Growing in the Greenhouse

Protecting the Climate by Putting Development First

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Table of Contents

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The Editors

Foreword

"The trouble with being poor" said the artist Willem de Kooning, "is that it takes up all your time." Countries faced with the problems of poverty—people without electricity, without transportation, without livelihoods—have little scope to raise their eyes from these immediate concerns. But the ways in which they deal with these challenges can make a big difference to future climate change.

In Brazil in the 1970s, we were faced with daunting problems. Our dependence on imported oil at a time of escalating prices was sucking resources out of the country, and our rural communities were battered by their dependence on volatile commodity markets, especially sugar. In response to these seemingly separate problems we began a consistent push to encourage and support the use of ethanol as a transport fuel. Over time the nature of this support both changed and shrank, as the technology and systems improved. But the clear government policy remained to keep ethanol as a major part of our energy mix. As the study in this book shows, Brazil is far better off today because of it; our national external debt stands at $100 billion lower than it would have done if we had relied exclusively on oil. The additional revenue in our rural areas has helped support agricultural communities and hundreds of thousands of jobs. And the world is also better off: Brazil's ethanol program offsets some 26 million tons of CO_2 every year. Was this primarily a climate measure? No. But the climate has benefited from Brazil's choices.

Developing countries are acutely aware of the risks of climate change. After all, our people are the ones most likely to bear the brunt of its impacts. The poor depend critically on agriculture, forests, fresh water resources and coastal ecosystems—the very systems most at risk from climate change. When disaster strikes, developing country governments do not have at their command the billions of dollars that their richer counterparts can bring to bear on fixing the mess.

So climate change matters to us. It is a problem not of our making: the greenhouse gases that have accumulated in the atmosphere to date are overwhelmingly from industrialized countries, and the average citizen of an OECD country still emits six times more CO_2 than his developing country counterpart. We expect these countries to make meaningful efforts to reduce their emissions first. Still, there is no escaping the fact that climate change brings a new reality. If we want to avoid a global catastrophe, developing countries will have to find development paths that avoid huge greenhouse gas emissions.

The question explored in this book is: where are the new opportunities for this kind of success? The studies presented here, in Brazil, China, India and South Africa are not just interesting in themselves, but because they represent a new way of engaging developing countries – by speaking directly to the pressing concerns of energy poverty, lack of mobility and energy security that are their immediate concerns.

Nelson Mandela once said: "If you talk to a man in a language he understands, that goes to his head. If you talk to him in his language, that goes to his heart." This book presents a way of talking to developing countries about climate change in our language: the language of those that see human need and poverty as vast and vital challenges that we must overcome. A language that does not merely talk of sustainable development as an adjunct to fighting climate change, but of climate change as one challenge in our fight against poverty.

This book then is a start. The world has far to go in finding the approach that will deal with the worst of climate change. But the ideas explored here are perhaps a basis for a more constructive engagement between developed and developing countries.

FERNANDO HENRIQUE CARDOSO
President of the Federative Republic of Brazil, 1995–2002
Director of the World Resources Institute

Executive Summary

This report explores an approach to climate change policy called Sustainable Development Policies and Measures, or SD-PAMs. SD-PAMs are policies and measures that are aimed at meeting the domestic objectives of the host country, but that also bring significant benefits to the climate through reduced GHG emissions. This concept offers a potentially less divisive approach to engagement between developed and developing countries in tackling dangerous climate change.

International climate change policy is based on the United Nations Framework Convention on Climate Change (UNFCCC), which emphasizes both the need to avoid dangerous climate change and the special challenges faced by developing countries. This raises a potential conflict: on one hand, meeting the objective of the UNFCCC of preventing dangerous climate change is impossible without limiting emissions in at least some major developing countries. On the other, these countries face vital and urgent priorities that inevitably trump considerations related to greenhouse gas emissions: the need to reduce poverty, extend the provision of modern energy services, meet citizens' growing demand for mobility, and many others. How can these two vital sets of priorities be reconciled?

While the concept of combining domestic and climate priorities is firmly embedded in the UNFCCC itself, existing climate agreements have not attempted to systematically foster the integration of climate change and development at the policy level. This report is an attempt to explore some ways in which this might be done, as well as provide some illustrative examples of the types of policies and measures that might fall under the SD-PAMs rubric and some of the advantages and limitations of this approach.

What are SD-PAMs?

SD-PAMs are defined broadly in this report as policies and measures taken by a country in pursuit of its domestic policy objectives—energy security, provision of electricity, improved urban transportation, for example—but which are shaped so as to take a lower-emission path to those objectives. These may be wholly domestic in nature, or involve support or other interaction from other countries or international institutions. By describing these SD-PAMs, this report seeks to open the possibility of including them in an international agreement, thus engaging developing countries more directly in climate change policy while promoting their development.

Why include SD-PAMs within an international climate agreement?

From the point of view of climate protection, the potential benefit of including SD-PAMs is obvious: important developing countries that are not yet ready to take specific measures aimed at reducing emissions can be helped to place their development on a significantly lower-carbon pathway.

From the point of view of developing countries the use of SD-PAMs brings several potential advantages:

1. Recognition. Many developing countries have implemented policies and measures that bring significant emission reductions, which if implemented in industrialized countries would be labeled as climate policy. Yet it is often claimed by some industrialized countries that developing countries are not contributing anything towards the fight against climate change. SD-PAMs offer the opportunity to dispel that impression, and codify contributions of different countries.

2. Learning. By formally sharing and examining each others' policies and measures there is considerable scope for exchanging best practice and other information.

3. Engagement. Rather than advocating a new set of priorities for developing countries, SD-PAMs engage precisely on the issues that these countries consider most pressing. This allows the leveraging of investment and policy efforts made in these core development areas, rather than trying to carve out a separate effort for climate protection.

4. Promotion. The potential to promote both development and climate goals in a way that reduces their total cost is a powerful incentive to both host and donor countries to support appropriate SD-PAMs. The fact that these SD-PAMs are not exclusively "additional" emission reduction measures also opens up a wider range of sources for support.

How might they be paid for?

SD-PAMs of the scale needed to change emissions and development trajectories will require higher levels of funding than have hitherto been available for mitigation in developing countries. Existing mechanisms based on explicit "climate" funding are assessed and found inadequate (Chapter 1). Accordingly, the real challenge is to instill climate benefits and risks into the broader set of international capital flows, only some of which are climate-specific.

Along these lines, it is suggested that SD-PAM funding should be able to come from any source: bilateral aid agencies, the Global Environment Facility, multilateral development banks, export credit agencies, the private sector, the host government (federal and perhaps state/local), state and local communities, or others. The aspiration of the SD-PAMs approach is that by targeting actions of clear mutual benefit, larger financial flows will be freed up than would otherwise have been the case. This remains a complex issue however, and one that requires further exploration.

How might SD-PAMs be incorporated in an agreement?

The report presents a pledge-based approach to implementing SD-PAMs. These pledges are voluntary, and may take several forms, as outlined in Chapter 2:

1. First, a *single country* might pledge one or more SD-PAM that is unique to its national circumstances and not directly related to the pledges of other countries.

2. Two or more countries may make *mutual pledges*, perhaps consisting of simultaneous pledges by both a developing and developed country. This might involve a developed country pledging support for a developing country's activities. This has the additional attraction of engaging donor countries on SD-PAMs in which they have a mutual interest, such as for the development of a particular technology or sector.

3. A group of countries could make *harmonized pledges* in an SD-PAMs negotiation process. This approach acknowledges the global nature of many industrial activities, and opens the door to multiple countries agreeing to the same kind of measures to promote or maintain an "even playing field" for competitive industries.

Accounting for SD-PAMs

Methods for defining SD-PAMs, establishing a registry, reporting and reviewing are examined in Chapter 2. Consideration is also given to whether and how emission reductions from SD-PAMs might be "credited." The premise of SD-PAMs, however, is distinct from project mechanisms such as the Clean Development Mechanism (CDM) in that an SD-PAM will not need to demonstrate that it was undertaken for climate protection reasons. This is a major advantage of the approach, but also means that it is unlikely to practicable to allocate credits for emission reductions achieved in the manner of a CDM approach.

Being able to reasonably assess, in quantitative terms, the contributions different countries make to the collective global effort to protect the climate would provide useful input and information to negotiations that will likely stretch over multiple decades. However, it is important to note that an SD-PAM is a commitment to implement a policy or measure, not on a specific outcome expressed in terms of emissions. Additional work is needed at the sector and policy levels to develop reasonably simple and transparent methodologies to quantitatively capture the GHG benefits of SD-PAMs.

Country studies

This report presents four country studies that examine the types of policies and measures that might be framed as SD-PAMs (Chapters 3-6). The authors of these studies are in-country experts, but the aim of presenting them here is both to investigate the potential SD-PAMs themselves and to draw some more general conclusions about the SD-PAMs model. The order in which they are presented is in some sense a descending scale of how compelling the cases are for an SD-PAMs approach. Seen another way, they are an indication of how much outside assistance would likely be needed to make them work. By a happy coincidence, the order is also alphabetical.

Biofuels for transport in Brazil

Brazil's biofuels program, discussed in Chapter 3, is the only policy set described here which is already implemented on a large scale and over a long time period. Brazil has used a range of measures to support the use of ethanol from sugarcane as a transport fuel since the 1970s, when this model emerged as a means of responding to the oil crisis. Although the system was initially based on large subsidies, these have declined towards zero, and ethanol is now competitive with gasoline. The authors find that the effects have been huge: although the extent of ethanol use has varied over time, it now accounts for approximately one third of Brazil's transport fuel. The savings in oil imports and associated debt servicing have saved the country around $100 billion in hard currency. Brazil's external debt would be 50 percent higher today were it not for ethanol. Over a million jobs in rural Brazil depend on ethanol and sugar production, and the industry has been protected from exclusive dependence on the volatile world price for sugar. Air quality has generally improved, and biofuel manufacture produces around 1,350 gigawatt hours per year of electricity for export to the grid, a figure that is rising fast as technology improves. These benefits are reason enough for Brazil to continue and expand ethanol use, but the incidental impact on GHG emissions has been significant: an estimated saving of 574 million tons of CO_2 since 1975, or roughly ten percent of Brazil's CO_2 emissions over that period.

The nature of Brazil's support for biofuels has changed over time, and is thus perhaps best viewed as a series of SD-PAMs, with costs declining over time to a situation requiring small or no subsidies today. The net effect has been considerable benefits to the country, and the authors consider that some 20 other countries might also find the Brazilian model attractive. The model depends on sugarcane, which at present offers much better energy yields than other crops, and a tropical climate to grow it effectively. But improved production technology, together with new flexfuel cars that can run on either gasoline or ethanol, will make implementation easier. In countries with more temperate climates, a technology breakthrough is still needed to make cellulosic ethanol more viable.

As one might surmise from the fact that it has survived for more than three decades, Brazil's biofuels program has flourished independent of explicit climate change concerns. It represents one end of a spectrum of SD-PAMs. A number of countries might be helped to implement such a program with little more incentive than exchange of information and easier access to relevant technologies, although depending on national circumstances more direct financial support might be warranted. The reduction in GHG emissions from this development would be very significant, but would not need to be treated as a mitigation cost.

Transport efficiency in China

China's growing transport sector, which is the subject of Chapter 4, presents a more complex case. In urban areas in particular, the growth in car ownership and use is spectacular, and the gap between China and developed economies suggests that this growth will continue for some time. The welfare benefits of the increased mobility that this implies are very large, but they also give rise to rapidly increasing GHG emissions.

The authors see potential constraints on these mobility gains emerging from two factors:

- China's rapidly-growing oil demand, which is making the price and provenance of its imported oil an increasing concern, and
- The rapid growth in car use, which is leading to gridlock in cities that were not designed, and cannot be easily adapted, for such traffic.

They present three scenarios for China's urban transport through 2020. "The Road Ahead" describes a business-as-usual scenario; "Oil Saved" applies measures taken expressly to curtail oil demand growth; and "Integrated Transport" includes measures to reduce the burden on China's urban infrastructure.

These scenarios give an indication of the scope for policy to work. Oil Saved results in a 55 percent reduction in transport energy use by 2020 relative to The Road Ahead, while Integrated Transport leads to a 78 percent reduction. These reductions come through three improvements: more efficient engine types (hybrids, compressed natural gas); smaller vehicles to adapt to constrained road and parking space; and lower vehicle-miles-traveled as people use public transportation alternatives. The authors are at pains to point out that these measures are likely to improve, rather than constrain, mobility for urban Chinese.

The challenges described in this chapter lend themselves to an SD-PAMs approach in several ways:

- China has already recognized these problems and is starting to implement policies to address them, such as improved vehicle efficiency standards.
- The scope for extending and accelerating such policies and measures appears to be significant, and the benefits are major both for Chinese policy interests and for reduced CO_2 emissions.
- The sectors involved, especially the automobile sector, are global in scope and work in global markets. Concerted international action may prove more effective than countries acting individually.

Rural electrification in India

Rural electrification is a pivotal development issue in many parts of the world. Electricity provides a wide range of development advantages, promoting better education, better health, and more economic activity. The Indian government has set ambitious targets for providing full electrification, but it is far from clear that these goals can be met. Experience in India to date suggests that electrification goals will prove extremely challenging. Despite repeated efforts, 56 percent of Indian households have no electricity supply, and the problem is growing worse as new connections fail to keep pace with population growth.

For the purposes of this study, the authors start from the premise that these goals will need to be met somehow, and consider three scenarios under which this is done: an extension of the grid using India's existing generation mix; a scenario dominated by off-grid diesel generators; and one dominated by off-grid renewable energy generation. They also consider three levels of demand in rural communities, including households, communal services, and (for the high level scenario) productive uses of power. They evaluate these approaches according to a set of non-climate criteria:

- speed in meeting the electrification targets
- quality and reliability of the power
- cost
- security of fuel supply

They find reason to doubt whether grid-based electrification can meet the ambitious timetable of the government's targets, given fundamental structural problems with India's electricity market. Diesel generation is perhaps more promising, with perhaps the best potential for quickly delivering electrification off-grid, and in many ways it can be expected to play an important role. However, the authors point out that high levels of diesel use do present a significant import dependence and fuel security problem for India. Depending on the demand scenario used, the increase in oil imports is between 6 percent and 41 percent of today's levels. The authors argue that this economic impact, together with the strategic issues associated with growing oil imports, raise doubts as to the desirability of seeing a large use of diesel in electrification.

Favoring renewable energy sources brings significant CO_2 emission savings: 14 to 102 million tons of CO_2 per year compared to using the grid. The authors argue that this in itself should not decisively influence India's choice of technology; they conclude however that based on the concerns raised about the grid and diesel technologies, there are significant reasons for India to prefer renewable energy on domestic policy grounds, provided that the institutional delivery mechanisms can be put in place. They acknowledge that the cost of renewable energy technologies tends to be high in India due to the high cost of capital, but suggest that making India's electrification goals part of an international climate effort might offer scope for addressing this obstacle.

India's rural electrification therefore seems to offer an opportunity for an SD-PAMs approach that is challenging in its scope but equally large in its potential development and climate benefits.

Carbon capture and storage in South Africa

South Africa typifies an important challenge for several major developing countries. A significant part of its population lacks access to electricity, and providing that access is an urgent political priority. However, the country's fuel mix is dominated by coal, and the large domestic coal resource suggests that expanding generation means a major increase in CO_2 emissions. Carbon capture and storage (CCS) technology, which involves the capture of CO_2 emissions from power plants or industrial processes and its permanent disposal in geological formations, offers the technical potential to address this problem. Can the implementation of this technology work as an SD-PAM? The authors examine the technical potential in South Africa for both the capture from particular facilities and the availability of disposal sites. They also address issues such as the technical and institutional capacity in South Africa to makes CCS work.

They conclude that CCS has significant potential for cutting emissions in South Africa. Some of this is at relatively low cost—some 30 million tons CO_2 per year may be available for capture and storage at an estimated $20 per ton—but most will be much more expensive than this. More importantly, they find few sustainable development benefits for South Africa beyond the mitigation of GHGs. One possible exception is in the potential for transfer of technologies that are more generally useful in South Africa, such as CO_2 gas transmission which may also be useful for piping natural gas. But this alone is far from making the case for South Africa to implement CCS in the absence of a formal emission constraint, which is unlikely in the foreseeable future.

This case illustrates one of the limitations of the SD-PAMs approach. CCS brings few sustainable development benefits, and none that come close to making it viable in the absence of explicit mitigation commitments. These mitigation commitments would not need to be on the part of South Africa: it would be possible for donor countries to finance the future capture and storage of South African emissions. But the amounts of money involved would be a step-change in the willingness of the international community to pay for GHG mitigation, which thus far has been low. The authors make a valuable contribution to the study of CCS in South Africa, but it does not seem that the SD-PAMs model will serve well, absent significant international support.

Conclusions

The use of SD-PAMs opens up a way of putting into more formal effect the provisions of the UNFCCC and offers hope of a more constructive dialogue around developing country emissions and the importance of development. While the concept is not new, this report aims to lay the idea out systematically and to explore some of its implications and potential applications.

The country studies presented in this report show a range of opportunities for SD-PAMs. In the case of Brazil's biofuels program, the potential is not so much to expand ethanol use in Brazil itself as to find ways to expand the approach to other countries. In China, more efficient vehicles and integrated transport solutions are already a target of government policy, but an SD-PAMs approach has potential to help the uptake of these be faster and deeper. India has already made rural electrification a policy priority, but has seen renewable energy as a relatively minor component within that policy; SD-PAMs can be used to set the conditions for a shift towards making renewables the core of a rural electrification strategy.

The chief advantage of SD-PAMs is that they align the interests of climate protection with those of policy goals that have a higher priority for developing country policy makers. The emphasis must be on how to improve the delivery of development goals at the same time as reducing emissions. This leveraging of existing policy priorities means both that the appropriate level of domestic incentive will exist to implement the necessary laws and policies, and that larger financial flows can be influenced, rather than depending on more limited funds dedicated to climate policy. The overwhelming importance of domestic and private capital in energy investment in major developing countries means that leveraging existing financial flows is far more significant than creating new funds specifically aimed at climate protection.

The process of establishing SD-PAMs promises to be more varied than many existing proposals for future climate policy. In some cases the approach may be a simple pledge and review; in others an agreement of comparable commitments in specific sectors; in yet others negotiation of mutual commitments between countries. This may seem messy, but in fact most international agreements with aims of a similar level of ambition to those of climate policy have proceeded a similar fashion.

More work needs to be done. Analysis is needed of sectors such as water, agriculture, forestry and non-electricity energy efficiency. The interaction between SD-PAMs and market mechanisms such as the CDM, how SD-PAMs might be financed, and how mutual commitments could work, are all important areas of further enquiry,

The world needs a climate agreement beyond 2012 that will meet the needs of all the world's countries, rich and poor; it also needs to accelerate the rise of its poorest inhabitants out of poverty. SD-PAMs offers some hope that these two crucial aims can be met.

CHAPTER I

Introduction to Sustainable Development Policies and Measures

ROB BRADLEY ▪ JONATHAN PERSHING

If you fill your car with petrol in Brazil, you're not getting quite what you may think. Even basic petrol is a quarter ethanol, which is produced from fermentation of sugar from Brazil's vast sugarcane crop. Indeed, if you have a "flexfuel" car, as do a significant proportion of Brazilians, you need not use petrol at all. Such cars can run on pure ethanol.

Ethanol was used as a supplement to petrol in Brazil for much of the 20th century, but starting in the 1970s it was actively promoted by the government. Then, Brazil—like most countries—faced a fast-rising oil price and insecurity over the future stability of the countries that sit atop the world's major reserves. It also had a large and economically important sugar sector, which was struggling in the face of low world sugar prices and eager for another source of income. Promoting ethanol as a transport fuel helped address both of these seemingly unrelated problems.

Climate change played no part in Brazil's decision to embrace biofuels. At the time, climate change was not even recognized as a problem. But the climate has certainly benefited. The Brazilian government calculates that between 1975 and 2000 this program avoided emissions of 403 million tons (Mt) of carbon dioxide (CO_2) equivalent.[1] Today, it still offsets some 26 MtCO_2 equivalent each year—more than would be saved each year by taking all of Sweden's cars permanently off the road. Wider use of this strategy, in both developed and developing countries, would be a major contribution to fighting dangerous climate change. If it were implemented in a developed country today, it would almost certainly be described as a climate protection measure. Yet at present international climate policy offers no way of recognizing and supporting such measures.

