in absolute terms, from US$ 1.7 billion to US$ 2.1 billion over the same periods (Runci, 1999).

However the decrease in the level of public and private funding for energy R&D cannot be attributed only to the reform process. National budgetary restrictions and low energy prices during the last decade also influenced corporate and public decisions to reduce the importance of investing in energy R&D, especially those related to new energy technologies (PCAST 1997). In the past, not only equipment manufacturers but also the vertically structured monopoly organisations pursued major R&D programmes themselves. Government-funded (taxpayers) research agencies did likewise, particularly on technologies for nuclear energy (Williams, 2001).

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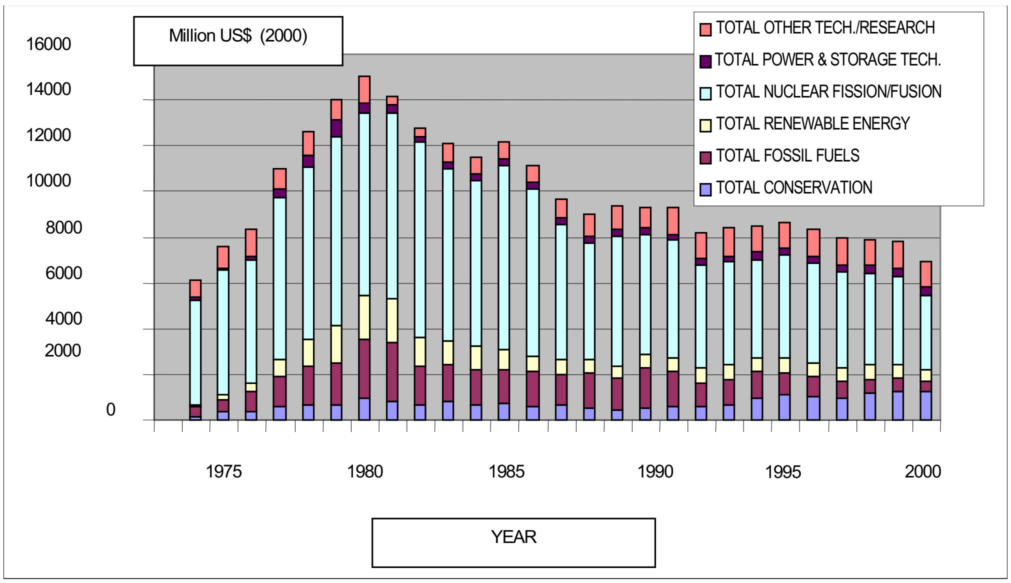
[10] Organization of Economic Development Corporation, OECD: an international organization helping governments tackle the economic, social and governance challenges of a globalised economy.

[11] The countries are the United States, Japan, Germany, the Netherlands, United Kingdom, France, Italy, Canada, and Switzerland.

In OECD countries, direct public spending for energy R&D had generally declined from a peak of about US$15 billion in 1980 to about US$7 billion in 2000 (Figure 4). With the advent of liberalisation, R&D investments became one of the first activities to be cut back (Friedman, 1998).

Figure 4: Total public Energy R&D investments in IEA countries 1976 -2000



Source: IEA (2002)

4.1.2 Decrease in private electricity R&D support

Individual utility investments in R&D have decreased since the early 1990s, but have not disappeared. In the U.S., the 112 largest investor-owned utilities, which perform over 93% of non-federal R&D, reduced their R&D expenditures from $778 million in 1993 to $486 million in 1996 (in constant 1997 US$) (PCAST 1997, Eto *et. al.* 1998). Private investments in energy R&D in the US dropped from $ 4.4 billion in 1985 by 40% in 1994 in constant 1997 US$ (Dooley 1997). The reduction in investments in energy R&D in the US, also had impacts on the number of energy technology-related patents, which decreased considerably since the early eighties (Herzog and Kammen, 2002).

Deregulation necessitates utilities to review their investment strategies and to cut costs and the risk that ratepayer-financed investments will become public rather than proprietary assets.

In the US, NARUC[12] recommended that utilities invested at least 1% of their annual revenues to R&D efforts, but in practice this has not been observed. In 1994, a total equivalent to 0.3% of electricity revenues was invested in R&D, while for the industrial sector as a whole, 3.1% is invested in R&D (Dooley 1998, Brockway and Sherman, 1996).

[12] NARUC: National Association of Regulatory Utility Commissioners.

4.2 Main impacts of reforms in developing countries

In general, we observe four types of consequences for energy R&D activities during power sector reforms:

a) Greater technological modernization in some developing countries coupled with an undermining of the domestic technological capacity;
b) Diversification of the electricity utilities' research agenda;
c) Greater interest in short-term projects;
d) An immediate reduction in funding of R&D activities in general; and
e) Interruption of collaborative processes and energy programs.

4.2.1 Modernisation and technology development

Power sector re-structuring in developing countries has brought about significant investments in technological modernisation that is coupled with the creation of new institutional setting required for regulation, billing, creation of spot markets, wholesale and retail sale competition. The Brazilian Association of Distributing Utilities ABRADEE reports that most of its associates technological needs are imported (ABRADEE 2002). There are indications that during 1995-1998 technological products imported by the electricity sector increased by 50% per year (Bicalho, 2002)[13]. For example new generation technologies such as combined-cycle turbines and co-generation systems have been introduced and several utilities in Brazil have upgraded considerably their information technology systems over the last years.

However the modernisation process has tended to aggravate the commercial balance of trade of most developing countries that need to import these technologies, software and services, and pay licences and royalties. Also, if local industrial and technological capacity is low, the impacts on the commercial and services balances of these countries will continue to aggravate as new technologies of electricity generation, transmission, distribution and systems operation are required and imported.

In the Brazilian case, the government is stimulating the technological modernization of the power sector by importing natural gas-fuelled thermal plants as part of its Priority Thermoelectricity Program (PPT), launched in the beginning of year 2000. The PPT program is intended to help meet the electricity demand increase, diversify the energy national matrix (governmental plans are to increase the participation of natural gas from the present 7% to 20% up to year 2010), and promote alternatives for private sector investments in generation. More recently, a proposed law is being discussed in the National Congress, extends incentives given to electricity producers using wind, small hydro and biomass to those plants using of aero derivative gas turbines (PL 5109, 2001).

However, in the particular case of gas turbines, the country does not have sufficient technical and industrial expertise in the technology. This has the consequence that technologies and services, even those related to O&M, are being imported aggravating the national commercial balance of trade (Zoratto, 2002). Contrary to hydropower technology, which is dominated in the country, the

[13] This rate of growth reduced considerably since 1999 reflecting the devaluation on the national currency, but are still considered important.

relatively small size of the proposed plants is one of the reasons why multinational subsidiaries and other private agents in Brazil do not invest in developing their local technological capacity. During year 2002, the CTEnerg public managed energy fund started to support an effort to bridge the domestic gap in gas turbine technology[14].

For many developing countries, power sector reforms present an opportunity to create strategies to increase investments in domestic technology R&D and capacity building which can help minimize the direct and indirect trade deficit associated with the power sector reforms. Very often, this aspect is not well researched or considered, especially because, developing countries have little tradition in investing in domestic energy R&D. If no action is taken, it is likely that there will be a preference of importing new technologies with proven track records from the international marketplace by the new utilities. However, it should be noted that existing information is extremely spotty and have not helped to provide a consistent picture, even for the countries considered in this book.