This report explores an approach to reconciling development and climate priorities, termed sustainable development policies and measures (SD-PAMs). This approach was first put forward in this form by Winkler et al. (2002) and describes policies and measures that are firmly within the national sustainable development priorities of the host country, but through inclusion in an international climate framework seeks to recognize, promote and support means of meeting these policy priorities on a lower-carbon trajectory. The SD-PAMs approach has been the subject of some discussion within the climate change literature[2] and has been presented as a component of a climate regime by the Climate Action Network (2003), among others. It has thus entered the climate policy vocabulary. However, a great deal of work remains to be done to explore the operational implications of SD-PAMs as part of an international policy framework. This report is a contribution to that effort. We first discuss the merits and limitations of SD-PAMs (Chapter 1) and how an SD-PAMs pledging process might fit within the international policy context (Chapter 2). We then examine in detail four case studies of policy options in developing countries: Brazil's use of biofuels for transport (Chapter 3), efficient urban transport in China (Chapter 4), options for rural electrification in India (Chapter 5) and carbon capture and storage in South Africa (Chapter 6).

SD-PAMs are not a panacea. In particular, they do not change the need for industrialized countries to lead with explicit action to mitigate their own greenhouse gas (GHG) emissions. However, they do offer the potential for a less confrontational approach between industrialized and developing countries, and a means to address developing country emissions by promoting rather than threatening their development. This approach has great potential for trust-building, as SD-PAMs are made complementary to, and not exclusive of, other forms of developing country policy. They can coexist with Kyoto-style targets, project mechanisms, and other forms of engagement.

This chapter presents the SD-PAMs approach in the following sections:

1) **Climate meets development:** why an innovative solution to the current impasse in climate policy is needed, and what SD-PAMs aim to achieve.
2) **Development meets climate:** the challenges faced by developing countries, and how these can and should be overcome in more climate-friendly ways.
3) **Fitting SD-PAMs into future climate agreements:** how SD-PAMs might work, their advantages, and how they relate to other climate instruments.
4) **Financing SD-PAMs:** how SD-PAMs might be paid for.
5) **Limitations of SD-PAMs:** the importance of understanding what SD-PAMs can and can't do.
6) **This report:** mapping out the remainder of this report.

1. CLIMATE MEETS DEVELOPMENT

The story so far

Ever since international efforts to combat climate change began, a tension has existed between developing and industrialized countries. Richer countries have pointed to the need for global climate policy and the rising absolute emissions of large developing countries such as China and India. Developing countries retort that their per-capita emissions remain much below those of industrialized countries, and that their historical contribution to today's greenhouse gas concentrations is still smaller. This implies that industrialized countries should therefore take the lead in reducing emissions, not least to allow for developing country growth. Furthermore, the "capacity" of developing countries—that is the resources and institutional capabilities—to invest in cleaner technology and take other mitigation measures is lower. Most of all, developing countries face urgent sustainable development needs—reducing poverty, increasing access to modern energy services, increasing mobility, and attaining the other benefits enjoyed by richer countries.

These tensions are apparent in the 1992 UN Framework Convention on Climate Change (UNFCCC, or "Convention"). The Convention establishes the basic principles and preliminary steps for addressing climate change at a global level, as well as an ultimate objective of stabilizing atmospheric concentrations of GHGs at a level that avoids dangerous human interference with the climate system. While the Convention has nearly universal membership, it also divides the world into two groups—Annex I (developed) and non-Annex I (developing). It places the primary responsibility on the developed countries to reduce their emissions and assist developing countries in doing the same. This is expressed as the "common but differentiated responsibilities" of the Parties: all have responsibilities, but these vary to reflect their differing national circumstances.

Under the 1997 Kyoto Protocol, the Annex I countries assumed legally binding emission caps to be achieved during the five-year period from 2008 to 2012. Targets range from a decrease of 8 percent relative to 1990 (European Union and others) to an increase of 10 percent (Iceland). However, two industrialized countries—the United States and Australia—have not acceded to the Kyoto Protocol, which entered into force in February 2005, and are therefore not bound by its emission controls. For their part, the developing countries have no emission limits under Kyoto, although they may host emission-reduction projects under the Kyoto Protocol's Clean Development Mechanism (CDM). Such projects, it is hoped, will generate some development benefits, while also earning emission reduction credits that may be used by Annex I countries to help meet their Kyoto targets.

The unwillingness of countries such as the United States and Australia to engage meaningfully in international climate policy remains the single biggest obstacle to confronting the problem of climate change. Looking ahead, however, some form of more active developing country participation is generally regarded as a prerequisite for a climate agreement to follow the first "commitment period" of the Kyoto Protocol, which ends in 2012. And these two challenges are to some extent linked—critics of the Kyoto Protocol point to the apparent lack of participation by developing countries, while developing countries are unlikely to take more active climate measures while the world's largest emitter remains unwilling to do so. Inasmuch as developing countries have made clear that they are not prepared to take on the same kinds of targets as Annex I countries (in large part because of the disparities in development discussed in section 2 below), moving ahead will require creative thinking on how to find more appropriate ways for developing countries to promote and accelerate their growth while limiting their GHG emissions.

The next phase

Examining the basis for future agreements, policy analysts have suggested a set of options for next steps. These include (1) the expansion and amplification of the Kyoto structure of emissions targets and market mechanisms; (2) a focus on technology, including research, development, transfer, and diffusion; (3) an emphasis on development policies and measures (the focus of this report), and (4) agreements that may encompass any or all of the above measures and options, but that may be regionally or sectorally defined rather than global in scope.

Kyoto Plus. With more than 150 countries and regions Party to the Kyoto Protocol, this option has enormous support. Targets are being implemented, and the markets established under the Protocol are operative. The European Union has allocated emissions allowances for more than 2 billion metric tons of CO_2—and prices in 2005 were approximately 30/ton. While still a relatively new market, the CDM, with support from similar efforts by the World Bank and others, has attracted approximately $1 billion of pledged investment in developing countries. However, notwithstanding the broad level of agreement on the structure, key countries—in particular the United States—have rejected the Protocol. Aside from this problem, the most important gap in this approach is that it lacks an appropriate means of dealing with developing country emissions.

Technology. A rather different approach, one emphasizing the need to develop alternate and long-term technologies, particularly for the energy sector, has been postulated as complementary to—or possibly as a replacement for—the Kyoto structure. Proponents have argued that the indirect and near-term influence of pricing mechanisms established through emissions caps are inadequate to create incentives that will drive the major technology changes required to redirect the global economy to zero net emissions. Aggressive efforts at research, development, and deployment (RD&D)—in specific technologies such as renewable energy, energy efficiency, new fuels such as hydrogen and biofuels, and carbon capture and storage to allow safe use of fossil fuels—are a focus of this vision. On the negative side, critics worry that such a program runs the risk of choosing poorly; governments have been notorious for technology push policies that have failed to generate benefits claimed—and that have cost substantially more than projected. Some also worry that too strong an emphasis on long-term technologies can act as a cover for deferring action on climate change altogether, while failing to create a carbon market, which provides one of the major incentives to develop technologies.

Development. This approach assumes that, particularly in developing countries, the priorities for the foreseeable future will be to tackle basic necessities, such as poverty alleviation, food supply, health, and access to modern energy services and transportation. However, as discussed in detail in this report, many of these development priorities can be met in a manner consistent with climate mitigation. The key is to identify such practices and promote them. This emphasis also has critics. Not least, proponents must address the rather woeful global history: the richest countries in the world have seen emissions of GHGs increase proportional to their economic growth. Even efforts to provide international development assistance have not apparently helped: both World Bank and bilateral loans in the energy sector (to choose but one example) have predominantly funded massive fossil fuel electricity generating facilities rather than clean, renewable energy alternatives (Sohn et al., 2005).

Regional Structure. Under this theory, progress is best made when like-minded groups of countries—or companies—band together to address common problems. For example, The African Union has sought to join together to address African development issues. It brings to the task an intimate understanding of the region's needs and opportunities unmatched by representatives of other regions. In climate mitigation, such groupings may emerge around oil exporting or importing countries, which in the 1970s gave rise both to the Organization of Petroleum Exporting Countries and to the International Energy Agency. Groupings might also be linked to sectors, such as automobiles; witness the effort by the European Union to set standards for vehicle emissions, which brought to the table European, Japanese, and Korean car manufacturers. Here too, critics have legitimate concerns: how to address issues of monopoly controls and trade distortions? How to promote more than the "lowest common denominator" solution—where the effect is likely to be minimal? How to integrate a series of such agreements to ensure that aggregate global emissions are really being curtailed?

In reality, the international climate effort is likely to be formed from an amalgam of these choices, with elements from each adopted by different countries depending on their circumstances and priorities. Indeed, a system based on only one seems likely to be insufficient. Each alternative brings complementary choices to the discussion, which if successfully implemented could help construct an effective global regime to address the climate problem. The SD-PAMs approach explored in this report has at its center of gravity the development component, but it is important to recognize that it is compatible with all the components discussed above.

2. DEVELOPMENT MEETS CLIMATE

Meanwhile, developing countries face the challenge of developing in what is increasingly likely to be a carbon-constrained world. Although developing country emissions are not constrained today, the threat of climate change means that an unchecked rise in emissions will inevitably act as a constraint to their long-term economic development. Heading down a lower-carbon path now may prove far cheaper in the long term than investing in energy systems today that become a liability through high GHG emissions.

While economic growth and prosperity matter to people all over the world, in developing countries the needs are particularly acute. Quite apart from the economic growth needed to lift billions of people out of poverty, there are a number of key services and opportunities that are vital from the point of view of development but offer additional challenges to climate policy. These include access to modern energy services (with concomitant provision of lighting, refrigeration, and other services), transportation, and improved agricultural practices that are linked to adequate food supplies. Presently, these services, where available, are provided in the main with the use of fossil fuels—with associated GHG emissions.

Increased Access to Modern Energy Services

Estimates of the number of people worldwide that lack access to modern energy services vary, but as many as 2 billion have no reliable access to electricity or clean cooking or heating fuels (ESMAP, 2000), with significant variation by country (Figure 1). The lack of such services is a contributing factor in poverty. Women in particular spend much of their time gathering wood for fuel, and then inhaling the fumes that come from the cooking fires. Forest cover is also reduced; modern appliances such as refrigeration are not available, and small businesses lack the motive power for many applications. The relationship between poverty and energy services is a complex one, but for any government determined to reduce poverty, rolling out access to electricity and other modern energy carriers is a high priority.

Building a Modern Economy

Most developing countries want to cultivate industries that will create employment, economic growth, and technological progress in their countries. This means building industries and jobs in sectors that promise growth, higher wages, improved domestic living standards, technological modernization, and export potential. Many of these sectors can lead to rising emissions. Conversely, there are a growing number of opportunities for the development of industries that produce the cleaner technologies that allow economic development with lower emissions.

Increased Mobility and Car Ownership

Improved mobility is both a cause and consequence of economic development. Access to cheap and efficient modern transportation increases the scope for economic activity, allowing workers to find work more easily and reducing the time wasted in transit, which is neither useful nor enjoyable. In addition, greater use of transport is a favorite purchase for people leaving poverty behind, and does much to improve their quality of life. At the same time, given that almost all mechanized transport is fueled by oil, improved mobility places strong upward pressure on GHG emissions. This will be especially the case in developing countries, where motor vehicle use is low, but poised to rise considerably relative to the industrialized countries (Figure 2).

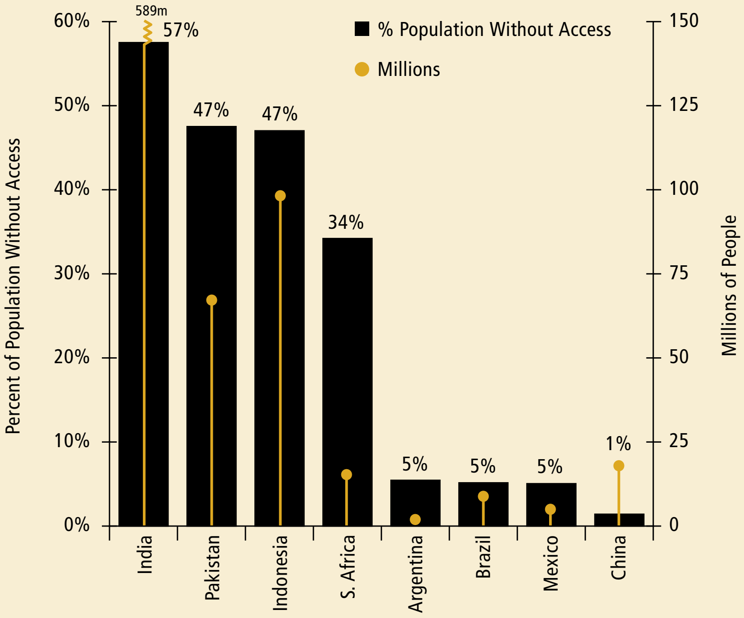
Energy Security and Access to Oil Supplies

The role that oil has played in the development of today's world economy is seminal. World trade may sometimes seem based on flashes of internet-based information, but it is likewise driven by oil tankers chugging across the oceans and kerosene-fired jets winging through the sky. Oil is an essential ingredient in a bewildering array of products, from plastics to medicines, transported in oil-fueled trucks to stores that are in turn visited by oil-fueled customers. But increasingly, getting hold of it and dealing with the consequences of its use are a major burden on most modern economies, and the burden is greater still in the case of developing countries, which use more oil per unit of GDP. The economic cost of this oil use is huge, and affects indebtedness in many developing countries (see Figure 3). The energy security concerns such imports raise are similarly daunting, in view of the sometimes unstable countries that produce them. Some 72 percent of known reserves are found in just seven countries (Saudi Arabia, Iran, Iraq, United Arab Emirates, Kuwait, Venezuela, and Russia) (BP, 2005). Nearly all of the world's largest economies, including the United States, Japan, China, India, Brazil, and South Africa, are oil importers.

Local Health and Environmental Quality

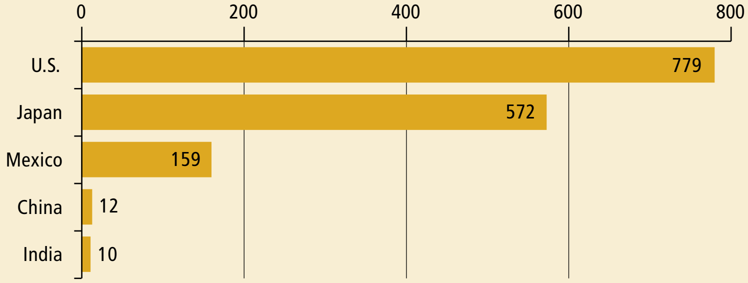
Often, reduced GHG emissions and improved local environment go hand in hand, but there are important exceptions. For example, the use of (carbon neutral) biomass indoors, particularly for cooking and space heating, is a major source of illness and premature death in many developing countries. A switch to more modern fuels such as electricity or LPG is often desirable. Finding low-emission ways to meet the same goal is a major challenge. Similarly, a switch to biofuel crops to replace oil may lead

Figure 1. Access to Electricity in Selected Countries



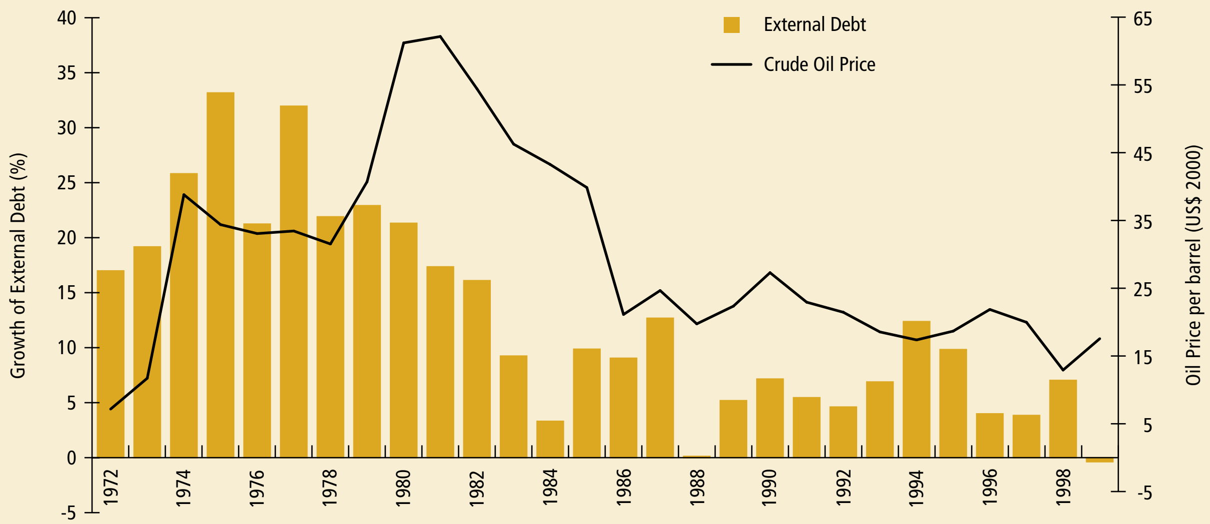
Source: IEA (2002)

Figure 2. Motor Vehicles per 1,000 People



Source: World Bank (2005). Data ranges from 1997-2000.

Figure 3. Developing Country External Debt Tends to Increase as Oil Prices Rise



Source: IEA (2003)

to increased requirements for fertilizers as well as additional soil erosion; both can lead to increased net GHG emissions as well as to local pollution.

While developing countries face urgent development needs, it should also be remembered that the poor are generally most dependent on natural resources and ecosystems, which can form the basis for their survival and even prosperity (WRI, 2005). Climate change, while not an immediately pressing issue for developing countries, is in fact a serious threat to precisely those systems on which their poor generally depend.

Climate change constraints and the imperatives of development are therefore often in tension. Developing countries need a means of dealing with these formidable challenges, while avoiding creating a serious future liability for themselves by making GHG emissions integral to their economies. This, as much as the present impasse in international climate policy, suggests that a future regime must improve the prospects of integrating GHG considerations into development considerations, and vice versa.

3. SD-PAMS: BREAKING THE LOGJAM

The SD-PAMs approach proposes to make the development policies of each country the basis, or even substitute, for climate policy in that country. In many cases, the priorities facing developing countries can be met in a variety of ways, with profoundly different outcomes from a climate perspective. For instance, a plan for electrification of a region that lacks electricity can be based on fossil fuel technologies or renewable energy. In some cases, the difference between the two is small from a local or national perspective, even though the difference in impact on the climate can be significant.

3.1 SD-PAMs within a climate agreement

The basic foundations of the SD-PAMs concept are contained in the 1992 Climate Convention, discussed above. Specifically, the Convention requires all countries to develop national GHG mitigation programs.[3] At the same time, the Convention affirms "Parties have a right to, and should, promote sustainable development." Accordingly, "policies and measures to protect the climate system . . . should be *integrated with national development programmes*."[4] The Kyoto Protocol reinforces this notion by observing that mitigation commitments be advanced "in order to achieve sustainable development."[5] Thus, under the climate agreements, sustainable development and climate protection objectives are to be pursued in an integrated and complementary fashion.

As many observers have noted, however, the Convention obligations are vague and indefinite. There is no official recognition of policies and measures actually undertaken, or review of their implementation.[6] Nor are there mechanisms within the Convention or Protocol that provide incentives or financing, or otherwise promote SD-PAMs in developing countries. Mechanisms such as the Global Environment Facility and the Clean Development Mechanism, while important, are oriented toward *projects* that reduce emissions.

These shortcomings are not surprising. The Convention is only a framework agreement containing mostly generalized provisions. The expectation is that the basic Convention obligations will help build capacity and experience, which can subsequently form the basis of adopting more defined and rigorous approaches. The challenge is for Parties to operationalize the vision set forth in the Climate Convention. SD-PAMs represent one such operational vision.

The possible operational mechanics of an SD-PAMs approach are discussed in detail in Chapter 2. In brief, an SD-PAM system could involve the pledging, by governments, of specific actions to be undertaken, or already being implemented. Additional provisions for monitoring, reporting, and review would also be essential, as well as funding. A pledged SD-PAM might be expected to have the following characteristics:

- A legislative, regulatory, or other government action. Thus it is distinct from purely private initiatives or projects.
- Aimed at the country's own sustainable development objectives, as defined by the developing country (Box 1). There is no need to prove or even claim that climate change is a motivation for implementing an SD-PAM—thus it does not need to demonstrate "additionality" in the same sense that a CDM project would need to.
- Having a beneficial effect on GHG emissions. This factor needs to be evaluated against some alternative (for example, a biofuels program would be replacing petrol use), but it would not necessarily have to be calculated against a specific baseline.

Such an approach would differ substantially from most existing and previous proposals for advancing and assisting developing country participation, in that it focuses on efforts and policy commitments rather than commitments to a specific outcome. In this respect, however, it does resemble international processes in other domains. The trade liberalization process under the World Trade Organization (and its predecessor, the General Agreement on Tariffs and Trade) has proceeded under rounds of interactive and flexible negotiations, which resulted in mutual commitments from the Parties. It has been suggested that a similar process could be followed in forming climate commitments (Victor, 2001). International Monetary Fund country reviews have also been suggested as a model (Chayes and Chayes, 1991). The Marshall Fund process after World War II involved a detailed sharing of each country's plans for (re)development, although the existence of the United States as an effective overseer is clearly different from the climate policy situation (Schelling, 1998).

An important difference between the Marshall Plan process and that of the UNFCCC was the number of countries involved. The fact that the largest 20 or so emitters (counting the European Union as a single emitter) account for over 75 percent of global GHG emissions has led a number of commentators to propose negotiations among a group of major emitters.[7] In the case of climate change, it is unlikely that the United Nations will lose its role as the principle venue for negotiations, but an SD-PAMs structure allows the possibility of smaller groups deepening their cooperation within a larger agreement.

Box 1. Defining Sustainable Development

The general enthusiasm for the concept of sustainable development is matched by the confusion over what it means. The best-known definition comes from the Brundtland Report (WCED, 1987): "[Development that] meets the needs of the present without compromising the ability of future generations to meet their own needs." In general, it is taken to mean development that goes beyond pure economic growth to include aspects of environmental and social protection.

Within the UNFCCC however, there has been strong resistance to any definition of sustainable development that appears to constrain developing country choices. The CDM, for example, is mandated to promote sustainable development—but this is defined as whatever the host country declares to be in line with its interests.

In this report, we do not attempt to define rigorously what sustainable development means. As the authors of the country studies (Chapters 3-6) show, national priorities are many and varied. In practice, it is likely that host-country definitions of sustainable development will remain the order of the day.

3.2 SD-PAMs and existing proposals for developing country engagement

To date, most proposals for limiting emissions in developing countries are oriented toward various formulas for quantitative GHG targets, including many with "top-down" determinations of national obligations.[8] Such proposals tend to lack an explicit development dimension, and are typically viewed by developing country Parties as potentially constraining their economic development. Overall, the adoption of emission targets in developing countries faces substantial political, capacity building, and technical hurdles.[9]

A second approach is to rely increasingly on project-based mechanisms, such as the CDM, as the main form of developing country engagement. While the CDM remains promising and could complement SD-PAMs, it differs from SD-PAMs in key respects. First, the CDM is restricted to projects, which limits its potential. Policy change, more than individual projects, is needed to achieve the Climate Convention and development objectives. It is widely understood that meeting sustainable development challenges will require "profound structural changes in socio-economic and institutional arrangements," (WCED, 1987) which will be difficult or impossible to bring about on a project-by-project basis. Second, because CDM credits are used by Annex I Parties to offset their own emissions, it is essential that CDM projects are "additional"—that is, projects need to prove that they reduce emissions relative to those that would have occurred in the absence of the CDM. This "additionality" requirement does not exist for SD-PAMs, which is not a crediting mechanism (although there may be scope for crediting, if certain safeguards were in place, as discussed in Chapter 2). Under an SD-PAMs system, it is more likely that pledged actions are motivated by non-climate considerations, such as energy security or local pollution reduction. Several case studies in this report are illustrative of such outcomes. Although SD-PAMs would complement and not replace the CDM, baselines for CDM projects can be affected by whether policies and measures are already in place in the relevant sector and country. At present, this leads to a clear disincentive for policies and measures in developing countries—CDM projects are valued, while policies and measures are not. An SD-PAMs approach may not remove this perverse incentive entirely, but by granting some value to policies and measures it may reduce it.

A final approach, focusing on *harmonized* policies and measures, has been under discussion for many years within the UNFCCC and Kyoto Protocol. This approach involves countries adopting identical or similar policies in particular sectors. An agreement on a common set of PAMs has been resisted by many Parties on the grounds that it intrudes too strongly into domestic policymaking prerogatives. Indeed, the prevailing principle of the Climate Convention that has facilitated cooperation is *differentiation*, not harmonization. Under Kyoto, for instance, governments are free to achieve their targets in any way they deem appropriate, including by using trading and other regulatory approaches. Similarly, under an SD-PAMs approach, there would be no specific policies and measures imposed on countries. Rather, a country would pledge only its own policies and measures, consistent with its unique national circumstances. As discussed in Chapter 2, it is possible that groups of countries with similar concerns might choose to coordinate their SD-PAMs, but this would be a bottom-up process.

3.3 Why take on an SD-PAM?

Although SD-PAMs, as noted above, are already a part of the Climate Convention, one may ask why any country should present (or subject) its current or proposed sustainable development policies to an international climate regime. There are several advantages discussed in this section: recognition, learning, better alignment between climate protection and other interests, and promotion.

First, official recognition of SD-PAMs would enable *all Parties* to participate formally in mitigation efforts under the climate regime. This would have positive political as well as substantive implications. The formal pledging of SD-PAMs could reduce the perception in industrialized countries—especially the United States, but also elsewhere—that developing countries are not contributing to global climate protection efforts. Indeed, as this report and others have illustrated,[10] developing countries are in some cases already taking measures to bend the trajectory of their emissions downward. However, developing countries are not getting sufficient recognition for climate-friendly actions. This leads to misperceptions on the part of politicians in some wealthier countries, who point toward apparent inaction in the developing world as part of a justification for their own lack of effort. Indeed, identical measures, especially on energy efficiency, may be presented as "climate policies" in industrialized countries and simply as "energy policies" in developing countries.

Second, a system of SD-PAMs implementation would help accelerate learning in climate protection efforts and help build capacity to take further actions. The information gathered in a review of implementation should enhance the ability of regulators and stakeholders to distinguish between policies that are effective from those that fail to produce desired results, either in terms of emission reductions or sustainable development benefits (Chapter 2). Many industrialized and developing countries share similar sets of concerns and/or natural resources, and a better understanding of each others' priorities may reveal new areas of collaboration. In this report, the value of learning is related to climate benefits. However, SD-PAMs may likewise accelerate learning on development matters. Policies taken by countries to increase energy security, to improve access to modern energy services, and to extend the reach of transport systems are of inestimable value on their own and provide an additional incentive to share information and learning.

Third, SD-PAMs offer a chance to make climate change policy matter to developing countries by aligning it more directly with their interests. Development is a key priority for decision makers in developing countries, so that building climate change policy on development priorities would make it attractive to these stakeholders. Starting from development objectives and then describing paths that also address climate change may be the easiest way for many developing countries to take the first steps in longer-term action on climate change.

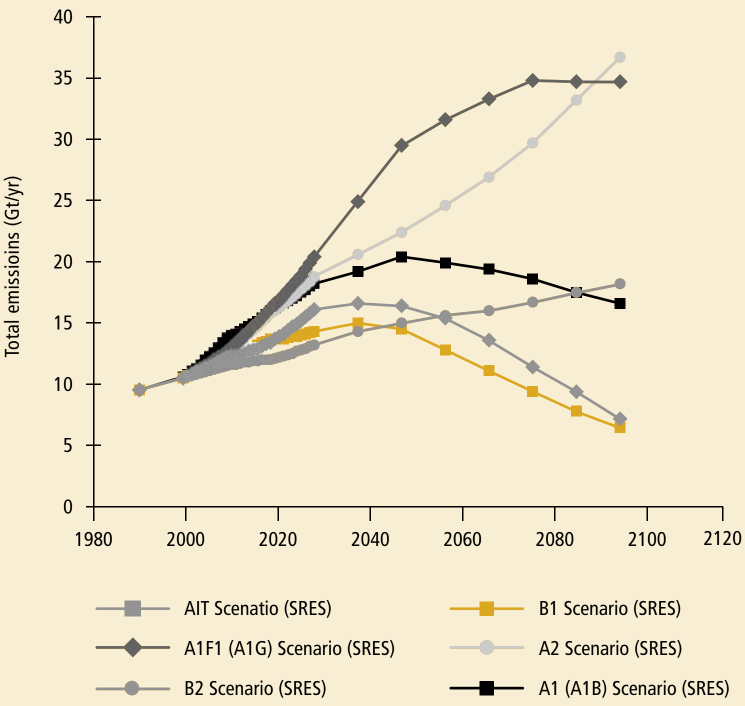
Finally, by articulating the kinds of measures that contribute to both the Convention objective and national sustainable development objectives, those measures can be more vigorously promoted by Parties and international organizations. This can be done in a number of ways, including new financing arrangements, discussed in section 4, and credit trading (Chapter 2). Formalizing SD-PAMs would likewise give stakeholders, including national civil society groups and the media, concrete policy options to promote, track, and evaluate at the domestic level.

If such an approach were successful in altering development paths, the climate benefits would likely be substantial. In fact, the scenarios of the Intergovernmental Panel on Climate Change (IPCC) suggest that the type of development path taken by a country is *more significant* in terms of long-term emissions than explicit mitigation measures (see Box 2). Because of this dynamic, the objective of the Climate Convention can be furthered by addressing development considerations more directly in its architecture. SD-PAMs can be thought of as a means of identifying and making operational the differences between these scenarios. This will not in itself be enough to deal with the climate problem—explicit mitigation measures will be called for—but it would make the task less daunting. More to the point, it is a task we can embark upon now in developing countries, while richer countries lead the way on mitigation.

Box 2. The IPCC Scenarios

The IPCC has modeled the possible trend in future global emissions through the lens of a number of scenarios. None of these scenarios includes any specific action to mitigate climate change. However, they vary significantly in terms of trade, technology development, energy prices, and other factors. For instance, the AIT scenario assumes technological development of non-fossil energy sources, while the B1 scenario emphasizes "global solutions to economic, social and environmental sustainability, including improved equity, but without additional climate initiatives" (IPCC, 2001). The resulting GHG emissions vary by a factor of six.

Figure 4. IPCC SRES Scenarios



Source: IPCC (2001)

4. FUNDING SD-PAMS

SD-PAMs of the scale needed to change emissions and development trajectories will require higher levels of funding than have hitherto been available for mitigation in developing countries. The present model for funding mitigation in developing countries has had only limited success. Developing countries, as discussed, are required under the UNFCCC to formulate and implement GHG mitigation measures. For their part, industrialized countries are obligated to provide the finance and technology to meet the "agreed full incremental costs" of implementing these measures.[11] Financial resources can be provided through the Global Environment Facility (GEF) or through bilateral, regional, or multilateral channels.[12] This system, however, has no definitions, guidelines, or requirements as to what measures developing countries might take, nor does it establish a systematic accounting of funding provided (aside from the GEF), or of the resulting emission reductions.[13] (See Box 3 for relevant existing financial mechanisms.)

For these reasons, both mitigation programs (with respect to PAMs in developing countries) and the associated financing and technology transfer (from developed countries) are viewed as more hortatory than required. Not surprisingly, funding is a topic of considerable disagreement and acrimony in the international climate negotiations. Developing countries tend to continually insist on more funding through the UNFCCC, whereas industrialized countries tend to resist open-ended promises of financing.

To achieve the Convention objective, the present system will need to improve. Whether SD-PAMs will deliver such an improvement cannot be known in advance. The approach does, however, offer more *rigor* and *flexibility* than the present system. It is more *rigorous*, as discussed below, in that it establishes tangible commitments toward which financial resources can meaningfully be directed. It is more *flexible* in that climate change funding need not be so separated from non-climate funding. The problem with continually creating discrete "pots" of money earmarked for GHG mitigation is that they will never be large enough to achieve the Convention objective. Accordingly, the real challenge is to instill carbon considerations into the broader set of international capital flows, only some of which are climate-specific.

Along these lines, SD-PAM funding should be able to come from any source: bilateral aid agencies, the GEF, multilateral development banks, export credit agencies, the private sector, the host government (federal and perhaps state/local), state and local communities, or others. Some funders—host governments, development banks, and aid agencies—would be primarily concerned with alleviating poverty or otherwise boosting economic development.[14] Other funders, such as the GEF, would invest because of the explicit climate benefit. Still others, such as private banks or corporations, would have commercial purposes, or finance the GHG component of a policy or project in order to acquire resulting emission reductions. The intent is to align and strengthen the linkages between the relevant financial institutions in a manner that maximizes resource and technology flows to development initiatives that deliver climate benefits.[15]

Which funding approach is most appropriate is dependent on the circumstances, as the case studies in this report illustrate. In some cases—such as biofuels or energy efficiency—measures may have no incremental costs, as they are sufficiently attractive on non-climate grounds and thus may not require international assistance. A whole basket of SD-PAMs in the transport sector, for instance, could benefit China (in terms of reduced oil dependency, greater mobility, and improved public health) as well as the global environment (Chapter 4). Here, international funding may not be critical, as domestic benefits drive down the incremental costs of climate friendly action. In other instances, such as carbon capture and storage

(CCS) in South Africa (Chapter 6), sustainable development benefits are low while global benefits are high. Here, international financing of CCS technology is crucial. In still other cases, such as renewable energy in India's power sector (Chapter 5), there are large national and global benefits, yet capital and institutional constraints necessitate international assistance.

An SD-PAMs approach to funding also offers rigor in that it would direct financial resources to tangible commitments. The fact that a country has committed to undertake a particular action might make it more likely to attract funding. By way of comparison, the successful financial mechanism of the Montreal Protocol on Substances that Deplete the Ozone Layer (together with bilateral assistance) finances the phaseout commitments agreed to by developing countries. If GEF and other assistance were similarly geared toward implementing pledged SD-PAMs, then developing countries may be able to negotiate additional funding, and all stakeholders could monitor progress.

The international carbon market may also be able to give a tangible financial boost to some SD-PAMs. Whether this is possible depends on the degree to which emissions reductions from certain SD-PAMs can be quantified, a topic returned to in Chapter 2.

Box 3. Existing Funding Mechanisms: the GEF and CDM

The two concrete mechanisms for financing GHG mitigation that do exist—the Global Environment Facility and the Clean Development Mechanism—are primarily focused on projects, rather than policy change or sectoral strategies.

During 2003–04, the GEF, as the financial mechanism of the Convention, contributed about $217 million to climate change activities, about $150 million of which was targeted at GHG mitigation efforts related to wind power, energy efficiency, and other areas. Since its inception in the mid-1990s, the GEF has committed $1.8 billion in grants to climate change projects, and leveraged about five times that amount in cofinancing. The GEF is capitalized by Parties from industrialized countries in multiyear replenishments.

The Kyoto Protocol's Clean Development Mechanism is expected to generate financial flows on the same order of magnitude as the GEF. A review of estimates of the projected size of CDM activity reveals a central estimate of about 250 million tons per year (range of 50 to 500). At a market price of $3 per ton of CO_2 equivalent, this would amount to about $750 million per year. The CDM is geared primarily toward private funding, and is expressly segregated from other financial flows under the Convention. Specifically, CDM project participants must provide an "affirmation" that "funding does not result in a diversion of official development assistance and is separate from and is not counted toward the financial obligations of those Parties."

The Special Climate Change Fund (SCCF) also provides funding for Convention implementation, including for mitigation projects. At the 10th Conference of the Parties to the UNFCCC in 2004, industrialized country Parties pledged $34.7 million to the SCCF.

Sources: UNFCCC (2004a); Haites (2004); UNFCCC (2001): Appendix B; http://unfccc.int.

5. THE LIMITATIONS OF SD-PAMS

There are few ideas so good that they cannot be killed by being oversold. While an approach based on SD-PAMs seems to offer some promise for engaging developing countries in lower-emission development, it has its limits. Some challenges include:

SD-PAMs do not substitute for mitigation by developed countries. Although the level of emissions consistent with avoiding dangerous climate change is subject to both scientific and political uncertainties, even the most "sustainable" of the IPCC emission scenarios does not seem likely to adequately reduce greenhouse gases. As an exclusive policy, SD-PAMs are aimed at poorer or less developed countries that are not able to take on explicit climate mitigation programs. Richer countries do not fall into this group. For this group, SD-PAMs may possibly be adopted as complements to, rather than substitutes for, existing and new mitigation policy options.

SD-PAMs do not seem appropriate for every technology or policy. The South Africa case study in Chapter 6 suggests that for a technology option such as carbon capture and storage, the sustainable development benefits are simply not a significant factor. Thus, measures such as these, if they are to be undertaken, will need full financial support on the basis of the climate benefits alone. Furthermore, some policies and measures that are appropriate for non-climate goals will be harmful from a climate perspective—for instance responding to oil security concerns with technologies that produce liquid fuels from high-carbon sources such as coal. Along the same lines, some potentially fruitful SD-PAMs might be counteracted by other PAMs that promote increases in emissions.

SD-PAMs implementation, on the scale needed, may not attract sufficient funding. The scale of the challenges being addressed by SD-PAMs is large in terms of the potential gains, both to development and to the climate. As with development itself, however, the associated costs are correspondingly high. It remains to be seen whether the multiple benefits from SD-PAMs make them more successful than other approaches in attracting the levels of support, both within the host country and from the international community, appropriate to the scale of the challenge.

6. THIS REPORT

At the core of the report are four case studies of actual or potential policies and measures that might fit within an SD-PAMs framework. They show the potential links between international policy and domestic efforts, and how this balance might differ for different SD-PAM types—in which some measures may be compelling in their own right, while others are dependent on funding and support from developed countries.

Chapter Two discusses some of the possible operational mechanics of how SD-PAMs might be incorporated into an international climate agreement. It addresses the key issues of definition of eligible types of SD-PAMs and the procedures for pledging, tracking, and reviewing SD-PAMs. Resolving GHG accounting issues may also enable quantification of the GHG benefits flowing from particular PAMs, or sectors within which multiple PAMs are targeted.

Chapter Three presents the case of the Brazilian biofuels program, which has promoted the use of ethanol as a transport fuel to substitute for petrol. This was established in the 1970s in response to both the oil crisis, which presented a major balance of payments problem for oil importers, and a weak sugar market, which was damaging Brazil's large sugarcane industry. To date, it has saved Brazil some $100 billion in external debt and created directly and indirectly an estimated 1 million jobs in rural areas. The climate has also benefited, as ethanol use in place of petrol offsets some 26 $MtCO_2$ emissions per year. While the authors conclude that the ethanol program does not depend on recognition of its climate benefits for its success, they suggest that valuation of these benefits might accelerate the expansion of biofuel use. Such benefits may also serve to promote the implementation of such a program in other countries.

Chapter Four examines two major emerging constraints on transport in the fast-growing "megacities" of China: oil supply and urban infrastructure. The government in China is beginning to take measures to encourage the use of higher-efficiency vehicles to reduce oil import growth, and small vehicle platforms to limit the impact on road and parking space. In addition there are a number of measures proposed to reduce car miles traveled by offering public transport alternatives. The study examines the consequences of significantly increasing the policy "push" in these directions, showing how adoption of thoughtful transport policies in China could decrease carbon emissions an enormous 79 percent in 2020 relative to a continuation of present trends. Such policies would have the major added benefit of reducing dependence on oil use and relieving pressure on urban infrastructure. It is these characteristics that make the measures attractive both for China and for other growing economies faced with similar energy supply constraints.