As noted by Katz (2001), the economic structural reform process in Latin America has caused significant changes in the technological behaviour of energy companies of several countries, which closed down their R&D and engineering departments and opted to promote the modernization of the energy infra-structure by importing technologies and expertise from abroad[15]. Very often, the newly privatised utilities owned by foreign utilities preferred to concentrate their R&D efforts in their home countries, accentuating the observed global trend for centralization of energy R&D activities (Bourgeois and Jaquier-Roux 2001).

On the other hand modernisation has helped to diminish the technological gap between developing and developed countries, illustrating a convergence of energy consumption and production patterns (as noted by Mielnik & Goldemberg, 2000, 2002) amongst them but at the expense of opening internal markets to imported technologies and reducing the domestic technological capacity in developing countries (Katz 2001).

Experience from many countries in Africa is that new investments in the electricity generation after power sector reforms has mainly concentrated on thermal technologies using gas, diesel, coal, bagasse and oil. This could be attributed by the low cost of investment and short-term nature of such projects. Table 3 presents some new investments initiated during the period of power sector reform in several African countries in operation by year 2002. Implementation of most of the above projects started 1996/97 and most of them are found in countries with inadequate generating capacity to meet demands for electricity. Ownership of the projects has been dominated by non-national companies or individuals and local participation in the sector is very limited because of high investment capitals required (Kerekezi and Kimani, 2002). Reforms

[14] This effort is being promoted by the Ministry of Mines and Energy, Ministry of Science and Technology and Industrial Associations. The Gas Turbine Programme aims to build indigenous capacity in project design, industrial manufacture, assemblage, operation and maintenance of gas turbines in the country. CTEnerg has already funded the creation of a network (Gas Turbine Network – RTG) of research institutions and initial R&D projects are being proposed together with participation of interested industrial sectors. The RTG efforts are being directed towards the development of small turbines (up to 5 MW) which are suitable to local market needs and are not interesting for the international turbines companies.

[15] Katz (2001) provides a detailed account of the telecommunications industries in Latin America, but also provides a brief discussion of energy R&D and power sector reforms in the region.

have improved generating capacity as well as financial performance in certain utilities. However, there are no indications if these investments have impacted favourably indigenous energy R&D efforts.

Table 3:Status of Installed electrical capacity in African countries si nce power sector reforms as of 2002 (MW)

Country	Oil	Gas	Solar	Hydro	Coal	Diesel	Geothermal	Baggase	Wind	Naptha	Wood
Cote d'Ivoire		869									
Egypt	1520	1300									
Eritrea						80					
Ghana	845	440		912		60					
Kenya						273	100	2.5			
Mauritius					138.3			185.6			
Morroco					1356				50		
Nigeria	586	586									
Senegal						93				168	
Tanzania	90	362						14.3			3.5
Tunisia		471									
Uganda				18							
Zimbabwe				0.75				20			
	3041	**4028**	**0**	**930.75**	**1494.3**	**506**	**100**	**222.4**	**50**	**168**	**3.5**

Source: Karekezi and Kimani, 2002.

4.2.2 The diversification of the energy R&D agenda

Utilities in many countries, such as the USA and England as well as in developing countries are diversifying their businesses to venture into other areas such as telecommunications, Internet services, cable television, and water services. This has also happened in Brazil where some utilities have created other Energy Service Companies (ESCOs, an unregulated industry) in order to expand their businesses in the area of energy efficiency and allocate the compulsory investments in energy efficiency programs.

From around 1999, Eskom started to diversify its activities in South Africa in preparation for change in its ownership status (from government owned to public owned). Plans are that within five years a significant proportion of its income will come from other services than electricity. In 1999, Eskom moved its Technology Research and Investigations Division into Eskom Enterprises, an unregulated part of Eskom's business[16]. The new division called Technology

[16] Non-regulated business is conducted by Eskom Enterprises PTY Ltd, a wholly owned subsidiary of Eskom, and Eskom's vehicle for ventures into Africa in the area of energy-related products and services. It is Eskom's vision that

Services International is a separate entity from the regulated electric utility Eskom (Eskom, 1999). This is an internal effort at preparing the company for the reform process. New research areas have been included in the company's portfolio in 2001: "Business and Market Technologies" that includes IT, technology markets, fuel and power markets and telecommunications (Eskom, 2001). This illustrates the pursuit of better positioning the company in the region's energy and related services market as it prepares to a more competitive environment in South Africa.This branch of the South African utility is also active and expanding its businesses in other African countries. Eskom is currently actively involved or seeking to participate in electricity industries in Malawi, Lesotho, Uganda, Tanzania, Mali, Senegal and Mauritania.

This diversity in utilities' businesses moving away from conventional electricity sales as their sole income source clearly influences the orientation of their R&D investment portfolio. There is also the possibility that utilities invest their financial resources in R&D areas other than energy, if corporation boards and shareholders find other options more attractive.

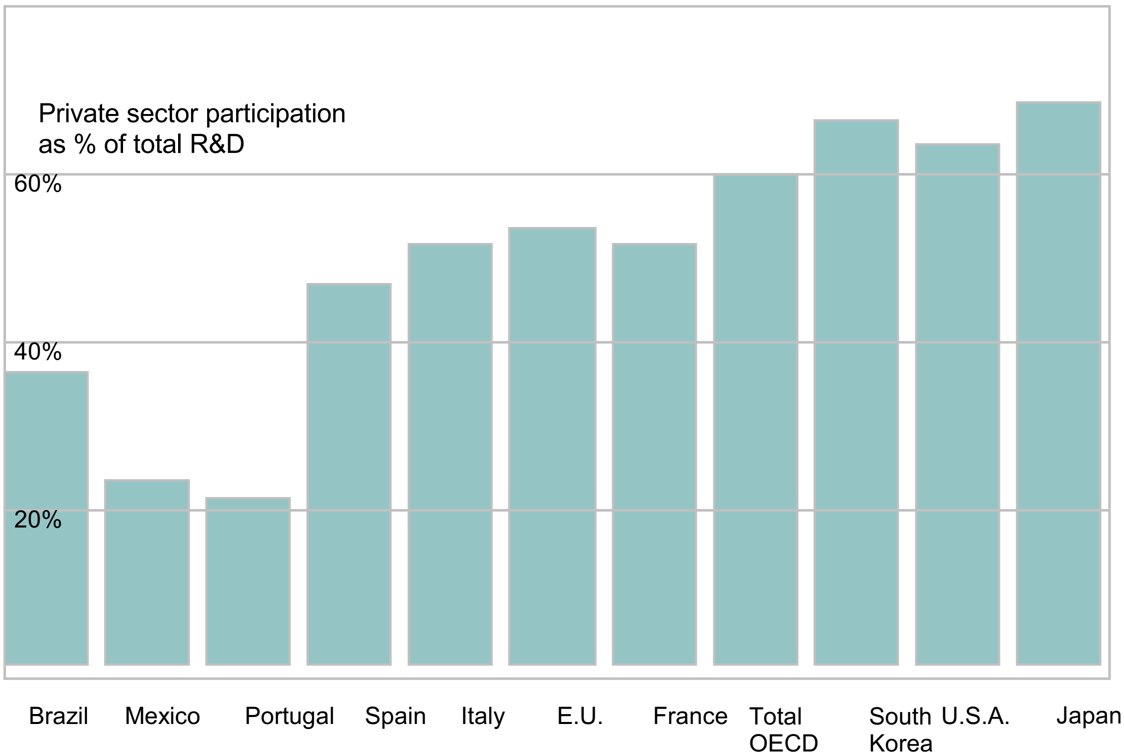
4.2.3 Impacts on R&D funding

Energy R&D can have three different sources of support: public funds (or taxpayers' money), energy users financing, and private investors.