Chapter Five looks at the options facing India as it aims to provide electricity to the more than 100 million households that currently lack it. While the task is daunting, the development stakes are huge. The study examines rural electrification approaches based on extension of the grid, as proposed by the Ministry of Power, as well as two alternative scenarios based on off-grid power: one dominated by diesel, the other based mainly on renewable energy. The authors suggest that a renewable energy approach brings some significant potential advantages, notably in reduced import dependence for both oil and coal, as well as setting rural India on a low-emission trajectory that will grow in importance as their power demand does. However, it is not clear that the non-climate benefits outweigh the additional cost of renewable technologies. This may present a potential opportunity for India to seek support from international donors to reflect the global benefit at issue; it may also provide the potential for the dispersion of new and lower-cost technologies that could find a large competitive market if prices did decline. Inasmuch as other developing countries face a similar cost hurdle—with comparable limits on financial wherewithal—this case is of clear relevance to a potentially large global renewable energy market.

Chapter Six examines the use of carbon capture and storage in South Africa. South Africa is one of several developing countries highly dependent on coal for power generation (93 percent of its power comes from coal), and likely to remain so for the foreseeable future. South Africa also shares with many developing countries the need to expand access to electric power, particularly in its rural areas. If indeed the country is locked into growing coal demand, then the use of carbon capture and storage to mitigate the resulting emissions is an option that has to be examined.

The authors suggest that some minor non-climate sustainable development benefits for South Africa may accrue, particularly in the transfer of some technologies with broader application. However, these benefits are tiny in comparison with the costs involved. This case study suggests one limit to the SD-PAMs approach: carbon capture and storage remains an explicit mitigation measure, and as such a developing country such as South Africa is unlikely to shoulder its cost. Although capture and storage is not going to be an SD-PAM, the case does provide a useful framework for evaluating the magnitude of the costs that may need to be borne in any country that chooses to adopt such a technology. Given the reliance on coal in other major economies—such as China, India, and the United States—this study provides insights that may have application beyond the SD-PAMs framework.

Chapter Seven offers some conclusions and suggests areas that need further investigation and debate to develop the SD-PAMs concept further. It argues that the SD-PAMs approach offers genuine scope for limiting emissions growth in developing countries while accelerating their economic development. The key aspect of SD-PAMs is that the sustainable development goals of the host country form the basis of a policy commitment, rather than an emissions-based target. There are limitations in the types of climate technologies that can be supported in this way, but this is in itself an indicator of what types of abatement strategies are most appropriate. The issue of how SD-PAMs will be supported is one that requires further work, but there is reason to hope that a mixture of financial and other types of support may be easier to leverage through a policy-based negotiation focused on development than by broader emissions-based commitments.

ENDNOTES

[1] See Chapter 3 reference MCT, 2004.

[2] See for instance Bondansky et al., 2004; Mquadi et al., 2005; den Elzen and Berk, 2004.

[3] UNFCCC, Art. 4.1(b), stating that "all Parties shall "[f]ormulate, implement, publish and regularly update national ... programmes containing measures to mitigate climate change..." This requirement, however, pertains mainly to developing countries, since industrialized countries have additional specific commitments.

[4] UNFCCC, Art. 3.4. Emphasis added.

[5] Kyoto Protocol, 1997: Art. 10.

[6] In terms of reporting obligations, some developing countries include PAMs in their national communications under the Convention, but there are no guidelines or requirements or for doing so. Kyoto Protocol, Art. 10(b)(ii) ("Parties shall *seek to include* in their national communications, *as appropriate*, information on [GHG] programmes ... ." Emphasis added.). Parties included in Annex I are required to report on progress made in implementing policies and measures (Marrakech Accords Decision 22/CP.7), but this obligation does not extend to developing country Parties.

[7] See for instance Victor et al, 2004, part of a broader process on creating an "L20" of the leaders of large countries to focus on major international problems. Available at: http://www.L20.org.

[8] See e.g., La Rovere et al., 2002 (exploring the Brazilian proposal based on historical responsibility), Aslam, 2002 (analyzing equal per capita entitlements), and Blanchard, 2002 (comparing three proposals).

[9] Baumert et al., 2005 (noting the technical and political problems, in particular associated with uncertainties in future emission projections in developing countries).

[10] Goldemberg and Reid, 1999; Chandler et al., 2002.

[11] UNFCCC, 1992: Art. 4.1(b); Art. 4.3.

[12] UNFCCC, 1992: Art. 11.

[13] See UNFCCC 2004b. The most recent estimates of bilateral assistance are from 1998-2000, when the OECD estimated "climate-change-related aid" (broadly defined) at about $2.7 billion per year (OECD, 2002). Multilateral funding through the World Bank, UNDP, and others for support of Convention implementation is significant, but not presently known.

[14] Care would have to be taken that SD-PAMs not divert development assistance flows away from other priorities (health care, education, etc.) that do not offer similar potential for cutting GHG emissions.

[15] For an excellent discussion of this concept, see Heller and Shukla, 2003: 132 (referring to "programmatic climate cooperation").

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CHAPTER II

Sustainable Development Policies and Measures and International Climate Agreements

Kevin A. Baumert ▪ Harald Winkler

One of the most difficult challenges facing nations attempting to implement the Climate Convention is the integration of GHG considerations into national development programs. Building on Winkler et al. (2002), this chapter explores this challenge at the international level. Namely, how might an approach based on policies and measures be formalized and defined within a future international climate agreement? In other words, how might Parties develop a mechanism for formally recognizing and advancing the kinds of sustainable development policies and measures (SD-PAMs) discussed in this volume?

The approach outlined here proceeds along several steps. First, the international community would likely need to agree on general guidelines for what constitutes an "SD-PAM" that is eligible to be pledged under the UNFCCC. These basic definitional considerations are outlined in section 1. Second, a process would be needed whereby Parties would actually pledge eligible SD-PAMs. Such a process, discussed in section 2, could work in a variety of different ways, either as unilateral, mutual, or harmonized pledges. Third, once pledged, SD-PAMs could be recorded and tracked by the Convention Secretariat or other body (section 3). Fourth, a broader program of assessing progress would likely be needed, including reporting and review procedures (section 4). Finally, while this is essentially a qualitative approach, it is conceivable that it could incorporate a quantitative dimension, and perhaps also be integrated into the nascent international carbon market. Section 5 discusses issues and options regarding quantifying SD-PAMs.

1. DEFINING AND FORMALIZING SD-PAMS

Generally, SD-PAMs deliver both tangible national and global benefits. This could include many of the actions described in the case studies presented here, as well as others, such as renewable energy initiatives, energy efficiency standards, and forest conservation programs. Beyond this foundational description and indicative examples, however, three of the salient characteristics of SD-PAMs warrant elaboration.

First, as discussed in Chapter 1, “sustainable development” is not a rigidly defined concept. Sustainable development, as articulated in the Rio Declaration on Environment and Development, is about the promotion of healthy and productive lifestyles through improved social and economic conditions (UNGA, 1992). This includes environmental protection and conservation. Because priorities and circumstances differ widely by country, the sustainable development aspect of SD-PAMs would be defined by individual developing countries (Winkler et al., 2002). This is similar to the approach taken in the Clean Development Mechanism (CDM), where it is the host country’s prerogative to determine whether a project assists in its sustainable development objectives (UNFCCC, 2001).

Accordingly, national sustainable development benefits may pertain to a wide variety of areas, including economic, social, and environmental. In a study of SD-PAMs in South Africa, for example, Winkler et al. (2002) identified energy development and housing as important priorities within a national sustainability context. Chapters 3-6 of this report identify some other priorities within varying national contexts.

Second, “policies and measures” could include legislative or executive acts, regulations, and public-private partnerships such as negotiated agreements. PAMs could be fiscal (taxes, charges, subsidies), regulatory (mandates, standards, sector reforms), or other initiatives that have some official status (Table 2, p. 19). Although there is no need to form a restrictive definition of what form of action might constitute a “policy” or “measure,” they are generally distinguishable from solely *private* initiatives or *projects*.[1] In this way, SD-PAMs are distinct from the project-based CDM, discussed in Chapter 1.

Of course, not all policies and measures have a beneficial effect on GHG emissions; in fact, development would generally be expected to increase emissions. Thus, a third basic characteristic of SD-PAMs is that they must have some beneficial effect on GHG emissions or absorptions. As this report and other studies demonstrate, there are a wide range of policies in transport, energy efficiency (industrial and buildings), power generation, forestry, and elsewhere that contribute to the Convention objective while having the primary purpose of supporting local and national priorities (Goldemberg and Reid, 1999; Chandler et al., 2002). Table 1 lists national (sustainable development) benefits and indicative global (emissions) benefits that might be derived from SD-PAMs.

An SD-PAM may have a beneficial GHG effect without reducing emissions in absolute terms. As the Climate Convention suggests, energy use and emissions in developing countries will need to grow to meet the requirements of sustainable economic development. This is illustrated clearly in China’s transport sector (Chapter 4) and India’s power sector (Chapter 5), where even the cleanest scenarios show emissions increasing. Rather than absolute emission reductions, the test should be whether development is proceeding using clean, efficient, and energy-saving technologies and processes.

Thus, pledged SD-PAMs must be (1) government actions that have (2) development benefits and (3) GHG benefits. In considering which SD-PAMs are eligible for international recognition and assistance, the motivating rationale among these factors should not be relevant. In most cases, developing countries are likely to act on the basis of development rather than global priorities, given that poverty, public health, employment, and other factors continually keep climate change low on the political agenda.

Finally, accompanying the pledge of a particular policy or measure might also be a description of what the intended results or impacts are in terms of both development objectives and emissions cobenefits. Such a description might be a set of key performance indicators reflected in particular policy goals (for example, the number of homes electrified, jobs created, and so on) or framed in more general terms (for example, the means by which GHG emissions are kept in check). Such an approach would assist in ascertaining whether the pledged action is in keeping with the basic characteristics of an SD-PAM.

2. PLEDGING SD-PAMS

The incorporation of SD-PAMs into the international climate regime could involve additional discrete stages, including (1) a pledging process for national governments, (2) the tracking of pledges through an international registry, and (3) review of implementation. This section considers the first operational stage—pledging—while the following sections consider the two subsequent stages.

Emission targets for industrialized countries under the Kyoto Protocol were established through the usual give-and-take of an intergovernmental negotiation process. The general approach was that a Party would propose a target for itself (pledge), and subsequently try to convince other Parties that this was a reasonable and fair level of effort considering the principles of the Convention, the unique circumstances of the Party, and the relative stringency of other countries' targets. Negotiations over SD-PAMs could proceed in a procedurally similar manner, but with notable differences.

Instead of setting a target emission level (as in Kyoto), developing country Parties would pledge either to implement existing policies or adopt new ones that meet the broad criteria agreed to by the Parties. Where good policies are on the books, but not being implemented, they could be worthy of recognition and support by the international community. In the course of negotiations, several different approaches to pledging SD-PAMs might be adopted, including single-country pledges, mutual pledges, and harmonized pledges.

First, a *single country* might pledge one or more SD-PAMs that are unique to its national circumstances and not directly related to the pledges of other countries. In this way, the system functions in a bottom-up fashion, starting from the premise that different countries are likely to prefer different approaches to social and economic development.

A second approach would be *mutual pledges*, which would involve simultaneous pledges by both a developing and developed country. Here, the approach envisioned in Article 4 of the UNFCCC[2] would be implemented. A developing country Party would pledge to undertake a particular PAM, and one or more industrialized countries would agree to assist in technology transfer or funding support. This approach might build on existing bilateral relationships between countries, including through provision of official development assistance. Particular industrialized countries might pledge to take lead roles in assisting with particular SD-PAMs, with further implementation and financing details to be worked out later among a broader range of participants and stakeholders. This has the additional attraction of engaging donor countries on SD-PAMs in which they have a mutual interest, such as for the development of a particular technology. Of course, as discussed in Chapter 1, entities such as the Global Environment Facility (GEF), multilateral development banks, private companies, or other organizations could also play important roles in financing or implementing mutual (or single-country) pledges.

Harmonized pledges among multiple countries could constitute a third element of an SD-PAMs negotiation process. This approach acknowledges the global nature of many industrial activities, and opens the door to multiple countries agreeing to the same kind of measures to promote or maintain an "even playing field" for competitive industries (Baumert et al., 2005). Iron and steel, chemicals, aluminum, and motor vehicles, for instance, are sectors characterized by significant cross-border trade and investment. In these kinds of areas, it is less likely that individual countries would unilaterally pledge significant actions, given the perceived or actual impact on international competitiveness.

Table 1. Indicative Policy Outcomes: Emissions and Development

Sustainable Development	GHG Emissions
Greater access to electricity	Improved energy efficiency*
Reduced costs to consumers	Improved energy conservation*
Reduced costs to companies	Switching to lower carbon fuels
Improved national security	Increased market share of clean products
Improved balance of payments	Reduced deforestation rates
Higher employment levels	Changed agricultural practices
Increased housing	
Reduced air pollution	
Improved public heath	
Export promotion	

* The amount of GHG benefit in these instances would depend on the underlying fuel mix.

Harmonized pledges might have particular potential among major trading partners, where relationships tend to already be established through regional organizations, such as MERCOSUR (in Latin America) and ASEAN (Southeast Asia). Although SD-PAMs are advanced here primarily as an approach for developing countries to engage in global mitigation efforts, it may be equally important to engage industrialized countries in harmonized pledge systems. The North America Free Trade system (NAFTA), for instance, might be one grouping that would bring together important Annex I and non-Annex I Parties. Other groupings, either formal or informal, also have potential.

A system within which governments pledge actions—either unilaterally, through mutual cooperation, or in a harmonized fashion—would require significant preparatory work at the national and international levels. At the national level, individual countries would of course need to determine ahead of time, through their own domestic processes, which actions they are prepared to pledge (Box 1). At the international level, governments might need to engage in bilateral, multilateral, and regional consultations prior to a formal negotiation session. A series of subnegotiations on specific topics would likely emerge.[3] This could resemble other international negotiations on complex issues, such as trade, which some have suggested is a model for climate negotiations (Reinstein, 2004). On a smaller scale, an analogous process took place at the 2004 Bonn Renewable Energies Conference (Box 2), where developed and developing countries made specific pledges.

Overall, the expectation is that a pledge-based system for engaging developing countries opens up new space and opportunity for international cooperation on what might be the most complex global issue. At the same time, it is equally important that the UNFCCC, by embracing SD-PAMs, coordinate its efforts with those under way elsewhere, including the U.N. Commission for Sustainable Development, the International Civil Aviation Organization (ICAO), the International Maritime Organization (IMO), and other specialized and regional organizations.

Box 1. Steps in Applying the SD-PAMs Approach

Winkler et al. (2002) outline five steps that a developing country might undertake in considering its commitment to SD-PAMs:

1. Outline future development objectives, where possible quantifying the expected benefits and possible risks. Many developing countries already identify development objectives through National Strategies for Sustainable Development or Agenda 21 plans.
2. Identify PAMs that would make the development path more sustainable, primarily for reasons other than climate change (e.g., greater social equity and local environmental protection while maintaining or enhancing economic growth). This might include existing or new policies.
3. Quantify the changes in GHG emissions of particular SD-PAMs, which should be reported in accordance with the Convention or other reporting provisions.
4. Compare the results from steps 2 and 3 to show which actions create synergies between sustainable development objectives and climate change policy, and which conflict.
5. Summarize the net impact of a basket of SD-PAMs on development benefits and GHG emissions.

Source: Adapted from Winkler et al. (2002)

Box 2. The International Action Programme for Renewable Energies

The International Action Programme (IAP) for renewable energies is one of the main outcomes of the 2004 Bonn Renewable Energies Conference. The IAP contains concrete actions and commitments toward developing renewable energy put forward by governments, international organizations, stakeholders from civil society, the private sector, and others. All conference participants were invited—through a "Call for Actions and Commitments"—to contribute to the IAP by pledging voluntary commitments to goals, targets, and actions within their own spheres of responsibility.

Source: Adapted from International Conference on Renewable Energies, Bonn, at: http://www.renewables2004.de/en/2004/outcome_actionprogramme.asp. The IAP and other documents can be found on this website.

3. KEEPING TRACK: INTERNATIONAL REGISTRY

An important element of formalizing an SD-PAMs system could be to maintain an international registry of pledged actions (Winkler et al., 2002). The registry could be a database containing information on all SD-PAMs pledged by governments. Such a system would serve several purposes.

The registry would serve as a tool to exchange information among governments and among governments and civil society, including industry. Making information on pledged SD-PAMs public would help inform the international community and national stakeholders of how various governments are contributing to the UNFCCC objective within the context of their own national priorities. A registry would be consistent with existing practice (such as the registry of CDM projects) and Article 6 of the Climate Convention, which calls on Parties to promote and facilitate public access to climate change-related information.

The SD-PAMs registry could be maintained by an international organization or body, such as the UNFCCC Secretariat. Parties would need to agree on the basic elements of the registry. Table 2 presents a series of indicative categories that might be used to structure such a registry.

4. ASSESSING PROGRESS: REPORTING AND REVIEW

A final element of a successful SD-PAMs system would be to assess implementation. This is necessary to ensure that pledged policies and measures are more than mere words contained in a registry. There are perhaps two central elements of a successful assessment system: reporting and review.

First, Parties should report on the implementation of their pledged SD-PAMs. This could come in the form of an annual or other regular progress report. Reporting could cover both aspects of PAM implementation—development and emissions—perhaps using key performance indicators pertaining to each. Some information from the reports could be entered into the registry as well.

Procedurally, one option would be to integrate reporting into the existing reporting structure of the Climate Convention, under which Parties must submit national communications that, among other things, describe the steps taken or envisaged to implement the Convention (UNFCCC, 1992: Art. 12.1b). However, this system suffers low levels of reporting, as some developing countries

Table 2. Indicative Classification Parameters for SD-PAMs

Policy Types	Sector	Fuel/Technology	Other Classification Details
Fiscal ▪ Taxes (exemptions, credits, etc.) ▪ Fees, charges, refunds ▪ Subsidies (transfers, grants, etc.) Market / Regulatory ▪ Mandates (products, processes) ▪ Standards (products, processes) ▪ Sector regulatory reforms ▪ Product labelling ▪ Disclosure requirements ▪ Consumer purchase options Voluntary Agreements ▪ Corporate challenges ▪ Public-private partnerships	Energy production ▪ Extraction ▪ Processing/refining ▪ Transport/transmission ▪ Electricity generation Buildings ▪ Appliances ▪ Heating ▪ Cooking, lighting, etc. Industry ▪ Steel, chemicals, cement aluminum, others Transportation ▪ Passenger, freight, air, etc. Waste Management ▪ Landfills, etc. Forestry Agriculture	Fossil Fuels ▪ Coal ▪ Oil ▪ Natural Gas Renewables ▪ Geothermal ▪ Solar ▪ Wind ▪ Biomass ▪ Tidal / wave ▪ Hydroelectric, etc. Others ▪ Hydrogen ▪ Carbon capture / storage ▪ Fuel cells ▪ Landfill gas ▪ Biofuels ▪ Industrial process change	Country Policy name & description Key Performance Indicators ▪ Sust. Development ▪ Emissions Status ▪ Pledged ▪ Enacted / Implemented ▪ Completed Effective Date(s) References / Links

Source: WRI, based on IEA/OECD (2001)

have yet to submit a single communication. Others have only recently submitted their first report, more than a decade after the Convention entered into force. One reason why is that national communications are presently accompanied by complete national GHG inventories, which are technically challenging and expensive to produce. A reporting system under SD-PAMs could focus less on inventories, and more on policies and measures, including the status and results of their implementation.

A second element of the assessment process would be a review of national reports. This process could be analogous to the present "in-depth" review system employed for reviewing the national communications of industrialized country Parties.[4] According to the UNFCCC Secretariat, these reviews aim "to provide a comprehensive, technical assessment of a Party's implementation of its commitments."[5] For SD-PAMs, these reviews would be facilitative in nature and would try to identify both successes and areas where implementation can be improved. Civil society groups and international organizations might also provide reviews of national reports, although these would have an unofficial status.

A process whereby an independent body evaluates implementation of SD-PAMs might assist in the learning process and help build capacity to take further actions. This kind of review might uncover underlying reasons why some SD-PAMs did not achieve their desired results. In some instances, it could be that promised financial or technology transfer was not delivered (for example, in a mutual pledge). In other instances, it could be that the effects of "unpledged" policies and measures nullified the expected influence on GHGs of the pledged policies. For example, the removal of coal production subsidies could be counterbalanced by increases in subsidies for combustion of coal in electric power generation. SD-PAMs, by their nature, would capture only the former and therefore would give an incomplete picture.

There are precedents for these kinds of approaches in other areas of international relations. The World Trade Organization's Trade Policy Review Mechanism, for example, provides a kind of "peer review" of a country's trade policies and practices, which helps "enable outsiders to understand a country's policies and circumstances," while "providing feedback to the reviewed country on its performance …."[6] This system provides for reports by both the WTO member country and a review by a body independent of the Parties, the WTO Secretariat.

With respect to SD-PAMs, the information generated in a review process would enhance the ability of regulators and stakeholders to distinguish between policies that were effective from those that failed to produce desired results, either in terms of local sustainable development benefits or emission reductions. This would inform future policy

making at the national level, as well as promote useful cross-country exchanges of experiences. Finally, beyond promoting learning, both official and unofficial country reviews would promote accountability and increase the likelihood that pledged actions are fully implemented.

5. QUANTITATIVE APPROACHES: ACCOUNTING FOR EMISSION REDUCTIONS

SD-PAMs are qualitative in nature and are clearly distinguishable from quantitative approaches to climate protection such as emission targets and the Clean Development Mechanism. However, it may be possible or even desirable to connect the pledged actions to these and other quantitative approaches in order to harness the potential benefits of the international carbon market. There are at least three possibilities of building a quantitative dimension into SD-PAMs: the existing CDM, an expanded "policy" or "sector-based CDM" (Samaniego and Figueres, 2002; Bosi and Ellis, 2005), and "action targets" (Baumert and Goldberg, 2005).

These three options each have advantages and drawbacks, and are explored briefly in this section. A cross-cutting issue that affects all options is whether a carbon market will exist after 2012 and, even if it does, whether it will establish a price signal sufficiently strong enough to affect widespread behavior. The viability of Kyoto's CDM, for instance, is partly a function of emission reduction commitments of industrialized countries, which stimulates the demand for emission-reducing projects in developing countries. If President Bush and subsequent U.S. administrations continue to oppose such an approach, it is uncertain whether the European Union, Japan, and Canada will be willing to continue with emission caps beyond 2012. Thus, broader future climate change policy considerations factor heavily into the viability of some options outlined in this section.

5.1 Clean Development Mechanism

The basic elements of the CDM are set out in Article 12 of the Kyoto Protocol and elaborated further in the 2001 Marrakesh Accords.[7] The CDM has a dual purpose: (1) to assist developing countries "in achieving sustainable development," and (2) to assist industrialized countries in achieving compliance with their emission limits. This is done through GHG-reducing projects in developing countries (such as installing wind-based power instead of coal-fired power), which generate emission credits that, in turn, can be used by industrialized countries to offset their own domestic emissions. The sustainable development dimension of the CDM, as discussed above, is decided on a project-by-project basis at the discretion of the host government.

Although the CDM is a *project-based* mechanism, it could be supportive of SD-PAMs. SD-PAMs could provide the regulatory mandates or market incentives to develop projects that have concrete sustainable development and climate benefits. Those projects, in turn, could be eligible for crediting under the CDM. Indirectly, this would provide a further incentive to implement SD-PAMs, given that some costs could be recouped through sale of emission reduction credits.

To operate in this manner, CDM rules may need to be changed. CDM rules are designed to ensure that projects are *additional* to what would have occurred in the absence of the CDM. Projects implemented under existing or new SD-PAMs could be rendered "non-additional" by the mere fact that they are now required by law or made financially attractive through government intervention. In other words, projects might be precipitated by an SD-PAM—not the CDM—and therefore be considered non-additional. In 2004, the CDM Executive Board, which oversees the mechanism, established guidelines that partially address this issue. Under the guidelines, "climate-friendly" policy incentives (such as an energy efficiency subsidy) may be ignored by project developers in baseline formulations (UNFCCC, 2004b). However, projects adopted pursuant to *mandatory* regulations are still not subject to any guidance, and it is not clear whether they would qualify for CDM crediting.[8]

Finally, the use of SD-PAMs as a platform for CDM project development could significantly increase the overall flow of projects. While this would be favorable, it would also overwhelm the already strained administrative capacity of the CDM Executive Board, which is responsible for registering projects, certifying emission reductions, and issuing credits. A renewable energy program in a single country, for example, could generate tens or even hundreds of projects that would all need to be validated and registered, with subsequent claimed emission reductions verified, certified, and issued. A significant restructuring of the mechanism's basic regulatory and administrative systems would likely be needed.

5.2 Policy or Sector CDM

Some observers have already examined the prospect of expanding the scope of the CDM to encompass policies or cover entire national sectors or geographic areas (Samaniego and Figueres, 2002; Schmidt et al., 2004; Bosi and Ellis, 2005). Under this vision, an SD-PAM itself, or the sector in which one or more SD-PAMs is targeted, could generate emission reduction credits.

This approach has some apparent advantages. It could help create incentives for positive policy change along the lines discussed throughout this report. Second, restructuring the mechanism along sectoral or policy lines could alleviate some of the bottlenecks and high transaction costs of a burgeoning project-only mechanism. A basket of policies and measures in a single sector could, for instance, all be aggregated together for a determination of emission reductions. All of the policies and projects undertaken in China's transportation sector, discussed in Chapter 4, might be treated collectively, for example.

There are also a number of challenges and shortcomings associated with a sector- or policy-based CDM. The most significant challenge would be determining the amount of emission reductions (or avoidance) associated with PAMs. Even under the present project-oriented CDM, this has proven controversial and more difficult than expected. Disagreement is particularly rife with respect to determinations of "additionality," as it is very difficult to develop simple rules capable of reasonably ensuring that credits are issued only to projects that would not have occurred absent the CDM. Additionality assessments in the context of SD-PAMs would be virtually impossible. Indeed, the very concept of additionality is at odds with SD-PAMs, which are likely to be implemented for non-climate reasons. Furthermore, the SD-PAMs approach would cover the implementation of existing policy.

Accordingly, a new framework would be needed for deciding which policies and measures are creditworthy and which are not. Rather than additionality assessments, a more promising approach might be to define a set of activities or policies—such as some of those discussed in this report—that are unquestionably climate-friendly and therefore *a priori* eligible for crediting, regardless of the motivation for enactment. Accounting standards, based on such a set of activities and policies, would then need to be developed to enable emission reduction determinations in a manner that is reasonably simple and transparent.[9] This might be done through a system of performance benchmarks or rate-based emission baselines (for example, CO_2 per unit of output), probably on a sector or subsector level.

Even if this is feasible, however, a sector/policy-based CDM still has a remaining problem pertaining to the structure and balance of the overall carbon market. A sector/policy-based crediting mechanism could generate large quantities of emission reductions. As illustrated in this report, just a handful of large sectoral initiatives could generate reductions of hundreds of millions of tons of CO_2. However, reductions of this scale might overwhelm the demand from industrialized countries, or otherwise dampen incentives in those countries to continue abatement efforts. This problem might be remedied by deeper emission cuts in industrialized countries. Yet such cuts do not appear to be forthcoming. In particular, some countries like the U.S.—even if it agreed to an emission limit—would not likely cap emissions at a level that would leave it overly dependent on credits from other countries to comply.[10]

5.3 Action Targets

Action targets, summarized in Box 3, are a third possibility for incorporating a quantitative dimension into SD-PAMs. Action targets would address some of the difficulties discussed above, though substantial challenges would remain.

Under an action targets approach, in addition to pledging SD-PAMs, a country would pledge to achieve a quantity of emission reductions (the "action target"). The expectation would be that the SD-PAMs ("actions") pledged would generate emission reductions that, in turn, would be used to satisfy the target. If SD-PAMs were to generate emission reductions in excess of the target, all or part of these surplus reductions could be sold to governments or private buyers, thereby generating a financial return.

Box 3. Action Targets

An action target would be a pledge to achieve or acquire an agreed amount of GHG *emission reductions*. For example, if a country adopted an action target of 2 percent for the period 2013–17, it would need to demonstrate emission reductions equal to 2 percent of its actual emissions during this period. In this way, an action target defines the amount of abatement to be achieved during a commitment period. This differs from Kyoto-style or dynamic targets, which define a level of *emissions* (or *emissions per unit of GDP*) to be achieved during a particular period.

To illustrate, suppose Country A agrees to an action target (AT) of 5 percent for the year 2015. If Country *A's* emissions (*E*) in that year are 100 million tons of carbon ($MtCO_2$), then the required amount of reductions is 5 $MtCO_2$ (5 percent of 100). It follows that, if emissions are *actually* 100 $MtCO_2$ in 2015 and the country has demonstrated 5 $MtCO_2$ of domestic reductions, then emissions *would have been* 105 $MtCO_2$ in the absence of any actions taken to reach the target. In this way, action targets would have the effect of bending the emissions trajectory of a country downward.

Source: Adapted from Baumert and Goldberg (2005)

Action targets entail some advantages over sector/policy CDM. In particular, the risk of overwhelming the demand for credits from Annex I is substantially reduced because not all credits generated are transferable; only emission reductions achieved in excess of domestic action targets could be sold. An appraisal of the expected abatement quantities generated by *existing* SD-PAMs might constitute a useful starting point for setting an action target. In this way, substantial quantities of "non-additional" credits (in the parlance of the CDM) could be used to satisfy domestic action targets, with new SD-PAMs generating emission reductions that, in whole or part, could be transferred.

Second, by adopting quantitative commitments, it is possible that SD-PAMs when coupled with action targets could attract more concessional financing from industrialized countries under the UNFCCC. With the added quantitative commitment, developing countries may improve their negotiating position with respect to additional funding. On the other hand, developing countries have long resisted quantitative commitments in any form, and might continue to do so.

The chief challenge associated with sector/policy CDM, however, remains for action targets as well. Namely, what constitutes an "emission reduction" that can be used to satisfy an action target or be sold? How could an accounting system be devised that captures emission reductions from diverse kinds of SD-PAMs, such as renewable energy portfolio standards, product efficiency standards, road charges, and clean energy subsidies, among many others? Although a full exploration of this topic is beyond the scope of this report, some preliminary observations can be made.

First, because not all emission reductions would be tradable, the need for quantitative precision is reduced, and in any case experience shows that accuracy is unachievable. The purpose of the accounting system for SD-PAMs, coupled with action targets, would be to identify and promote the kinds of SD-PAMs that are needed to achieve the Climate Convention's objective, including those actions taken mainly for economic, social, or other purposes. In this way, it would differ substantially from the CDM's additionality tests. A system of performance benchmarks or rate-based emission baselines might be called for (as with sector/policy CDM), probably on a sector or subsector level.

Second, lessons from Kyoto suggest some procedural safeguards that could improve the likelihood of success. Most importantly, negotiators should agree on an accounting system—at least the main contours of one—*prior* to adopting action targets under an SD-PAMs system. In doing so, governments would avoid the approach taken under Kyoto, which turned negotiations on CDM project eligibility, additionality methodologies, and other issues into *de facto* renegotiations of national targets. To the extent possible, an accounting system should be developed through broad stakeholder participation (given the inevitable policy issues that will arise) coupled with the input of technical competence and expertise.[11]

6. CONCLUSION

This chapter has outlined several ideas and parameters for formalizing SD-PAMs in the context of the broader evolution of the climate change regime. A number of elements are likely to required, including definition of eligible types of SD-PAMs, as well as procedures for pledging, tracking, reporting on, and reviewing SD-PAMs implementation. Resolving GHG accounting issues may also enable quantification of the GHG benefits flowing from particular PAMs, or sectors within which multiple PAMs are targeted. Additional future work is needed in these areas.

While the concept of pledging national policies and measures may be untried, many elements described above are adapted or borrowed from existing practice under the Convention. For instance, the process of agreeing on emission targets involved, in some sense, a bottom-up pledging process. Likewise, the Convention already employs a system for reporting and review of policy implementation. To be successful, an SD-PAMs system would need to build on and improve these systems.

ENDNOTES

[1] The line between projects and policies could be blurred in some instances, particularly if a project is large scale. Large-scale infrastructure projects, for instance, may require enabling legislation, partnerships, or even international agreements as prerequisites to planning, financing, and implementation.

[2] UNFCCC, Article 4.1(b), states that "all Parties shall "[f]ormulate, implement, publish and regularly update national ... programmes containing measures to mitigate climate change..." Article 4.3 then states that the developed countries shall "provide such financial resources, including for the transfer of technology, needed by the developing country Parties to meet the agreed full incremental costs of implementing measures that are covered by paragraph 1 of this Article...."

[3] An issue for future consideration would be whether pledge "periods" (i.e., negotiations) should be set in regular intervals or be rolling. Parties may need to hold pledge periods in regular intervals (such as every three to five years).

[4] In-depth review process is defined in COP decisions 2/CP.1 (1995) and 6/CP.3 (1997).

[5] UNFCCC, 2005. *National Communications Annex I: Review of Information.* Available at: http://unfccc.int/national_reports/annex_i_natcom_/items/1095.php.

[6] See WTO, 1995 and "Trade policy reviews: ensuring transparency." Available at: http://www.wto.org/english/thewto_e/whatis_e/tif_e/agrm11_e.htm.

[7] UNFCCC, 2001. Ongoing guidance is also promulgated by the CDM Executive Board. For information about the Executive Board, see http://unfccc.int/cdm/EB.

[8] UNFCCC, 2004b (Referring to type L- and L+ policies or regulations).

[9] See the GHG Protocol Initiative (convened by the World Resources Institute and World Business Council for Sustainable Development) for an example of such accounting standards at the corporate and project level. Information available at: http://www.ghgprotocol.org.

[10] See e.g., Bush Administration, 2001 (Asserting that the "Kyoto Protocol would leave the United States dangerously dependent on other countries to meet its emission targets ... There is no guarantee that these allowances would be available.") Similar objections would likely be expected from future administrations as well.

[11] The GHG Protocol may be a useful multistakeholder model for developing such standard. *See supra* note 9.

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Editor's Note

In the 1970s, Brazil faced two seemingly unrelated challenges. Most critically, the oil crisis and the huge rise in prices had imposed a damaging burden on the country's economy, pushing its external debt up to levels that would be difficult to sustain. At the same time, Brazil's sugar industry, a major component of its economy, was struggling with low world market prices, and rural community revenues were depressed.

The answer to both of these problems lay in the production of ethanol from sugarcane. The government implemented wide-ranging measures to ensure that ethanol was a significant part of the transport fuel mix—partly blended with gasoline, and partly for use as a pure fuel in specially-adapted car engines. Since that time, Brazil has saved some $100 billion in foreign exchange, both in reduced import costs and in reduced service payment on the debt that it would have incurred from larger oil imports. This saving is equivalent to 50 percent of Brazil's actual (sizeable) national debt, and some 8 percent of current GDP. Over a million jobs in rural Brazil depend on ethanol and sugar production, and the industry has been protected from exclusive dependence on the volatile world price for sugar. Air quality has generally improved, and biofuel manufacture produces around 1,350 gigawatt hours (GWh) per year of useful electricity for export to the grid, a figure that has risen from a mere 80 GWh in 1997 and is still rising fast as technology improves.

These domestic gains have been the real measures of the program's success, but the incidental benefits to the climate have been considerable. Without the biofuels program Brazil's cumulative emissions of CO_2 *from higher oil consumption between 1975 and the present would have been 10 percent higher—a saving of almost 600 million tons of* CO_2.

The strategy examined in this chapter is the only one in this report which is already implemented on a large scale and over a long time period. Although the goal of promoting ethanol has remained constant, the policy mix employed to this end has changed over time. Initial subsidies were high, but as the technology and the infrastructure developed, these have steadily declined and have now been eliminated. A mandated level of ethanol admixture remains central to the ethanol market, but pure ethanol sales are also important. The market for renewable electricity is emerging as mutually supportive with ethanol production, and new "flexfuel" vehicle technology makes ethanol more appealing to consumers.

The authors suggest that some 20 other countries have suitable conditions for a similar expansion of sugarcane ethanol. In countries with more temperate climates, a technology breakthrough is still needed to make cellulosic ethanol more viable. Both approaches have some local impacts, particularly on land use, that will need careful management, but the authors suggest that these can be overcome. An appeal of ethanol is that it allows a gradual increase in its use rather than an all-or-nothing switch to a new technology, so adverse impacts can be managed as they arise.

Brazil's biofuels program represents, in a sense, one end of a spectrum of SD-PAMs and raises some interesting questions of its own. Brazil's ethanol program has reached a stage at which it requires little additional support, though it is possible that this might change if oil prices return to low levels. International recognition no doubt has some appeal, but the additional benefit of exploring this as an SD-PAM may seem to be limited for Brazil. Conversely, a number of countries might be helped to implement such a program with additional support ranging from exchange of information and easier access to relevant technologies, to financial support in cases where this is needed. This illustrates the potentially eclectic nature of SD-PAMs, as a similar technology choice may be supported in different ways as the needs of the host country dictate.

The climate benefits of this development would be huge, but would not need to be treated exclusively as a mitigation cost. Furthermore, as today's oil market shows, the levels of demand from one country affect, to a greater or lesser degree, prices for all. There can be few more compelling examples of policy areas ripe for international cooperation.

CHAPTER III

Biofuels for Transport, Development, and Climate Change:

Lessons from Brazil

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1. INTRODUCTION

Scientific consensus suggests that avoiding serious or even catastrophic impacts from climate change will require global emissions of greenhouse gases (GHGs) to begin to decline within the next few decades. While rich industrialized countries must lead in making these emission cuts, large developing countries must also find ways to avoid emissions growth and even reduce their emissions. However, urgent development needs mean that findings ways to combine development and emission reductions is imperative.

One major potential opportunity for this kind of synergy is the replacement of fossil fuels by biofuels for transport. This approach has been promoted in many countries as a way to reduce dependence on imports of fossil fuels, reduce price volatility, and provide local environmental benefits. In addition, biofuels can also bring large potential climate advantages. Brazil has for several decades been at the forefront of introducing these fuels, and is an ideal place to look for lessons that can be applied elsewhere.

This chapter looks at the non-climate reasons behind Brazil's biofuels program; the technical, economic, and institutional hurdles it faced; the incidental climate advantages; and how lessons learned in Brazil might be usefully applied elsewhere.

1.1 Sustainable Development Policies

To put the biofuels issue in perspective, we begin with a few words about Brazilian sustainable development goals and the policies and measures to achieve them. A policy designed for sustainable development must, as a minimum, guarantee development. Since shortage of capital is a frequent problem in developing countries, economic development depends strongly on foreign investment. Unfortunately, the country has faced several serious economic crises. The overall international current transaction account was positive during only six of the last 40 years, and negative values have been as high as 4.6 percent of GNP (Banco Central, 2004).[4] Brazil's external debt is the largest of any large developing country. Risks associated with Brazil's capacity to repay debt pushed interest rates to high levels. Since 2003, 4.25 percent of GNP has been set aside for external debt repayment in the federal government budget, but absolute debt levels have declined only modestly. These issues undermined Brazil's credibility, often reducing foreign direct investment.

On the other hand, the low-technology industrial sector and the agricultural sector were not able to push exports at a significant rate until recently (2003–05). With a modest flow of foreign currency receipts, economic survival required significantly reducing imports. Given the large cost of oil expenditures in the country's trade, any national alternative displacing imported oil would bring major benefits. With less spending on oil, it would be possible to use scarce capital domestically.

As economic development has proceeded, the next issue, sustainability, has gained importance in the country's planning. But several barriers to sustainable development concerned government policymakers, including (1) the nation's low education level; (2) lack of adequate infrastructure; (3) poor income distribution; and (4) insufficient social welfare spending. A number of these problems are encapsulated in the state of much of Brazil's rural economy. Although significant programs exist to help address each of these problems directly, there remains a significant demand for jobs for workers with low education levels, as well as a need for revenue in rural areas. The lack of rural employment affects both low rural incomes and migration rates to urban centers.