Data from Brazil and India shows that government is the main investor in total R&D efforts, including energy. In Brazil data from the Ministry of Science and Technology indicates that about 63% of the national expenditure on R&D is made by government (federal and state) and the remainder by private sector. In most industrialised countries such as South Korea the majority of investments in R&D is undertaken by the private sector (Figure 5).

any business that is lost as a result of electricity reform in Africa is more than made up with new business in the continent (Eskom Annual Reports 2000, 2001).

Figure 5: The participation of private sector investments in R&D activities (1999) in percentage



Source: OECD, 2001, and Brazilian Ministry of Science and Technology (2002)

Sagar (2002) also shows that in India the government dominates the investments in R&D. During 1996-97, central and state governments were responsible for more than 80% of the country's expenditures on R&D, and like Brazil most of the efforts were carried out inside the country's scientific agencies. Investments in energy-related R&D represented 7.6% of the national R&D expenditure during 1996-97, and again most of this (95%) comes from the central government and states.

Reforms in Brazil have brought a sharp cut in financial support and stability of the main power sector R&D facility. As major utilities were privatised they stopped their traditional contribution to CEPEL. This resulted in a reduction of research staff and projects initiatives. CEPEL now has to compete with universities and newly established firms that are being contracted by utilities to undertake some of their own R&D projects. Federal support through Eletrobras for electricity R&D has decreased. This was a signal of decreasing federal direct support to power sector R&D activities in CEPEL.

On the other hand, since year 2000 a Bill approved by the Brazilian National Congress obliges that a percentage of utilities (generation, transmission and distribution) is spent in utilities efficiency and R&D programs and also another percentage is collected by the newly created national Electricity R&D Fund (CT-ENERG), which is publicly managed[17] (see Table 4). In the case of Brazil, funds dedicated to power sector R&D have more than tripled with this mechanism.

Table 4: Legal annual investment requirements in energy efficiency and energy R&D by electricity utilities in Brazil (as % of their annual net sales revenues)

Sector/types of utilities	Year	Energy Efficiency[a]	Energy R&D (% of net annual revenues)		
			Total	Utilities	CT-ENERG
Generation [b] and Transmission	≥ 2000	-	≥ 1,00%[d]	0,50%	0,50%
Distribution	1998-1999	≥ 0.25% end-use, ≥ 0.65% supply-side	≥ 0.10%	≥ 0.01%	-
	2000-2005	≥ 0,50%	≥ 0,50%	0,25%	0,25%
	≥ 2006	≥ 0,25%	≥ 0,75%	0,375%	0,375%

Notes: ([a]) Since year 2000 only end-use energy efficiency projects can be financed (Law 9.991/2000). ([b]) Generators using renewable resources (solar, wind, small hydro plants and biomass) are exempted from these requirements.
Sources: Jannuzzi&Gomes (2002)

Ghana established an Energy Fund by the Energy Conservation Act (1997) which collects a levy on petroleum products and has the purpose to invest in renewables, energy R&D and efficiency programs. However, this fund has not yet become operative as of 2002.

Thailand's Energy Conservation Fund allocates budget expenditures for R&D. R&D is one of the subprograms under the voluntary program (ENCON Programs are categorized into compulsory, voluntary and complementary programs). During 1995-1999 about one-third of the allocated resources for voluntary programs was dedicated for R&D, but for the period 2000-2004 the allocated expenditures are proportionally much less and more resources are allocated for diffusion and promotion of technologies (Table 5).

South Africa's Eskom has also increased its budget towards R&D (Table 6) motivated to be better positioned by future competitive advantages in the African region. However, it is important

[17] The CT-ENERG is managed by a board of 9 members representing the Ministry of Science and Technology, the National Research Council (CNPq), the Agency for Project Funding - FINEP, Ministry of Mines and Energy, the Regulator (ANEEL), 2 representatives from the academic community and 2 from the private sector. CNPq and FINEP are agencies under the Ministry of Science and Technology.

to note that most of the increase in Eskom's R&D budget is allocated to commercial oriented R&D.

Brazil has been the only developing country amongst those surveyed in this work that has seen an increase in funding for PIER&D and increasing power sector utilities investments in R&D with a specific policy instrument[18]. As part of the economic reforms introduced in the nineties several dedicated sectoral R&D funds have been introduced in the country (Table 7). Each of these funds has a governing board composed by members of government, academia and private sector, which is responsible for approving R&D investment portfolios. The Brazilian Ministry of Science and Technology is in charge of presiding the governing body and responsible for providing administrative support for the operation of the Energy Fund. It has also created a new institution, the Centre for Strategic Studies in Science, Technology and Innovation[19], that hosts the fund's technical secretariat and is responsible for recommending research plans, developing technology foresight exercises and evaluating research activities undertaken.

Table 5: Thailand: Expenditure on Energy R&D under the ENCON Fund Voluntary Programs (Actual and Planned) during 1995 -2004 (in million baht)

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Expenditure Plan	100	100	120	140	150	165	217	192	247	247
Total estimated expenditures	275	553	626	655	672	691	1,075	1,201	1481	1,974
Actual expenditures	30	11	31	213	240	Na	Na	Na	Na	Na
Total actual expenditures	52	135	40	856	522	Na	Na	Na	Na	Na

Source: Pacudan (2003)
Note: 1.00 US dollar = 40 baht (Dec. 2002)

Table 6: South Africa's Eskom annual expenditures in R&D (1993 -2002) in million Rands

	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002
Expenditure Plan	15,000	27,000	31,855	61,951	85,698	105,000	189,000	184,000	284,000	160,000

Source: Eskom (2002)
Note: 1.00 US dollar = 9 rands (Dec. 2002)

[18] South Africa's Eskom is increasing its budget for R&D activities as part of its strategic preparation towards the country's power sector announced reforms.
[19] http://www.cgee.org.br

Table 7: Annual Budgets of Sectoral R&D Funds in Brazil (1999 -2002) in millions of R$

Sectoral R&D Funds	1999	2000	2001	2002*
Oil and Gas	109.4	245.7	151.1	193.0
Infra-structure		45.1	138.6	160.0
Space		5.4	5.4	5.4
Telecommunications (a)			239.0	255.3
University/Industry			192.0	214.1
Energy			80.0	71.4
Information Technology			40.0	44.0
Hydro resources			26.8	28.3
Mineral resources			2.7	3.2
Agro-business				50.7
Health				50.7
Biotechnology				21.7
Aviation				21.7
Total	109.4	297.8	887.6	1,124.3

Notes: (*) These are total budgets allocated in the beginning of each fiscal year, actual expenditure data may differ. (a) Fund managed by the Ministry of Telecommunications.
Source: MCT (2002)

In general, we observe that power sector reforms over the past 10-15 years had different impacts on sources and levels of funding for energy R&D: decrease in government (taxpayers money) and utility support, and the appearance of new mechanisms to fund PIER&D, such as public benefits charges, which will be discussed in more details later.