Infrastructure improvement has occurred in areas such as energy production and distribution, sewage and water, and construction of roads and—to a lesser extent—railways. Unfortunately, restrained demand is huge, and infrastructure maintenance is not a priority. In essence, demand for services is outstripping available resources. Environmental priorities also are starting to emerge. Environmental institutions, officials, and NGOs already exist and are gaining prestige. In more developed states, compliance with environmental legislation requires a significant effort on those proposing new projects. Large energy projects are facing severe limitations due the enforcement of environmental norms. Sustainable development conditions are being sought much more emphatically than in the past, and results are starting to appear.

We shall see in this chapter that the use of biofuels has had positive impacts on each of these areas, as a contribution to the rural economy and job creation; to energy infrastructure, including electricity; and to the environment.

2. BIOFUELS IN BRAZIL

2.1 What is a biofuel?

A biofuel is a fuel produced from dry organic matter or combustible oils produced from plants. There are several kinds of biofuels, including alcohol (from fermented sugar), black liquor from the paper manufacturing process, wood, and soybean oil (IPCC, 2001). While a range of biofuels can be used as automotive fuel, either pure or blended with fossil fuels, the important biofuel for transport in Brazil is ethanol from sugarcane. Although other kinds are being considered, in particular biodiesel (see Box 1), their use remains minimal. By contrast, there were about 21 million vehicles in the country running on ethanol or ethanol blends as of 2005. So, in the Brazilian context, biofuels are virtually synonymous with ethanol.

2.2 Current status of biofuels in the Brazilian market

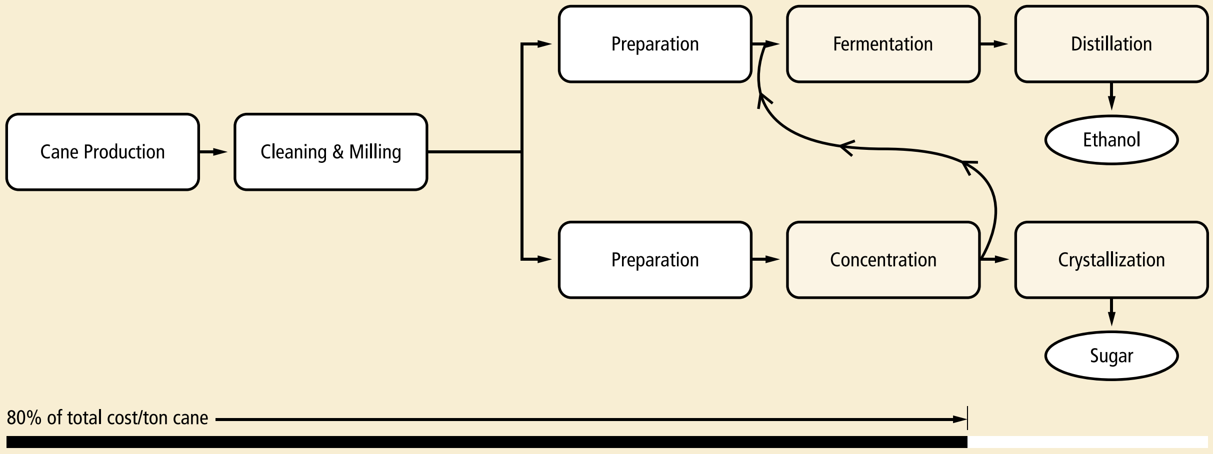
Ethanol is largely used as an alternative for gasoline in the automobile sector. In Brazil, all ethanol is produced from sugarcane through the fermentation of sugars contained in sugarcane juice. The same agricultural product can be used to produce either sugar or ethanol (see Figure 1). The market for ethanol is therefore intimately interlinked with that for sugar and related products, and the history of ethanol needs to be understood with this in mind.

Box 1. Biodiesel in Brazil

While ethanol has been successfully introduced as a partial substitute for gasoline, there has so far been no equivalent replacement of diesel fuels. Diesel oil is the most important fuel in Brazil, with an annual consumption of about 38 billion liters, amounting to 36 percent of total oil product demand. Today, 15 percent of Brazilian diesel demand is imported. A national biodiesel program was launched in January 2005 and is now under development. An official national standard for biodiesel is already available. Recently, the National Petroleum Agency (ANP) issued a set of regulatory documents to prepare the downstream oil industry to deal with biodiesel implementation. Since January 2005, the government has allowed the blending of up to 2 percent of biodiesel in regular diesel. This amount will be adjusted annually, moving toward 5 percent in 2008.

Source: Ministério de Minas e Energia, Programa Combustível Verde, Brasília (2004). Available at: http://www.mme.gov.br.

Figure 1. Simplified Flow Diagram for Sugar and Ethanol Production from Sugarcane



Source: Macedo (2003)

Sugarcane is grown in more than 100 countries worldwide and accounts for the majority of global sugar production. Brazil plants and harvests a large amount of sugarcane: about 400 million tons were harvested in the 2004–05 growing season, covering an area of 5.5 million hectares. Aside from sugar and ethanol, products from the cane include biodegradable plastics and low-grade paper. The byproducts, bagasse (residues from the sugar manufacturing process) and barbojo (tops and leaves remaining from harvesting), are generally burned. Bagasse, in particular, is traditionally used as a source of heat and electricity for the agroindustries processing sugarcane into ethanol and sugar, as well as in other agroindustries such as orange juice production.

Nearly half of Brazil's cane is destined for ethanol. Brazil has two distinct sugar producing regions. The Southern-Central region is dominated by the state of São Paulo, which alone accounts for 65 percent of the country's sugarcane production. This region supplies three-quarters of the country's cane, over 70 percent of the sugar output, and approximately 90 percent of the ethanol. The Northeast accounts for less than 20 percent of Brazil's sugarcane production, approximately 25 to 30 percent of the country's sugar output, and about 10 percent of its ethanol.

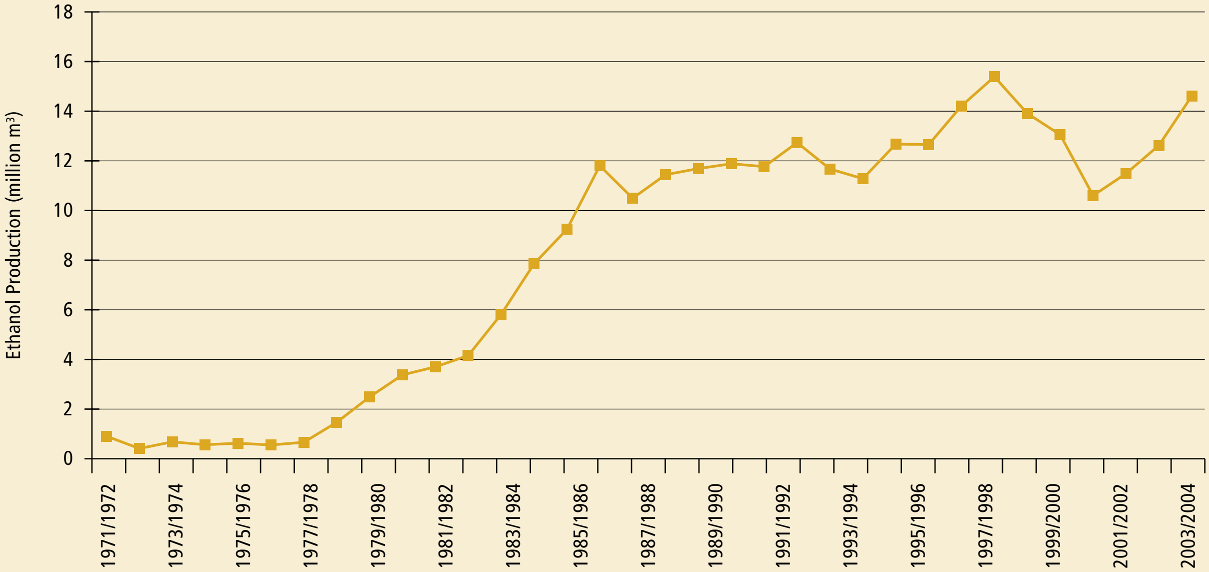
Table 1 summarizes major indicators of the sugar/ethanol sector in Brazil for the year 2003. Raw and refined sugar account for roughly 2 to 4 percent of Brazil's exports, depending on yields. The large-scale use of ethanol as fuel for vehicles in Brazil dates from 1931. From 1931 to 1975, around 7 percent of total Brazilian gasoline consumption was replaced by ethanol, as established by law. In 1975, the Brazilian Alcohol Program (Proalcool) was launched, increasing the use of gasohol and promoting pure ethanol use in dedicated models. Figure 2 shows the evolution of alcohol production since then.

Table 1. The Sugar/Ethanol Sector in Brazil, 2003

A US$12 billion annual market	
Gross Turnover	$12 billion (R$36 billion)
Share of National Income	3.5 percent of GNP
Employment	3.6 million jobs (direct, indirect, and some induced)
sugarcane growers	70,000 farmers
sugarcane harvest	340 million tons of sugarcane
Output – Sugar	24 million tons of sugar
Output – Ethanol	14 billion liters of alcohol
Exports – Sugar	13.5 million tons of sugar
Exports – Ethanol	690 million liters of alcohol
Taxes	$1.5 billion (R$4.5 billion)
Investments	$1.2 billion/year (R$3.5 billion/year)
Producers	302 mills

Source: Moreira (2004)

Figure 2. Ethanol Production (Anhydrous plus Hydrous) by Growing Season



Source: Datagro (2004); Datagro (2002)

It is commonly asserted in the international alternative energy literature that biomass-derived transport fuels are uneconomic at present. However, substantial cost reductions have occurred for sugarcane-derived ethanol since the early 1980s (Goldemberg, 2005). This trend accelerated further after the 1999 currency devaluation. This effect, plus the increase in the cost of oil since 2000, has made ethanol cost-competitive with gasoline. The number of new automobiles running on pure (or "hydrous") ethanol was almost zero in the period 1995–2000 but recently has started to show significant improvement (see Figure 3).

2.3 A brief history of biofuels in Brazil

Ethanol has been proposed as a fuel since the beginning of automobile use in Brazil. In 1903, a national meeting on applications of ethanol put forward plans to develop an infrastructure to produce and distribute ethanol from sugarcane as a motor fuel.[5] During World War I, the use of alcohol was compulsory in many areas of the country. By 1923, production of ethanol had grown to 150 million liters per year; in 1927 it was blended with diethyl (ethyl) ether and castor oil. In 1931, a Federal Decree established the compulsory addition of 5 percent of ethanol in gasoline; this was elevated to 10 percent in 1966. By 1941, ethanol production had reached 650 million liters.

The impetus for the huge growth of ethanol use in recent decades started in the 1970s. Brazil faced two seemingly unrelated challenges. The oil crisis and the consequent rise in oil prices were putting great strains on Brazil's external trade balance. At the same time, the international market price for sugar was falling rapidly, and the sugarcane sector was looking for alternative sources of revenue. In 1975, the Federal Government decided to encourage the production of alcohol to replace gasoline (see Box 2).

In a sense, there have been two ethanol programs: the somewhat fluctuating use of pure ethanol fuel, and the steady success of mixed (anhydrous) ethanol in gasoline.

The target set in 1975 was to displace a share of gasoline by blending it with 10 percent anhydrous ethanol (see Figure 4). In addition, the government, which had at that time full control over fuel distribution and pricing, mandated that all filling stations should have at least one ethanol pump. Significant ethanol production and the continuing high price of oil pushed the government to steadily increase this proportion. In 1979, cars running on "neat" (pure) hydrous ethanol entered the market, and both these and "gasohol" cars running on blended ethanol and gasoline were popular. Between 1975 and 1985, the production of sugarcane quadrupled and alcohol became a very important fuel in Brazil (see Annex 1 and Figure 3).

Government intervention in the sugar and alcohol market was significant (see Box 2). Although oil prices declined in the 1980s, the impact of this decline on the ethanol program was minimized, as the government indexed the price of ethanol to the price of gasoline, ranging from 59 to 75 percent of its price. The gasoline price was always higher than that of other oil-derived fuels due to differentiated federal and state taxes charged on fuels. Even so, interest in alcohol declined significantly when it reached the upper limit (75 percent) of its price index against gasoline.

The neat ethanol car faced some technical problems during the first two years, but after that it was a significant success up to 1989. In that year, a shortage of ethanol hit those with cars that would only run on that fuel and seriously dented consumer confidence and sales of neat ethanol vehicles (Figure 3). After 1996, much lower oil prices and the decline in government support made sales drop even further. Ethanol subsidies came to an end in 1998. Even then, gasoline prices were kept higher than other fossil fuels due to an extra tax. As the fuel markets were liberalized, hydrous ethanol was sold in service stations at up to 90 percent of the price of gasoline (or to be more precise, gasoline/ethanol blends). This virtual elimination of its price advantage coupled with memories of the supply crunch of a decade before brought sales of neat ethanol cars down close to zero.

By 2001, however, a falling ethanol price caused by stronger competition—coupled with a significant devaluation of the national currency—revived consumer interest in neat ethanol cars. Initially, there was an increase in neat ethanol car sales, but the arrival of flexfuel cars on the market accelerated this effect (see Annex 1 and Figure 3). Such cars can operate either with gasoline (all gasoline in Brazil has 25 percent ethanol blend) or with hydrous alcohol, or any combination of these fuels. The

Box 2. Overview of Government Support for Ethanol

From 1975 to the 1980s

Ethanol:

Level of guaranteed purchase, at controlled prices

Fixed ratio of ethanol/gasoline selling prices

Low interest rate in loans for investment (1980–85)

Sugar:

Government issued "production quotas"

Exports: by the government

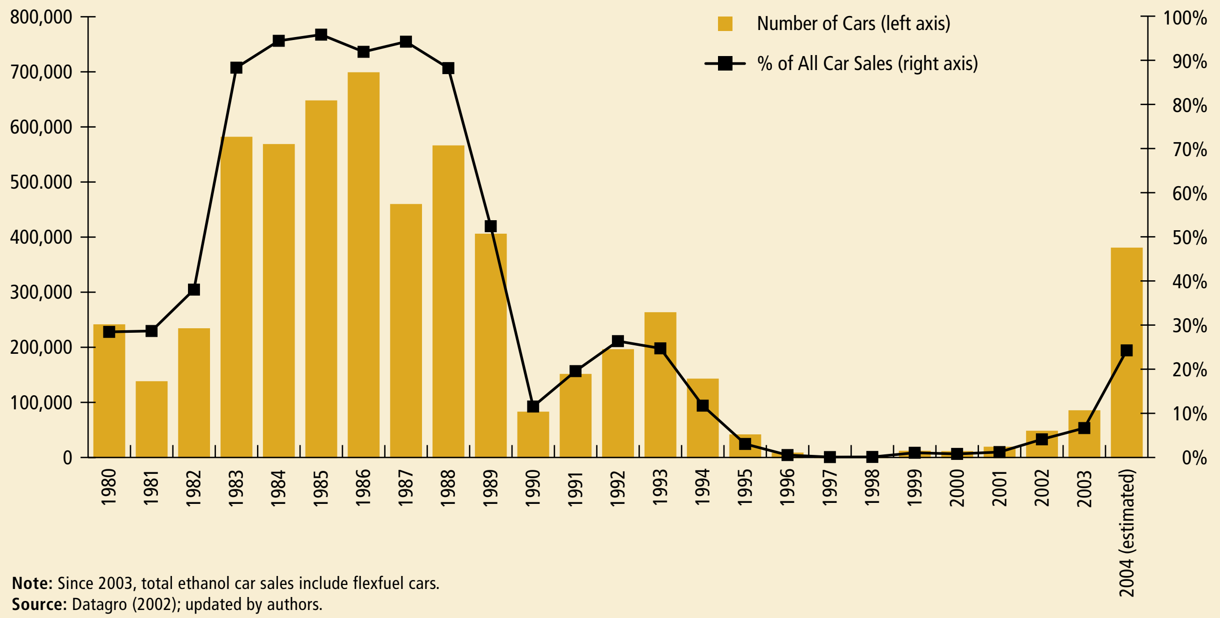
From 1990 to 1999

Ethanol and sugar:

Production and commercialization were entirely deregulated for both products

Source: Macedo (2003)

Figure 3. Ethanol-fueled Vehicle Sales since 1980



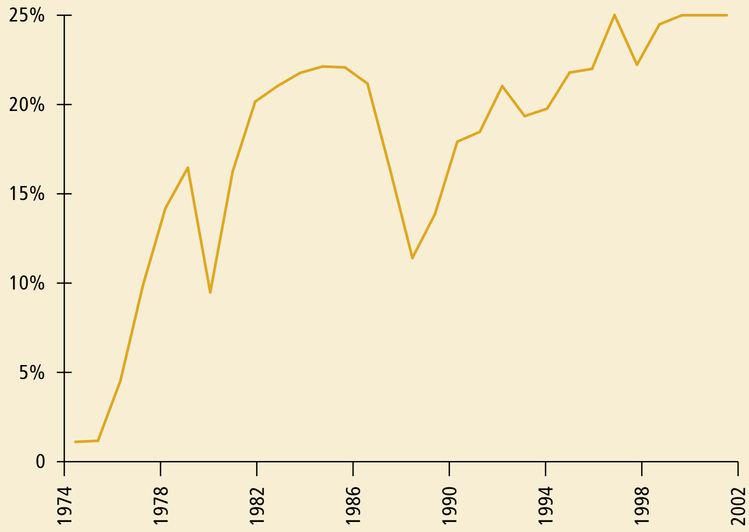
Note: Since 2003, total ethanol car sales include flexfuel cars.
Source: Datagro (2002); updated by authors.

flexfuel technology was improved in Brazil and its cost was significantly reduced. Flexfuel cars were being sold at the same price as models running exclusively on gasoline or on hydrous ethanol. There was a significant increase in sales in 2004, when several local car manufacturers offered flexfuel models.

Conversely, anhydrous ethanol blended with gasoline, fixed by government mandate, had a smoother path over the last 30 years. During the 1980s, the shortage of ethanol caused some variability in the share of ethanol blended with gasoline during this period, but it has stabilized in more recent years (see Figure 4). Figure 5 shows a breakdown of the pump price of gasohol, diesel and ethanol fuels (note that pure gasoline is not generally sold.)

With an accumulated production above 280 billion liters and with technical improvements, it has been possible to produce ethanol at a cost below $0.20 per liter.

Figure 4. Share of Anhydrous Ethanol in Brazilian Gasoline



Source: BEN (2004)

3. REASONS FOR THE SUCCESS OF BIOFUELS IN BRAZIL

As discussed above, the biofuels program in Brazil had more than one aim and was in turn affected by a number of factors. In this section, we examine some of these factors and their impact on ethanol use in Brazil.

3.1 Synergies with the sugar market

As discussed above, the production of ethanol is intimately linked with sugar production. Sugarcane produces exceptionally good yields as an energy crop (Figure 6), and technical improvements are expected to push these yields further. The 2001 worldwide average (over 22 million hectares [Mha] of land) for aboveground biomass yield was 28.4 dry tons per hectares per year (dt/ha/yr) (Hall et al., 1993, and FAO, 2002). The yield for Zambia (averaged over 10,000 ha) was 77dt/ha/yr (Hall et al., 1993).

Brazil has a large sugar industry, which has been able to take advantage of the flexibility between ethanol and sugar production. During most of the period of declining ethanol car sales (1990–98) and low sales (1999–2003), as shown in Figure 7, sugarcane producers expanded sugar production; both sugarcane productivity and planted area increased. As ethanol production declined, this production was diverted to sugar. Between 1992 and 2004, Brazil's share of world sugar exports grew from 10 to 30 percent due to lower costs in Brazil and difficulties in other producing countries.

The coupled production of alcohol and sugar can be seen as a significant driver for the successful alcohol program in Brazil. The steps involved in sugar and alcohol production from sugarcane, as shown in Figure 1 (p. 27), allow flexibility of production. If sugar production becomes less attractive due to reduced prices in the international market, it might become more profitable to shift production to alcohol. In common with many agricultural commodities, international sugar prices have been both highly volatile and on a general downward trend. However, it is important to take into account the need to protect the fuel alcohol domestic market; that is, sugarcane producers often have to produce ethanol even when they could make greater profits by selling sugar. This was an important lesson learned from the past alcohol shortage.

The sugar industry has shown significant improvements in its productivity, which has in turn benefited ethanol production (see Table 2).

3.2 Synergies with electricity and heat production

A second important area of synergy, which is still being fully realized, is in associated energy production. Globally, the energy content of sugarcane *residues* has been evaluated as 7.7 exajoules (EJ) per year (Hall et al., 1993). Updating this figure using crop area and yield data for 2001 (FAO, 2002), we calculate that the energy content of such residues today to be 9.83 EJ per year.

Capturing this energy for electricity generation and heat production is an important contributor to the success of biofuels. At present, cogeneration of heat and electricity from bagasse residues covers most of the energy needs of the biofuel production process itself. It also allows an increasing amount of electricity to be exported to the grid.

From 1997 to 2004, the amount of electricity from biomass sold to the grid increased from 80 to 1,350 gigawatt hours (GWh) in the State of São Paolo (see Figure 8). This energy came mainly from retrofitting existing energy supply facilities in some 30 sugar mills (from a total of more than 300 presently in operation in Brazil). This growth is expected to continue, sponsored by a renewable energy support system (PROINFA) recently instituted by the Federal Government. This program provides a guaranteed price for biomass electricity ($32 per megawatt hour [MWh]), the same price as for new hydropower and around half that ($60-70 per MWh) of wind. The aim is for a total of 9,000 MW of new renewable power, of which biomass contributes up to one third. Such goals are difficult to achieve due to the difficulties of competing with low-cost hydropower in Brazil. Some hydro production costs (for example, in the case of Itaipu) do not really reflect the real cost, since the cost of building the plant ($14 billion) has not been fully incorporated into the final price of electricity; that is, much of this cost has been written off as foreign debt.

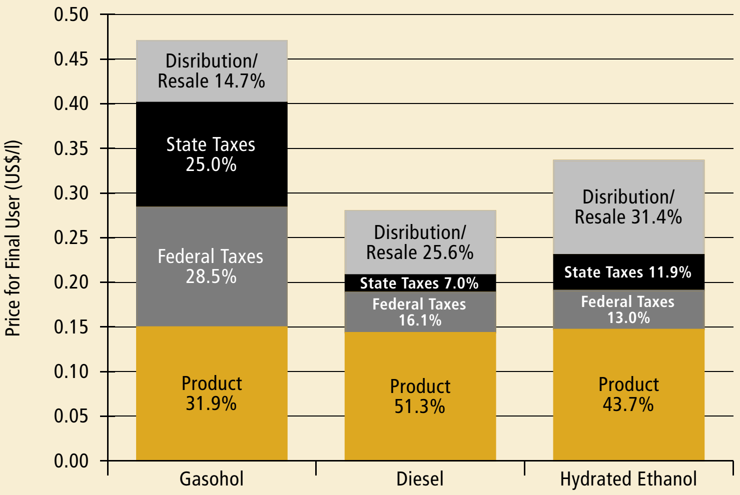
3.3 Institutional support

For a variety of reasons, replacing gasoline with another fuel has been a challenge in several countries. One reason has to do with a "chicken-and-egg" problem in the supply chain. Consumers are afraid of buying cars that use any new fuel due to difficulties in finding the new fuel in the large area around which an automobile is designed to move. Service station owners are not interested in investing in a parallel fuel supply distribution system, since the number of potential users is usually very small.

In this context, the leadership role of the Brazilian government (at both the federal and state levels) in providing incentives and a clear institutional framework was absolutely essential. This role included the setting of technical standards, support for the technologies involved in ethanol production and use, financial advantages, and market conditions.

The set of incentives has changed significantly over the lifetime of the ethanol program. In the 1970s, the government controlled the fuel market through its state-owned oil company Petrobras, which had a monopoly on ethanol distribution. The government's role receded gradually, and the monopoly ended in the late 1990s. The government's remaining participation, according to Presidential Decree, regulates the level of ethanol to be blended into gasoline. As noted, the program started with subsidies, but they were gradually phased out. This is an ideal policy for renewable fuels, but it may not be possible in many cases.

Figure 5. **Gasoline, Diesel, and Hydrous Ethanol Price Composition – Oct. 2002**



Source: Nogueira (2003)

Table 2. **Technology Evolution 1975-2000 (São Paulo Region)**

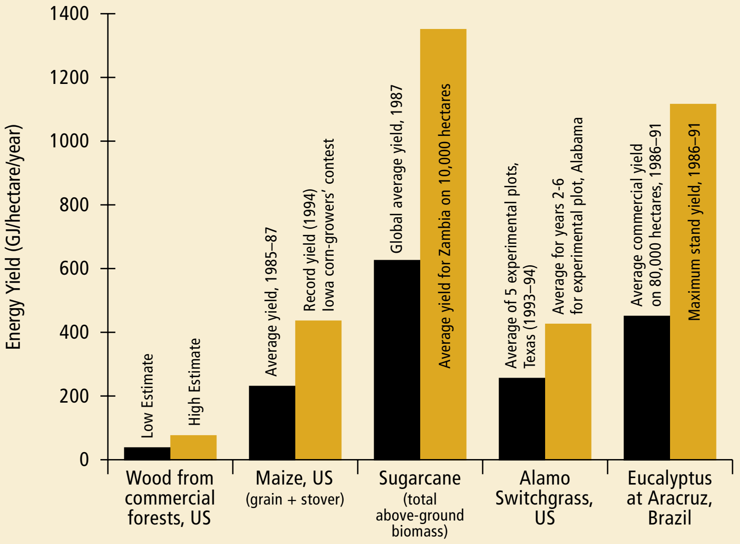
Production parameter	Change 1975–2000
Sugarcane yields (ton cane per ha)	+ 33%
Sugar production from cane (ton sucrose per ton cane)	+ 8%
Ethanol production from sucrose	+ 14%
Fermentation productivity: m^3 ethanol per m^3 reactor per day)[6]	+ 130%

Source: Macedo (2003). For absolute value of some parameters, see Table A, Annex 1.

3.4 Geographical aspects

Brazil has a large area of agricultural land and an appropriate climate for sugarcane. Its sugarcane industry was already developed. São Paulo, the dominant state in this industry, has accounted for over half of the country's car fleet. In other areas of the country, the transport costs of ethanol were subsidized in order to ensure wide geographical coverage. This policy was used for all fuels in the country for decades, with the purpose of setting uniform prices for each fuel everywhere. Since ethanol production occurs in fewer states than oil derivatives, this policy was very helpful in promoting the alcohol market.

Figure 6. Biomass Energy Yields from Various Activities



Source: IPCC (1996)

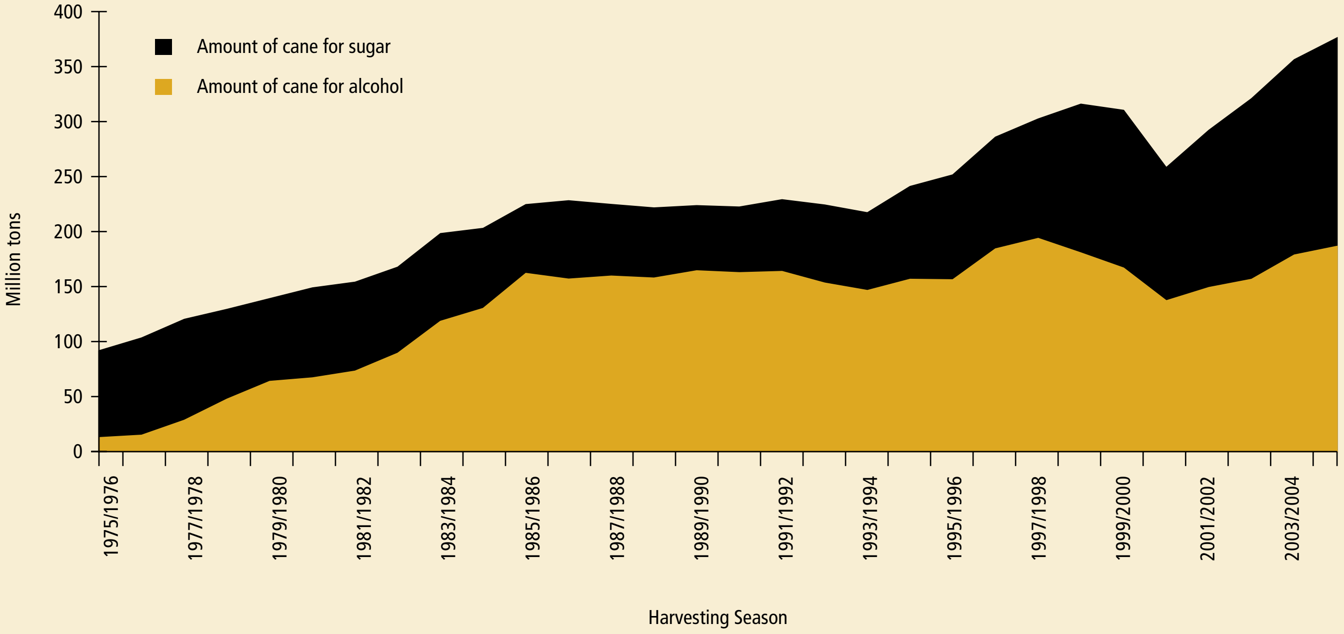
4. THE SUSTAINABLE DEVELOPMENT BENEFITS OF BIOFUELS

The reasons for supporting biofuels have changed somewhat over time. In the beginning, these reasons were purely economic and—after the first and second oil crises—were tied to the high cost of oil. More recently, the rationale behind this support broadened; its roots are in factors that might impact the country's economy in the short- and mid-term, such as (1) global future oil depletion and energy security, (2) global air pollution caused by GHGs, and (3) job creation opportunities and local pollution reduction. Even more recently, these aims have been tied to mid- and long-term issues, such as the growing importance of renewables, the use of fuel cells based on ethanol, and public policies that guarantee rural development.

4.1 Employment, economic development, and land rights

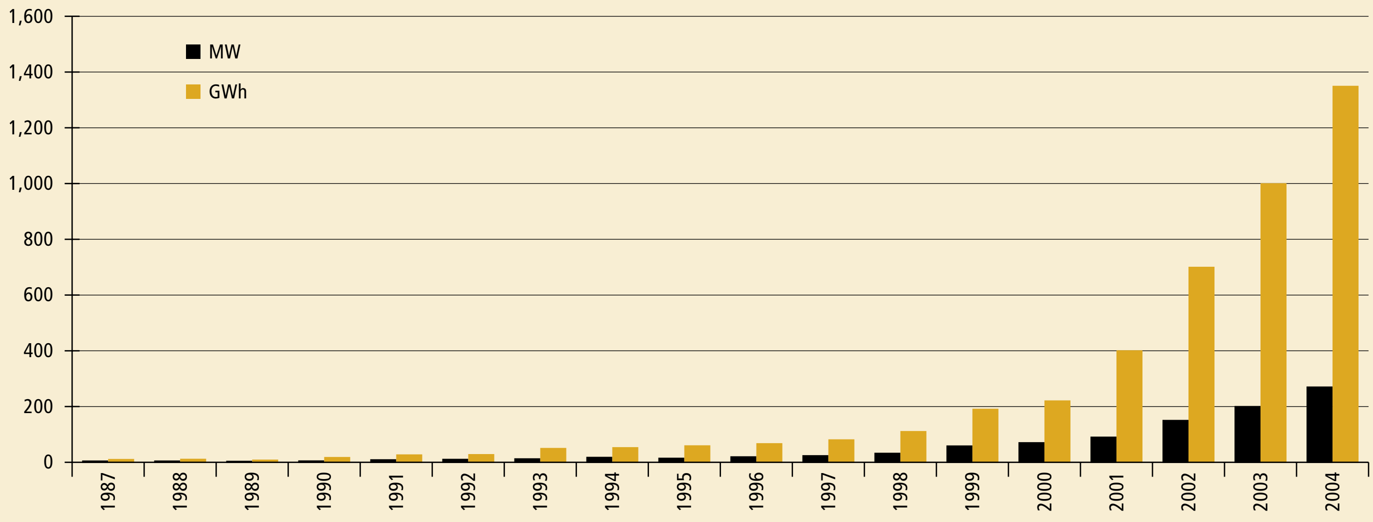
The issue of land rights is a particularly important one in Brazil, where landless people are a major group of rural poor. The federal government has a program aimed at allocating nonproductive farms to landless farmers. Any policy

Figure 7. Sugarcane Production for Sugar and Alcohol, 1975–2004



Source: Datagro (2004); Datagro (2002)

Figure 8. Electricity Sales from Cogeneration at Sugar Mills—Electricity Sold to the Grid—State of São Paulo



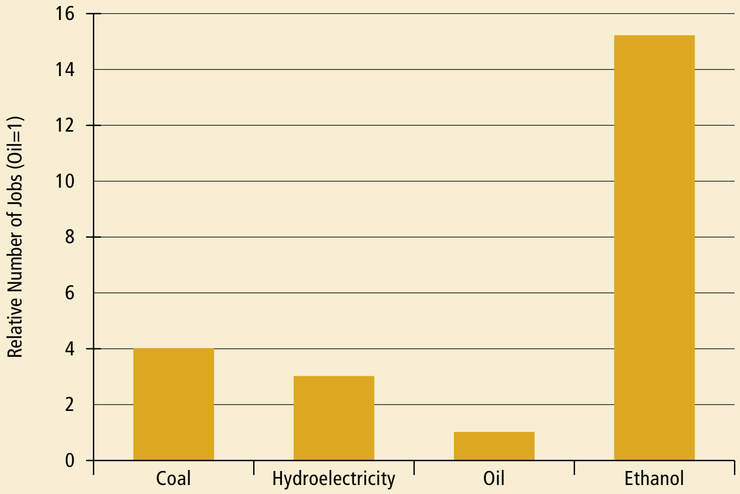
Source: Authors

that affects land use therefore must be considered from this perspective. It is not clear what the impacts might be in the case of expanded ethanol production, but there are reasons to think that they will not be substantially either positive or negative. Since sugarcane crops are an expanding agricultural activity, carried out in good to moderate quality soils, and in regions where commercial agricultural activities are well-established, there is likely to be little impact on agricultural reform.

Conversely, the number of landless property claims has been significantly reduced by the major creation of employment by the sugar/alcohol sector. This sector is a major employer: in 2001, an analysis using 1997 data (Guilhoto, 2001) concluded there were roughly one million jobs in ethanol production in Brazil, of which about 65 percent were permanent and the remainder seasonal (for harvesting). The indirect creation of employment in manufacturing and other sectors is estimated at roughly another 300,000 jobs (Macedo, 1995). Ethanol production creates job opportunities at a level 15 times bigger than the oil industry (see Figure 9).

This employment intensity will of course decline as mechanization increases.[7] Manual harvesting is a major generator of employment, but for ethanol derived from sugarcane, this labor cost alone represents $7.60 per barrel of oil equivalent. Sugarcane workers in the state of São Paulo receive relatively high wages—on average, 80 percent more than the labor force employed in other agricultural sectors. Their incomes are also higher than 50

Figure 9. Jobs Provided by Various Energy Sources



Source: Goldemberg (2002)

percent of the labor force in the services sector and 40 percent of those in industry. Social conditions are reported to be improving in the Northeast region. Special legislation has mandated that one percent of the net sugarcane price and two percent of the net ethanol price be channeled into medical, dental, pharmaceutical, sanitary, and educational activities for sugarcane workers (Melquiades, 1996).

This ability to create jobs in rural areas, most of them for unskilled workers, fits nicely with the labor supply level and has made sugarcane plantations attractive, particularly in developing countries. In many countries, sugarcane plantations and sugar production are managed by public enterprises and/or are extremely regulated by governmental bodies. However, Brazilian sugarcane producers are all privately owned. Around 30 percent of sugarcane production is in the hands of 60,000 independent producers, representing a major activity for small farmers.

Table 3. Harvested Area of Main Crops in Brazil

Crop	Harvested area (million hectares)		Share of cultivated land (%)	
	1988	**2004**	**1988**	**2004**
Corn	13.2	12.4	24.0	19.1
Soya	10.5	21.5	19.2	33.1
Bean	5.9	4.0	10.7	6.2
Rice	6.0	3.7	10.8	5.8
Sugarcane	4.1	5.6	7.5	8.6
Wheat	3.5	2.8	6.3	4.3
Coffee	3.0	2.4	5.4	3.7
Cotton	2.6	4.8	4.7	8.4
Cassava	1.8	1.8	3.2	2.7
Orange	0.8	0.82	1.5	1.3
Other crops	3.7	5.1	6.7	7.8
Total	**55.0**	**64.8**	**100.0**	**100.0**

Source: IBGE (1989); FAO (2005)

4.2 Land use and competition with food crops and deforestation

Sugar/alcohol production from sugarcane is a land-intensive activity. A medium-size Brazilian industrial plant (processing 300 tons per hour of crushed cane) needs 11,000 hectares (ha) to supply its demand for sugarcane. Some distilleries require areas over 55,000 ha. These land requirements have produced a concentration of land ownership and displacement of food cultivation (Oliveira, 1991).

The availability of agricultural land is a heavily discussed and debated issue in Brazil. Sugarcane production (for alcohol) competes with food supply and other export crops. Recent data, however, show a relatively low level of utilization of agricultural land in Brazil, even in the State of São Paulo, by far the most developed in the country. Furthermore, some 200 million hectares (Mha) are classified as "pastureland;" most of the cane expansion areas west of São Paulo are using this pastureland. They may include old "cerrados." Nevertheless, an excessive concentration of crops can be a source of pests and diseases, or when poorly planned, can create difficult access to food crops for small villages that may have most of their nearby areas used for non-food crops (Rosillo-Cale et al., 1996). The risk of pests and diseases is minimized in Brazil through the use of several varieties of sugarcane.

The cultivated area in Brazil in 1988 and 2004 is presented in Table 3. Sugarcane corresponded to about 5.6 million hectares, 8.6 percent of the total harvested area with essential crops (Borges, 1990). This is a small relative increment since 1988 when it represented 7.5 percent of total area. The total agricultural area increased by around 10 Mha in this period, which is modest for a country with a large potential agricultural area.

In addition, crop rotation between food crops and sugarcane is increasingly being applied. This has been an effective way to maintain the balance between energy and food, improving the profitability of the land. Other crops—such as tomatoes, soya, peanuts, beans, rice, and corn—have been harvested in rotation with sugarcane (Borges, 1990).

While the displacement of food cultivation is a debatable issue, further sugarcane plantations can lead to increased deforestation through indirect activity. Displacement of extensive cattle ranching from present pasture land by strong expansion of sugarcane areas or other crops may become a driver for deforestation. Although many of the current sugarcane areas were already being used at the beginning of Proalcool in 1975, the practice of cutting forests for sugarcane plantations continued in the following decades, although it has shown signs of having stopped more recently. Most of the land planted for sugarcane came from earlier coffee plantations, although the recent trend has been to replace cattle ranching activities with more advantageous crops.