4.2.4 Collaborative efforts

Research done in collaboration amongst private or public energy companies is one way to pull resources and share risks over long-term and uncertain projects. It also helps to reduce individual costs in trying to solve problems that are common to all participants, lowering the total societal costs of energy R&D. The introduction of competition, however, raises new concerns over private utilities that perceive new comparative disadvantages if there is the possibility of other companies to free-ride on the benefits that can be associated with the results of those investments. Therefore, investors will consider an enhanced screening of projects that can be yield exclusive proprietary rights to the investors.

The transition from state-owned vertical monopolies towards a more competitive and liberal structure leaves to market forces the creation of a research agenda for the utilities, unless there is appropriate regulation and government policy that addresses this issue. If not, competitive and profit-seeking utilities will be interested in an agenda centred mostly on commercial R&D. The situation is worrisome especially in developing countries that have in the past created and maintained research establishments in close association with state power companies (e.g. Brazil, Mexico, India).

Prior to reforms, as mentioned, often developing countries had a single (or few) large utilities which supported their own R&D facilities or had a government supported research institution (e.g. Central Power Research Institute in Bangalore, India, Instituto de Investigaciones Eléctricas in Cuernavaca, México, CEPEL, Rio de Janeiro, Brazil). One of the outcomes of reforms breaking-up large vertically integrated utilities into smaller units, is that this eliminated economies of scale in R&D and left similar companies to face and try to solve similar problems. In fact, the recent experience in Brazil is pointing exactly towards this direction (Jannuzzi and Gomes 2002, ABRADEE 2002).

4.2.5 Greater interest in short-term R&D

Reforms oriented the energy research agenda, cutting back programmes that had long-term objectives and relatively large societal spillovers (Defeuilley&Furtado, 2000, Williams, 2000). In the US, the Electric Power Research Institute EPRI had to re-formulate its portfolio of projects and in 1995, 50% of its resources were dedicated to projects that should produce results up to 5 years, 30% in projects with duration ranging from 5-10 years, and 20% in projects with duration of 10-20 years (Jannuzzi 2000).

An analysis of the utility R&D proposals submitted to the Brazilian regulator during 1999-2000 shows a concentration on low risk and short-term programs (Jannuzzi & Gomes, 2002). Table 8 shows the expenditure on R&D projects by Brazilian utilities operating in São Paulo State during 1998-2001[20] according to the type of project. The information illustrates the concentration on applied research and demonstration projects, which together represent more than 80% of R&D expenditures during the period considered. Utilities' R&D projects are modest in size and scope, generally conceived as annual or biannual projects and with limited technological contributions. The Brazilian Association of Distributing Utilities (ABRADEE) corroborates these conclusions (ABRADEE, 2002).

[20] São Paulo State Utilities' R&D expenditures represent approximately 50% of the country's "regulated energy R&D".

Table 8: Investments in R&D project by Brazilian Utilities operating in the State of São Paulo (1998-2001) in current R$

Type of R&D	1998/1999	1999/2000	2000/2001	Total Expenditure (R$)
Experimental Development/ Demonstration (ED)	3,287,372.00	2.900.937.40	5.195.916.00	11,384,225.40
Applied Research (AR)	4,372,721.00	6,214,670.92	17,750,274.51	28,337,666.43
AR and ED		620,272.00	2,622,780.00	3,243,052.00
Basic Research (BR)	373,292.00	1,784,976.00	2,305,077.00	4,463,345.00
Total	8,033,385.00	11,520,856.32	27,874,047.51	47,428,288.83

Note: Exchange rate US$ 1.00 = R$ 3.54 (Nov. 2002)
Source: CSPS (2002)

It is likely that once cost reduction opportunities with the existing methods, processes and technologies are exhausted there might be a renewed interest for private companies to invest in longer-term R&D.

5. Barriers to promoting energy R&D activities in developing countries

Several of the energy challenges facing developing countries' electricity sector and illustrated here would be mitigated by greater use of clean and efficient technologies. However bringing such technologies to market, will require substantial investment. The energy technologies that offer private benefits as well, the public benefits from their increased use will occur as a result of market forces. Therefore it might be important to implement public policies that promote market transformation in order to promote their dissemination.

There are several barriers inhibiting investment in innovative, clean and efficient electricity technologies in developing countries and other public interest energy R&D activities.

First, there are lacking mechanisms for sharing the risks and returns from technology development and commercialisation among agents in the private sector. R&D investments are usually inherently risky. Indigenous equipment manufacturers, electricity utilities, ESCOs, and renewable energy developers may not have sufficient experience, incentive or resources to invest in technology development with uncertain outcomes. In addition, domestic private entrepreneurs, in many cases, cannot face the competition and technical expertise of larger multinational corporations with increased access to local markets. Traditionally governments in developing countries have been the main (and sometimes the sole) supporter of R&D activities. In Brazil, for example, in 1999 about 63% the direct investments made in R&D in general came from government (federal and state), whilst in many industrialized countries the private sector is responsible for most part of investments (Figure 5).

Second, there are lacking mechanisms for collaboration between the public and private sectors. For example, once the public sector has developed a technology to the stage at which the private sector can capture some of the benefits of R&D, it makes sense to share the risks and returns between the public and private sectors. For example, relatively few universities and research institutions in Brazil have experience in developing collaborative research with private utilities. Nevertheless, the experience has been much more relevant with regards to collaborative R&D with state companies, such as ELETROBRAS and PETROBRAS, and this collaboration tends to decrease as state companies are privatised.

As a consequence of these two barriers, most of the R&D activities are carried out in public universities research laboratories and very little activity is observed in the private sector. More than 50% of the resources invested by Brazilian utilities in the State of São Paulo are contracted with universities (Table 9). However, there has been a recent trend of increasing partnerships between universities and utilities in projects carried out by mixed teams, as shown in Table 9.

South Korea has been one of the very few developing countries that has promoted consistently public policies to stimulate R&D activities in its industrial sector with direct results in increasing the number of patents when compared to other developing countries with similar conditions in the early eighties (Table 10)

Table 9: Executing agents of R&D projects in the State of São Paulo, Brazil (1998 -2001) in % ot the total resources allocated

Executing Agent	1998/1999	1999/2000	2000/2001	Total 1998-2001
Utilities	22%	10%	0%	6%
Private Consulting Firm	4%	5%	4%	4%
Electrical industry	0%	0%	18%	10%
Research Institutes	15%	15%	5%	9%
Partnership Utility/University	0%	4%	28%	17%
University	58%	66%	45%	52%
Total	100%	100%	100%	100%

Source: CSPS (2002)

Third, given different investment choices the private sector tends to make investments in projects with shorter-term payoffs than energy R&D. This is aggravated when developing countries experience economic and political instability, which makes private firms still more cautious about long-term investment.

Fourth, utilities are facing competition in generation and/or retail services tend to focus their R&D on projects that will make them more competitive in the short term The introduction of reforms in many developing countries has also brought up the creation of new institutions to regulate power sector activities. The relatively long period of time required to set and implement new rules and regulations has led private companies to suspend most of their longer-term activities.

Fifth there is limited experience in developing countries to design, manage and fund energy R&D programs that comprise numerous activities and projects developed by several different agents (academic, private and public research establishments, and industry) over a lengthy period of time[21].

The result of these conditions is a mismatch between actors who have the resources to undertake such R&D and their incentives and capacity to do so. Thus, despite several agents active in electricity sector R&D, there may still be under-investment in R&D in new clean and efficient energy options relative to the potential social benefits of increasing the use of such options.

[21] Of course, there are exceptions, e.g. the Brazilian Alcohol Energy Programme, the Nuclear Energy Programmes in India and Pakistan.

Table 10: Number of Patents in the US by countries: Brazil, Argentina, Mexico and South Korea (1988-2000)

Year	Brazil	Argentina	Mexico	South Korea
80	24	18	43	8
81	23	25	45	17
82	27	18	43	14
83	19	21	34	26
84	20	20	43	30
85	30	11	35	41
86	27	17	37	46
87	29	16	45	97
88	36	20	41	159
89	41	17	34	225
90	62	16	42	405
91	40	20	45	538
92	57	24	50	779
93	60	32	52	943
94	63	31	45	1.161
95	63	30	46	1.493
96	62	35	57	1.891
97	74	43	77	3.259
98	91	44	94	3.562
99	98	54	100	3.314

Source: U.S. Patent and Trademark Office (USPTO). Based on presentation given by A. Amaral, Ministry of Science and Technology 2002a, Brazil 15/October/2002.

6. Policy recommendations

6.1 Electricity Challenges and R&D activities in Developing countries

The ability of public policy makers to determine an energy R&D agenda which contain a list of technologies and the criteria to set priorities is the key factor that will guide the investments and policies and regulatory measures to be implemented. Basically policy makers will try to answer the question; what is the set of technological developments that are needed in the country? The process of finding the responses will create a R&D agenda and priorities to rank and guide the required efforts.

6.1.1 The search for a relevant PIER&D agenda and priorities

Over the next few years to come, the power sector in most developing countries will face several challenges as a result of restructuring and privatization and objectives to promote sustainable development. As seen in other chapters there are still significant challenges with regards to the improvement of the quality and access to affordable electricity services, deployment and innovations in energy efficient and renewable energy technologies and energy planning in developing countries. Ideally, these challenges can necessitate initiation of the search for innovative solutions which may help to the organise domestic expertise and businesses.

Utilities whether privately or publicly owned are faced with greater competition which will avoid capital outlays and long paybacks on their R&D activities, and will concentrate on opportunities to promote cost reductions. This is illustrated by the information displayed in Table 11. Countries surveyed during the early stages of reforms show the short-term concern to improve the financial health of utilities (inefficient operation and management, technical and commercial losses). If we look for longer-term objectives, such as providing access to electricity to all households, including rural areas, this allows the creation of an agenda for PIER&D in these countries.

In other African countries most utilities are in their initial stages of power reforms and apart from efforts to expand their grid networks, they are also struggling to improve their efficiency in electricity transmission, distribution, billing and debt collection. For example in some utilities, system transmission losses are as high as 30%, and customers per employee ratios as low as 20:1 compared to 10-12% and 125:1 respective values set as nominal targets internationally.

Table 11: Selected countries and their main electricity challenges

	Short Term	*Longer Term*
Indonesia	Solve power sector financial problems and reduce technical and economical losses, improve access	Domestic oil reserves are limited. Geographical difficulties to create a whole-nation on grid system
India	Reduce commercial and technical losses. Solve power sector financial crisis	Complete electrification of all households and villages, specially in rural areas. Promote environmentally ways to use indigenous coal resources
Brazil	Secure supply of electricity Improve end-use efficiency Reduce financial problems of utilities	Diversification of the generation mix. Universal access to electricity. Develop domestic technologies and expertise. Contribute to improve the industrial competitiveness. Guarantee public interest characteristics of the power sector.
South Africa	Provide affordable energy services to low income households, create more competitive electricity industry for new investment	Social equity, economic efficiency and environmental sustainability
Ghana	Rapidly growing demand and need to import power. Improve the distribution network and administration of utilities	Develop domestic generation affordable to households and business
Thailand	Supply security and environmental problems	Development and insertion of alternative sources of energy into the energy mix, decrease the participation of natural gas and diversify the electricity generation mix.

The search for a more focussed PIER&D agenda for developing countries needs to be consistent with their *national development plans*. The pursuit of an energy R&D agenda is not an end in itself but needs to be closely integrated with the industrial development plan, and needs to be part of the country's vision towards its future. Therefore a relevant PIER&D agenda is conceived in a particular context of socio-economic development and is a component of a long-term national energy plan, as initially mentioned in the chapter.

It is possible to list some of the most pressing power sector-related energy challenges that can help establish PIER&D agenda in developing countries:

- meeting the rapid growth in demand for energy
- developing more cost effective approaches to extending electricity services to rural areas and promoting universal access;
- preserving and enhancing service reliability and power quality and protecting customers' rights;
- limiting foreign exchange outlays due to energy-related activities;
- ensuring that access to electricity services remains affordable to the whole range of income classes of firms; and households; and,

- harmonizing energy sector development with the country's or region's goals towards economic prosperity and environmental sustainability.

These challenges can be met partly by increasing efficiency in supplying and end use of electricity, and increase use of renewable energy sources for both grid-connected and off-grid. R&D activities can play a pivotal role in stimulating greater use of these energy options.

Depending on the technology in question and the quality of available human resources, the objectives of R&D investment needed varies widely. Examples include the following:

- developing domestic expertise to conduct baseline studies of electricity end use, and analyses of the technical, economic, and market potential for different supply and demand side technologies;
- developing new electric generation technologies;
- adapting existing technologies to developing country market conditions;
- creating domestic technical and managerial capability to operate, maintain and improve technologies and services related to generation, transmission, operation and distribution of electricity, as well as promoting the efficient end-use of electricity;
- reducing the cost of energy from critical technologies through performance improvements, economies of scale, and learning curves; and
- developing new models for delivering electricity services and improving mechanisms for transforming end use markets.

These examples illustrate not only the range of energy supply and end use (and the required funding) technologies that might be the focus of PIER&D, but also the range of activities that might be needed depending on the barriers inhibiting market penetration of a specific technology.

Developing countries need to develop processes to select robust sets of R&D themes that are relevant to meet their energy challenges and best strategies to implement the required efforts.

6.2 Policy and regulatory instruments to advance PIER&D

This section discusses some of the instruments that policy makers can implement in order to create public policies that protect and enhance the contribution of indigenous energy R&D efforts in developing countries to promote economic development balanced with environmental sustainability and social equity. Three issues are discussed in this section: criteria for government support and intervention for PIER&D, funding energy R&D and institutional arrangements for managing PIER&D.

6.2.1 The need for regulation and government intervention

As mentioned earlier, in the past most of the support for energy research and training has been provided by the public sector. This support can be considered small, but it has been the only main place where these activities have been taking place. In Brazil, participation of private sector in energy R&D is a very recent experience and has been a consequence of compulsory requirement for investments in R&D by utilities and the creation of the National Energy R&D Fund (CTEnerg), a public interest energy R&D fund.

As discussed in the previous section, the presence of several barriers to individual private firms to make investments in the energy sector have been offered to justify the need of continuing governmental support either to promote PIER&D or fund them, and sometimes to complement private funding. The following are the barriers relevant for regulation action and government intervention in developing countries:

- The majority of firms in developing countries have little (or no) tradition in R&D activities.
- R&D risks are too high for the private sector, the time for full scale commercialization is too long and the potential returns based on present energy prices are too low.
- Private returns to R&D do not usually have to capture the environmental benefits, reduced dependence on fossil energy, regional development needs and creation of jobs.
- Public investment is crucial for maintaining industrial competitiveness.internationally.
- Given that information is a public good, the private sector would be expected to under-invest in R&D relative to its benefits to society as a whole.

Geller et al (1987) have demonstrated the importance of federal funds for R&D in advancing energy efficiency and benefits to society for the US case. The issue of governmental support is controversial though. Some analysts from the US cites evidence to the contrary and have challenged the justifications for public intervention in R&D activities. These critics argue that the government has a poor track record when it comes to picking technologies in which to invest, and that they tend to over invest in R&D programs that have a low public payoff and (Sutherland and Taylor, 2002, Wallstem, 2001, Kealey, 1997). However, this may be a case of poor ex-ante evaluation of government funded programmes and consistency of long-term public policies. Mostly, the main problems with government-funded programs are that they may have little relationship with the market failures they intend to address, and sometimes they are poorly managed and heavily politized.

It also should be noted that the assertion that private firms will not invest in basic research or that they have not engaged in risky, long-term R&D is not correct for many large corporations located in industrialised countries. Leading companies in rich countries spend increasing amounts of money to develop new products (e.g. oil companies, lighting equipment industries). However, the situation is entirely different for the majority of developing countries where most companies (with some remarkable exceptions) tend to ignore efforts to invest in R&D because most of its technology needs have been traditionally supplied from purchases and licensing from abroad.

Of course, not all technologies need to be developed locally, but an assessment of cost-effective and strategic options need to be performed by developing countries as part of a public-interest oriented energy R&D policy. At least these efforts will create local capability to develop, adapt, maintain and therefore disseminate the new technologies. Photovoltaic systems and CFLs programmes are examples of technical capacity building in several developing countries.

6.2.2 The establishment of goals and objectives of PIER&D

It is necessary to establish goals and objectives to be met by PIER&D that are consistent with broader developmental policies of the country and address the energy challenges. This is the first step of the process of creating a PIER&D agenda and requires that planners/policy makers share a consistent and long-term vision of the future with the society.

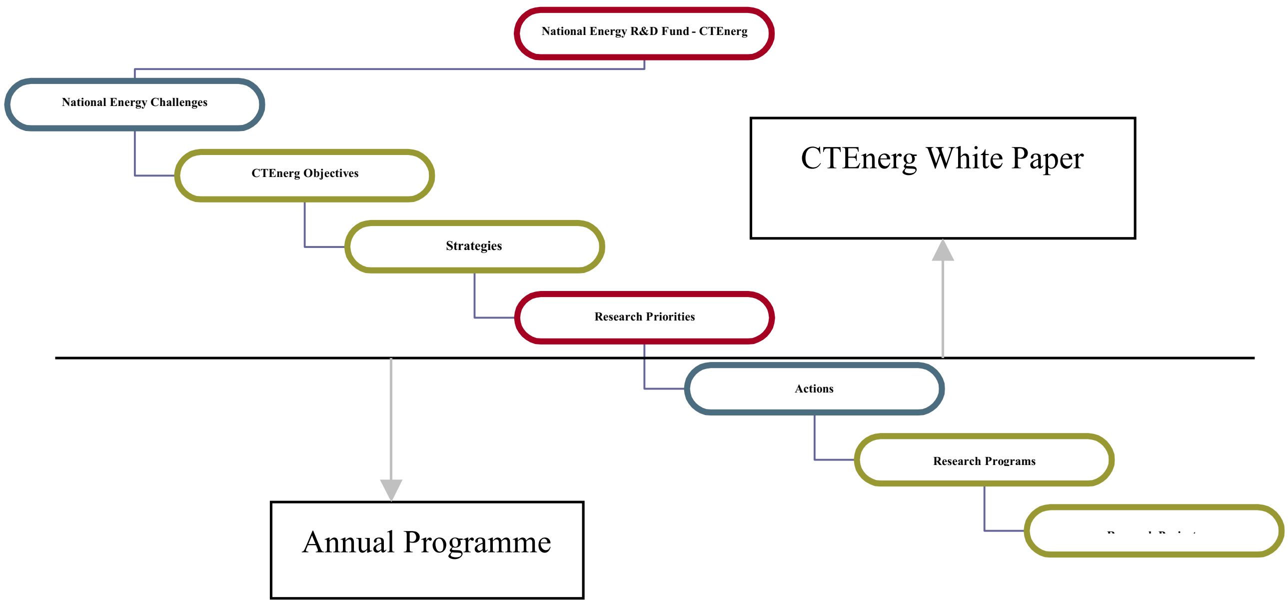
In general, investments in PIER&D in developing countries should contribute towards:

- decrease electricity intensity of the economy;
- increase the technological options available to the country, reducing technological dependence, offering lower costs and better services to customers, addressing universal access issues and particular regional and rural characteristics;
- develop, consolidate and promote the country's industrial competitiveness and increase the opportunities to export know-how, technologies and technical services;
- promote domestic capacity building in the areas of energy analysis, regulation and technology development.

These are suggestions for the objectives of a PIER&D that help create an agenda for R&D activities. This agenda basically lists all the activities that are considered relevant, consistent with the country's developmental goals and are not entirely financed by the market.

In Brazil the existence of compulsory investments in energy R&D by utilities required the definition of public interest purposes for the National Energy Fund CTEnerg. Figure 6 shows the organisation of its objectives, strategies, research priorities, and ultimately energy programs. The CTEnerg White Paper establishes the general philosophy and directives that guides investments. Annually it also establishes a multi-year program with action plans consistent with research priorities approved by its governing board.

Figure 6: Organisation of Energy Challenges, Research Priorities, Programs and Projects of the Brazilian National Energy Fund CTENERG



Source: CTENERG White Paper (Ministry of Science and Technology. 2002b)

The second step, after the creation of a PIER&D agenda is to establish a process that establishes criteria to set priorities to the list of activities in energy R&D. Basically, this process requires a clear and consensual understanding amongst the stakeholders on issues concerning: why do we need innovation in the energy system? Who are the main beneficiaries of such innovations?

The public sector can also create several incentives (tax benefits, grants, subsidies, etc) to private firms and consumers to encourage investments in development and commercialization of innovative energy technologies.

6.2.3 Regulated Energy R&D

Besides PIER&D and commercial energy R&D presented so far, the regulator can also play an important role in energy R&D and is another possibility to enhance the provision of *public benefits* in a reformed power sector. We call R&D efforts done by utilities under the regulator screening as "regulated energy R&D". This type of R&D activity is distinguished from PIER&D because very often it referes to compulsory initiatives funded by utilities, and may be (or not) included in the tariff structure of utilities. For example, the regulator may establish compulsory investments on R&D activities as to ensure a continuous upgrade of system performance and power quality.

These regulated investments can produce public benefits (benefits to all consumers) and can generate private benefits to utilities as well, but are not necessarily motivated by competitive forces. Regulators will try to implement sectoral policies that have a well-defined range of interests and are under the regulator's mandate (for example: ensure that R&D investments by each utility contribute towards the optimisation of the overall performance of the electrical system).

In Brazil, since 1998 the regulator ANEEL determined that privatised utilities invested part of their annual revenues in R&D programs carried out in the country (Table 4). The regulator so far does not set research priorities nor compulsory areas for investments, but reviews all projects and then authorizes the utilities' investments in new R&D programs. This measure had the initial objective to avoid the risk that the new companies, mostly owned by foreign investors, would transfer all their R&D efforts elsewhere, a trend already noted by analysts (e.g. Bourgeois and Jacquier-Roux, 2001).

An analysis of the research projects conducted by Brazilian utilities shows a high concentration on similar problems, low risk and short-term projects. Table 12 shows that most of utilities investments have been on strategic (commercial) energy R&D, although there has been a trend of diversification as budgets increases. One of the roles that the regulator could be doing is to direct utilities' investments into areas that could maximise system (or societal) benefits (areas A and B of Figure 7) and stimulate cooperation amongst the utilities.

Table 12: Regulated investments in energy R&D in Brazil 1998/1999, 1999/2000 e 2000/2001[a]

Cycle	*Energy efficiency*	*Renewable Energy*	*Generation*	*Environment*	*Strategic Research* [c]	*Total (million R$)*
1998/1999	5%	-	-	3%	92%	12,9
1999/2000	16%	8%	10%	5%	61%	29
2000/2001[b]	14%	5%	7%	10%	64%	80,4

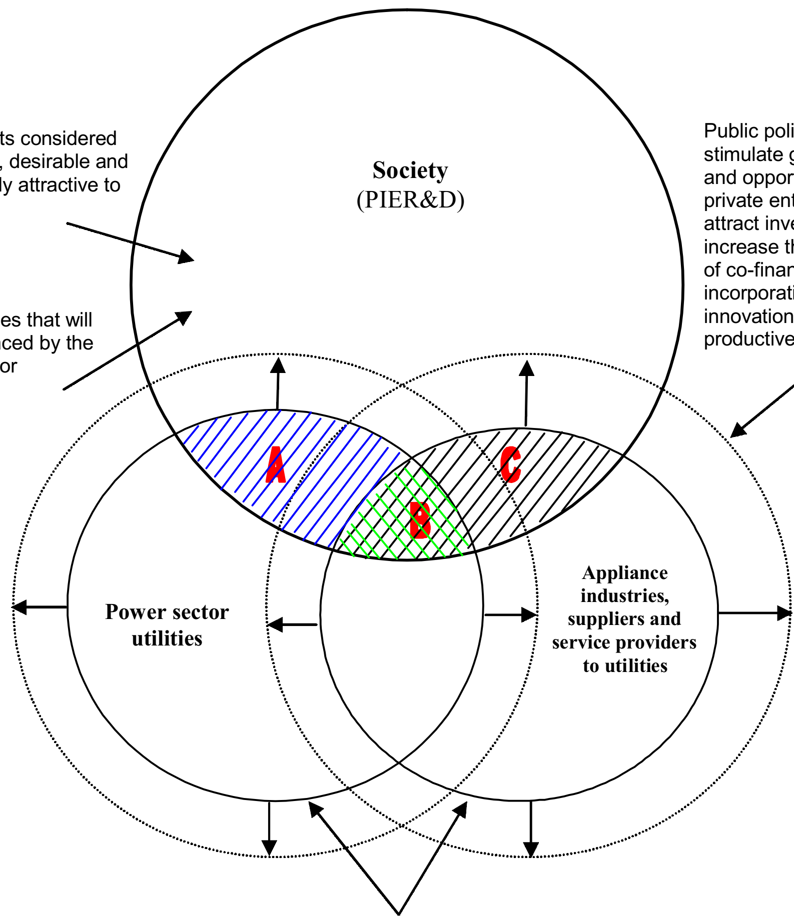
[a] The total number of regulated utilities required to do R&D increased progressively during these cycles 13, 43 and 58, respectively.
[b] Preliminary results.
[c] Commercially oriented projects, as considered by the utilities.
Source: Jannuzzi & Gomes (2002)

In the U.K. there has been experience with the privatised water industry that was able to increase its expenditure levels and patents applications after a comparative performance regulation scheme that forced companies to pursue cost reduction practices. These industries also decided to collaborate when they realized that some spillovers were inevitable and affected the industry collectively. Collaborative research in these cases would liberate funds that could be better spent on company-specific R&D projects (Powell & Szymanski, 1997).

Thus, the activities in this category (regulated energy R&D) are subjected to review by the regulator but are implemented by the utilities. This procedure implies that there is some level of public transparency; therefore utilities will disclose only certain types of information and types of projects that will not harm their corporate interests.

Figure 7 presents the concepts of Public, Corporate and Regulated energy R&D and its relation to the main players. It is very possible (and desired) that R&D done by private agents (utilities or electricity-related industry) yield public benefits as can be depicted from the figure (in many instances public benefits associated with privately motivated innovation will only be realised through widespread dissemination). We see that there is a role for public policy makers to devise ways to give incentives to private agents and promote market transformation so that societal spillovers are maximised.

Figure 7: Types of Energy R&D (Corporate, Regulated and Public Interest) and their relation



Notes:

1) The regions A and B represent R&D project types which can be funded/oriented by the resources under the regulator's supervision (REGULATED ENERGY R&D) and complemented by public funds. Moreover, the region C can be contemplated by public funds too.
2) The expansion arrows (⟶) show a sector's interest area increase.
3) The full line (—) limits the interest areas of R&D activities considered satisfactory, desirable and economically attractive to society, or utilities and other industries.
4) The dashed lines (- -) limit the increased interest areas of a sector's R&D activities. This increase results from public policies which ease or stimulate greater private entrepreneurs' participation.

Source: Based on CTEnerg White Paper 2002

6.3 Funding Public Interest R&D

By definition PIER&D requires public funding to be invested in areas considered socially desirable and are consistent with the national development plans and goals.

Many energy R&D investments have the attributes of a public goods. That is, its outcomes typically have benefits that are not restricted to the party that pays for it (taxpayers of one state or ratepayers of one utility). Some benefits, however, can be captured by private firms (at least for the period of time before patents expire). Other energy R&D investments may have benefits that accrue more to some regions of the country than others; for example, solar energy technologies that rely on direct radiation are applicable primarily to sunnier parts of a country. Also, some investments may be burdensome to specific groups who may not benefit proportionally of the results. These aspects have to be considered when discussing the funding of PIER&D.

The degree of consistency and predictability over time may be as important in stimulating PIER&D as overall trends in funding levels. Irregular funding may damage seriously, and sometimes compromise the entire progress of a programme.

Public Benefits funds as discussed previously may represent a more stable source of public support for PIER&D. But this depended on the regulatory or legislative basis that created them, and this varies widely across countries.

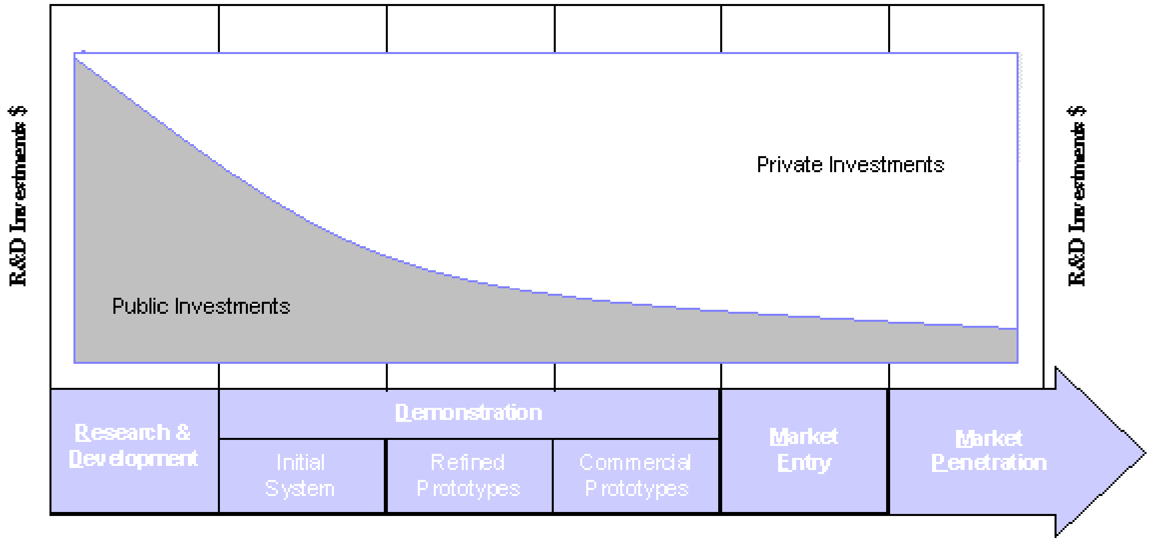
In general, longer-term funds provide greater stability in the commercialisation process.

6.3.1 Matching sources and uses of funding

Funding PIER&D investments is more defensible in areas least likely to be undertaken by the private sector. These areas tend to be R&D on technologies (such as energy efficiency and renewable energy) whose social benefits cannot be easily captured by private firms and where businesses tend to under invest in long-term research because the high cost of discovery makes a profitable return on the investment in R&D risky and difficult.

Figure 8 illustrates a hypothetical share of public and private funds along the energy R&D chain, the closer it gets to the commercialisation stage, the greater participation of private capital is expected. Public funding can be directed to the areas of greater risks and uncertainties of the energy R&D chain.

Figure 8: Cost-sharing between public and private funds in energy research and development



Public programs that subsidize energy R&D may generate incentives that undo the intended benefits, especially when private firms apply for the subsidies. If government agencies fund the most commercially promising proposals, they support projects that firms are most likely to support on their own. This risks crowding out private R&D spending. Because government subsidies cost less than capital from other sources, firms may be tempted to look to government before turning to other sources of support. Government thus must determine which projects would benefit society but not attract private funding, thus determining the PIER&D portfolio. This means that government should not fund the most commercially appealing proposals. If government does its job right, some of the funded PIER&D projects will and should fail.

Unfortunately, this principle runs counter to the incentives of R&D program managers. Program managers may be reluctant to allow too many failures for fear that project failures will be interpreted as program failures. Moreover, they want to avoid rejecting proposals that are especially promising.

The process for allocating PIER&D funds is subject to political pressures. Politicians face incentives to treat technology programs like other government spending, that is, as a way to reward constituents rather than to correct market failures. At the same time, they like to claim successes.

<u>6.3.2 Funds collected from energy consumers</u>

In some countries new mechanisms for collecting funds directly from energy consumers to sponsor energy efficiency and/or R&D programs have been implemented in the course of power sector reforms. These mechanisms have the purpose to replace the decreasing participation of federally and government sponsored programmes and have been increasingly been applied in several countries.

In the USA, many states have created the "public benefits funds[22]", during the process of reforms with the purpose of maintaining the prior level of spending in areas such as energy efficiency, renewable energy, R&D and some low-income services. In general, these funds are not intended to create new charges to consumers and aim to be competitively neutral and non-by passable to ensure that everyone contributes towards activities that benefit all. The mechanism used there is called Systems Benefits Charge (SBC) that are collected from utilities in amounts that vary from 0.5-3% of gross annual revenues, or fixed values as mills/kWh, or lump sums to be spend over a period of time (UCS, 2000).

In the US, several states implemented SBCs, and total support via this mechanism was estimated to be $750 million for energy efficiency, $270 million for renewable energy, and $70 million for energy R&D (UCS, 2000). SBCs have maintained, and in some cases increased, the total amounts spent on public benefits programmes. Brazil has also introduced such mechanism to fund energy efficiency and energy R&D.

6.3.3 Consistency in support

The effectiveness of public funding for PIER&D has been hampered by lack of consistency and swings in political ideology. If PIER&D does not enjoy a sufficiently consistent level of investment over a time period cost reduction or product improvement objectives may be at risk. It is a good strategy that funding PIER&D is insulated from government's budgetary swings due to changes in administrations, or political priorities. Whether SBCs offer greater funding stability in the light of energy users' responses to volatile rates, remains to be seen.

Energy R&D is a long-term process that takes technologies from the research laboratories to market penetration (Figure 2). The technology commercialization process involves basic research, development, demonstration, and scale-up, although not always in linear order, as already mentioned. Government or public agencies that not only sponsor projects spanning the full range of the R&D process, with varying degrees of participation (Figure 8), but also need to integrate and coordinate a range of mechanisms in support of an ETC strategy over time.

7. Conclusions

Power sector reforms have not meant necessarily a decrease in PIER&D activities, but the experience shows so far that unless explicit public policy efforts in the first place, and then regulatory measures are implemented, these initiatives are in fact at threat. It is shown in this chapter that some developing (and developed) countries are increasing their commitments to R&D with new funding mechanisms.

Radical change is necessary in the global energy system if sustainability and climate-change issues are incorporated in future technological choices. It has been observed that reforms have obliged some countries to address and define the role of PIER&D, and establish procedures to

[22] These funds have also be referred to as "Public Goods Funds".

create their own R&D agenda and evaluation procedures. Consequently, developing countries need to create funding mechanisms, establish new (or re-define) institutional arrangement and governance to carry out PIER&D. As these initiatives progresses these countries may benefit from better positioning themselves in global learning systems of energy technologies. This way they will become less dependent, collaborate internationally, and may identify and explore technological niches in similar countries.

It must be noted that developing countries face several barriers and challenges to develop and disseminate innovative, clean and efficient electricity technologies. In additional to the barriers that power sector reform may impose to PIER&D, these countries, in general, have little tradition in investing in R&D and for the most part, rely in international markets to provide solutions to their technological problems.

The concept of public interest energy R&D is socially constructed and is aligned with national development goals. Important national developmental goals that take into account environmental sustainability need a better and efficient power sector infra-structure and PIER&D can play a pivotal role in developing countries once these concepts are embedded in current energy policies.

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- ensuring that market restructuring and/or liberalization in the electricity and petroleum industries focuses on measures that expand the provision of public benefits
- addressing policies, regulation, institutions, financing and management issues to promote sustainable energy practices
- initiating and strengthening capability in energy analysis, information, advocacy, and implementation in developing countries

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