Although it does not lead to complete deforestation, the recreational activities of the harvesters in the season can severely disrupt the local ecosystem. The small wildlife and nature reserves still existing in the proximity of the estates are under heavy stress (Zandbergen, 1993). In 2001, a Governmental Decree was issued requiring that a part of the land be put aside for non-cane use or for recuperation of native vegetation.[8]

4.3 Air quality

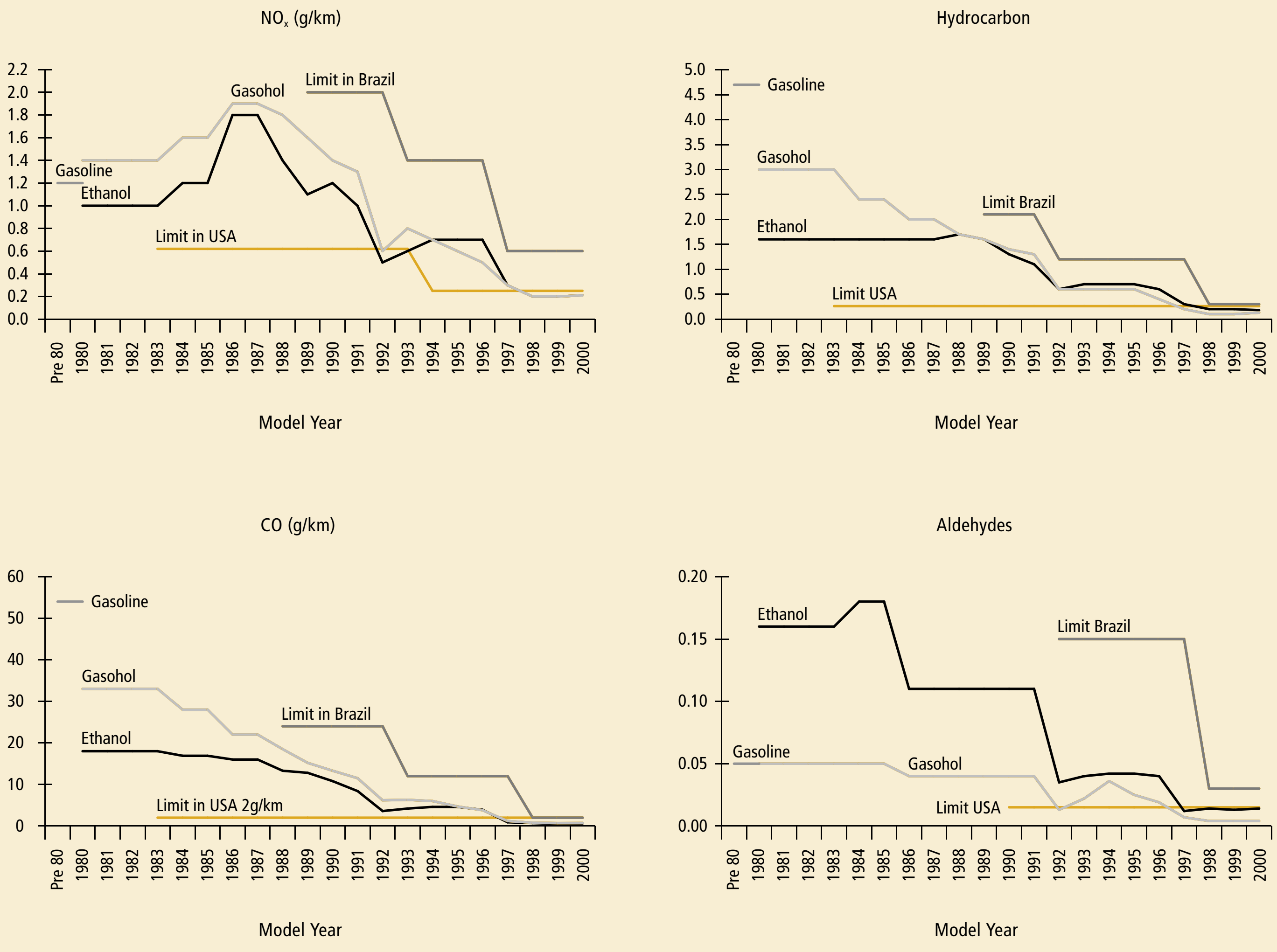
Cities

The introduction of gasohol has had an immediate impact on the air quality of large cities, particularly São Paulo. As the amount of alcohol in gasoline was increased, lead additives were reduced (and eventually eliminated in 1991). Aromatic hydrocarbons, such as benzene, which are particularly toxic, were also eliminated, and sulfur emissions were reduced (Figure 10).

In addition, carbon monoxide (CO) emissions were drastically reduced. Before 1980, when gasoline was the only fuel in use, CO emissions were higher than 50 grams per kilometer (g/km). This amount was reduced to less than 5.8 g/km by 1995.

Compared to gasoline or gasohol, one of the drawbacks of the use of ethanol is the increase in aldehyde emissions (formaldehyde + acetaldehyde). There is an increase in exhaust emission of aldehydes when ethanol is blended to gasoline, and this increase is greater still in the case of pure ethanol.[9] The significance of this issue to air quality must be evaluated carefully to avoid misinterpretation. Typically, 2003 model-year Brazilian vehicles fueled with the reference blend[10] for governmental certification (a blend with 22 percent ethanol by volume – E22) emit 0.004 g/km of aldehydes, a concentration that is about 45 percent of the strict California limit that is required only for formaldehyde (CETESB, 2003). Automotive use of diesel oil can be a more important source of aldehydes than gasoline-ethanol blends. Data from diesel vehicle aldehyde measurements

Figure 10. Automobile Emissions in Brazil, 1980–2000



Source: CETESB (2001)

show that emissions (formaldehyde + acetaldehyde) are 5.6 to 40 percent higher than those from vehicles running on E22 (Abrantes, 2003). The acetaldehyde from alcohol use is arguably less harmful to human health and the environment than formaldehyde produced when gasoline is used.

There have been a number of evaluations of ethanol's impact on air quality. Some key findings are that:

- A 10 percent blend of ethanol reduces carbon monoxide—a precursor to ground-level ozone formation—by more than 25 percent. The reduction in CO emissions increases as the percentage of ethanol in the fuel increases.
- Ethanol when used as an additive displaces highly toxic and volatile components of gasoline (benzene, toluene, and xylene).
- Ethanol at a 10 percent or lower blend also increases the total volatile organic compound (VOC) emissions from the gasoline by about 15 percent. However, since the VOCs emitted by pure gasoline are more reactive than those produced with ethanol blends and because of the significant carbon monoxide reductions resulting from the use of ethanol, any increase in ozone formation is negligible.
- At higher concentrations of ethanol, the volatility of the gasoline-ethanol blend drops. At concentrations above 25 to 40 percent, evaporative emissions drop below the level they were before any ethanol was added to the gasoline. This eliminates volatility as a problem.
- There is some concern that an increase in oxygen will increase nitrous oxides (NO_X), also a contributor to ozone formation. But NO_X is generated from high combustion temperatures and ethanol burns cooler than gasoline. That is one of the reasons it makes such a good racing fuel. The new low-emitting vehicles that are entering the marketplace in ever-higher numbers (including hybrids) appear not to lead to a NO_X increase from an increase in fuel oxygen.
- Improvements in gasoline quality (low sulfur and aromatics) together with improved engines and efficiency have themselves improved air quality, making the relative benefits of ethanol in this respect more marginal.

Rural areas

Despite widespread concern about health impacts, sugarcane is burned in almost all countries where it is produced, including the United States and Brazil. Preharvest burning (where dry leaves are burned) is intended to promote pest control and lower harvesting costs; it is carried out just a few hours before harvesting. Post-harvest burning (tops and remaining green leaves), which involves smaller amounts of material, eliminates residues and expedites plowing and replanting.

Little is known about the health effects of cane burning emissions on employees or surrounding communities, although it is generally considered that any amount of smoke will worsen an existing respiratory condition. Contradictory reports exist with respect to lung cancer (Echavarria and Whalen, 1991). According to Coopersucar (Macedo, 1995), there is no proof that the burning of the cane-fields has a damaging effect on human health, a statement mainly based on studies in Hawaii. The health effect is considered to be relatively minor, because the particles are rather big and inhalation is not likely to result in lung damage to the extent caused by very fine particles (Zandbergen, 1993). The nuisance of the particulates, however, is obvious.

There is already legislation in effect in São Paulo State (Law 11241 from 2002) that sets procedures and limits for burning of open sugarcane fields. The land area where burning is allowed is declining. It will be prohibited by 2021 in areas suitable for mechanical harvesting and by 2031 for all areas.

4.4 Oil import dependence and security of supply

The 1973 OPEC oil embargo caused oil prices to soar from $3 per barrel in 1973 to $12 per barrel in 1973–74. This was chiefly responsible for the global economic recession that followed. This price rise represented a significant increase in import expenses—from around $500 million in 1972 to $2.8 billion in 1974.[11] In 1979, the Iranian revolution led to a second surge in oil prices to $40 per barrel—pushing Brazilian expenditures for oil imports to over $10 billion and causing another global recession (Brasil Energia, 2003).

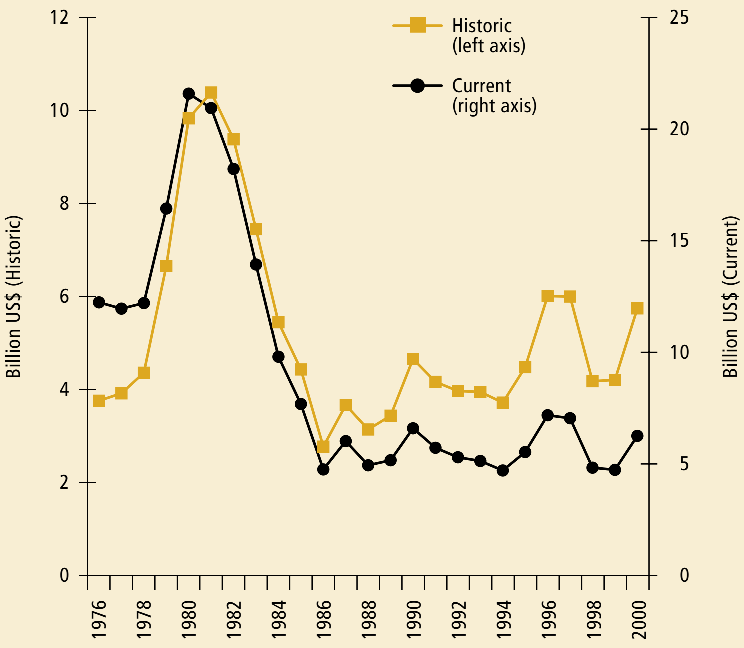
In order to pay these high import bills (Figure 11) and to develop domestic energy alternatives, Brazil, like many other countries in Latin America, absorbed excessive liquidity from the United States, European, and Japanese banks in the form of loans on favorable terms. Huge capital inflows were directed to infrastructure investments, and state enterprises were formed in areas that were not attractive for private investment. In the case of Brazil, this occurred mostly in the energy sector (refineries and large-scale hydropower plants).

In the early 1980s, however, the significant rise in U.S. interest rates began to affect international capital markets, ending the favorable conditions to foreign debtors. A substantial increase in interest rates worldwide forced Brazil, along with other Latin American countries, to implement strict economic adjustments that led to negative growth rates. The suspension of capital inflows reduced Brazil's capacity to invest. The debt burden affected public finances and contributed to an acceleration of inflation.

The critical fuel situation in the country started to be significantly mitigated by the beginning of the 1990s, when growth in national oil production started to overcome the growth in demand, thus reducing the volume of imported oil. In the late 1970s and 1980s, ethanol production played an important role in promoting fuel security with the advantage of not requiring hard currency. The amount of ethanol produced was significant; during a few years in the 1980s, it surpassed gasoline consumption.

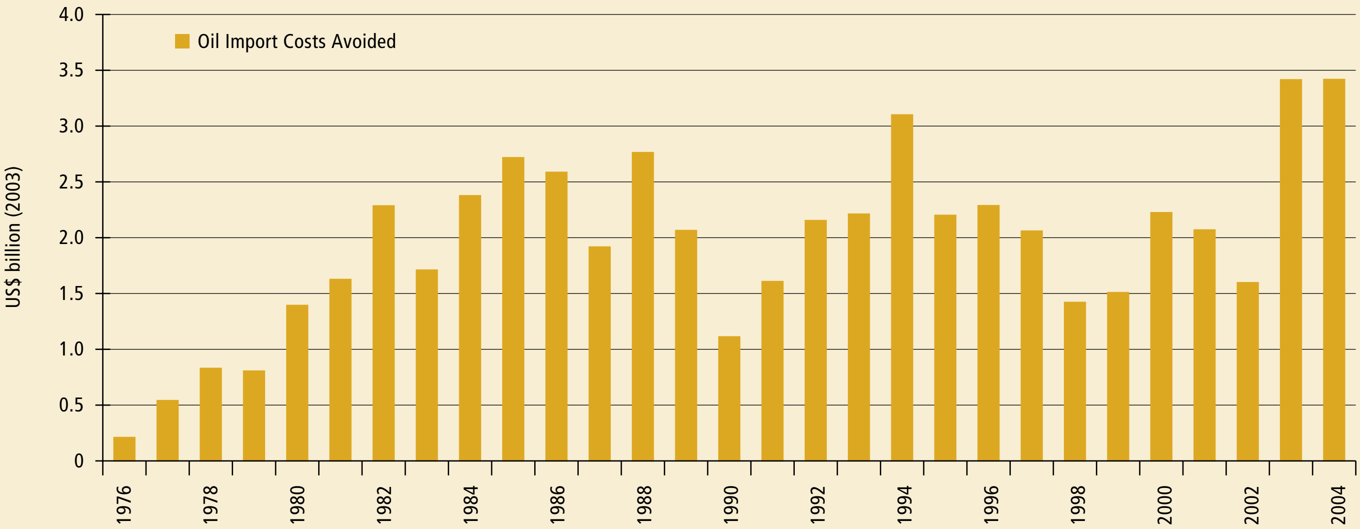
Alcohol production and its use as an alternative fuel have brought significant benefits to the Brazilian economy. Since 1975, ethanol has displaced over 240 billion liters (1.5 billion barrels) of gasoline. It not only avoided disbursement of more than $56 billion in direct oil importation (Figure 12), but a much larger amount ($94 billion) once we include the avoided cost of servicing the debt that would have been incurred to import this oil (Figure 13). Due to the country's poor economic performance, any disbursement in hard currency would have added to the already large external debt, implying higher interest rate payments. Typical interest rates paid were 5 to 10 percentage points above LIBOR.[12]

Figure 11. Net Fuel Expenses in Brazil



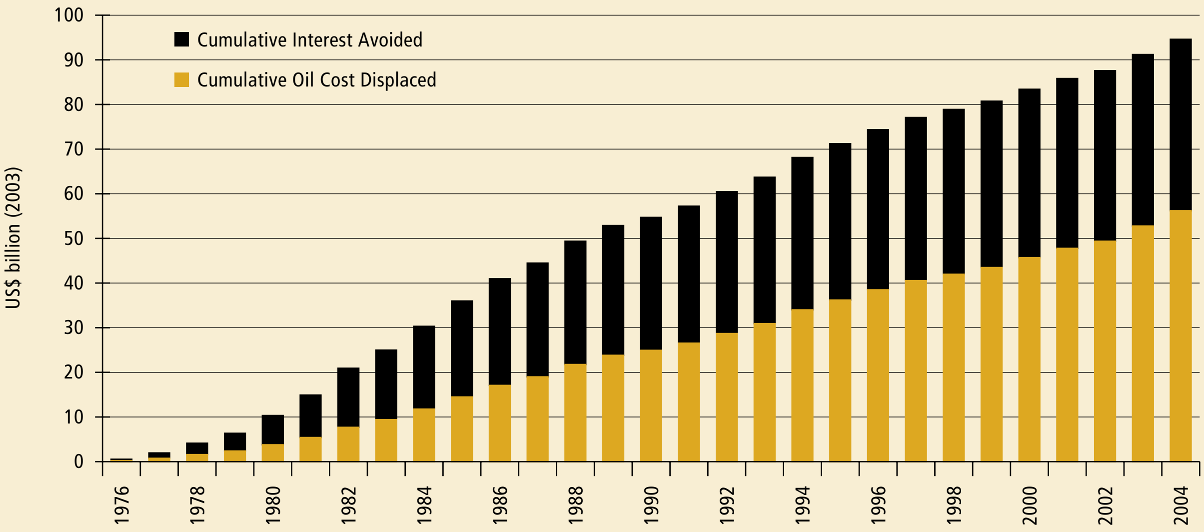
Source: Brasil Energia (2003)

Figure 12. Annual Savings from Displaced Oil Imports



Source: Authors, based on Petrobras data, Brasil Energia (2003)

Figure 13. Cumulative Savings from Avoided Oil Imports and Debt Service



Source: Moreira and Goldemberg (1999), updated by authors.

The traditional approach to energy security has been to diversify energy sources and suppliers, both internally and externally. Internally, the emphasis is on maximizing the use of domestic resources, preferably based on domestic technologies; externally, it is selecting a variety of products from a diversity of supplies from different geographical regions. However, there is no consensus about the level of energy import dependence considered acceptable or sustainable, and this varies from country to country. In the case of Brazil, ethanol use has brought a major diversification of fuel options in a sector that is generally dominated by oil.

5. THE POTENTIAL FOR EXPANSION OF BIOFUELS USE IN BRAZIL

This section explores the potential for scaling-up biofuel use in Brazil. The discussion is centered on ethanol, because the issues regarding its production and use are well documented. Biodiesel, for which there is at present little information, also has potential.

Ethanol production in Brazil in 2004–05 was about 14 billion liters, corresponding to 185 thousands barrels of oil per day.[13] This could increase significantly in the next decade, driven by both escalating internal demand and the growing international trade for such biofuels (Nastari, 2003). Figure 14 shows a projection for national ethanol demand, while Figure 15 displays potential demand for ethanol in the internal and external markets, as well as potential increases in sugar exports. Based on these forecasts, in 2013 total ethanol production is expected to be 26.4 billion liters, of which 17 percent are for export (Macedo and Nogueira, 2004). The market clearly expects such growth: 34 new distilleries are under construction, enough to raise the milling capacity 80 percent by 2009 (Gazeta Mercantil, 2004).

Sugar production is also forecast to grow by 44 percent during this time. Together, these products will require an annual production of 572 million tons of sugarcane, roughly 150 million more tons than currently. This would require approximately 3 million additional hectares of land.

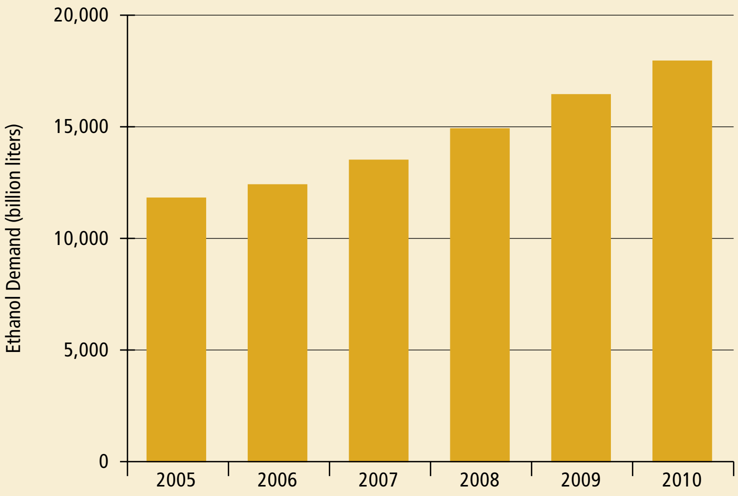
In recent times, Brazilian oil production has increased significantly, and it could reach self-sufficiency in the near future. Coming mainly from offshore oil fields, current oil production is about 1.7 million barrels per day, 90 percent of national oil demand. However, considering the level of proved reserves of fossil fuels—about 17 billion barrels—and the forecast demand, the duration of such oil reserves is only about 16 years. Moreover, according to a study on the evolution of oil production curves, using the Hubbert approach, peak oil production will probably occur in 2013—associated with ultimate reserves of 27 billion barrels (Andrade and Santos, 2002). The continuation of the Brazilian biofuels program is not dependent on Brazil's oil production levels.

Productivity growth in Brazilian sugarcane agriculture has been strong: during the period 1990 to 2003, sugarcane production increased 3.7 percent and sugar production 4.7 percent annually (see Annex 1). Important drivers of this evolution were the genetic improvement of sugarcane and the introduction of new varieties. Currently, about 550 different varieties are simultaneously cultivated, assuring good biodiversity and allowing a natural resistance against plagues and diseases. Many other technical improvements enhanced productivity, including better soil preparation, planting, harvesting, and transportation. Paying for cane according to sugar content rather than by weight provided a strong motivation for many of these improvements.

The area currently cultivated for ethanol production is about 5.5 million ha. An evaluation by the Brazilian Agricultural Research Agency (Embrapa) estimates that around 100 Mha that are currently natural pastures and low-density savannas could be used for annual-cycle plants.[14] Additionally, as a result of improvements in cattle ranching practices, it is estimated that about 20 million hectares of low productivity pastures could be liberated for biofuels production. If this hypothetical total of 120 million ha (14 percent of the country area and 25 percent of available land for agriculture) were used for the ethanol agroindustry, a total annual production of about 312 billion liters would be feasible. That is more than twice the total current Brazilian consumption of all oil products.

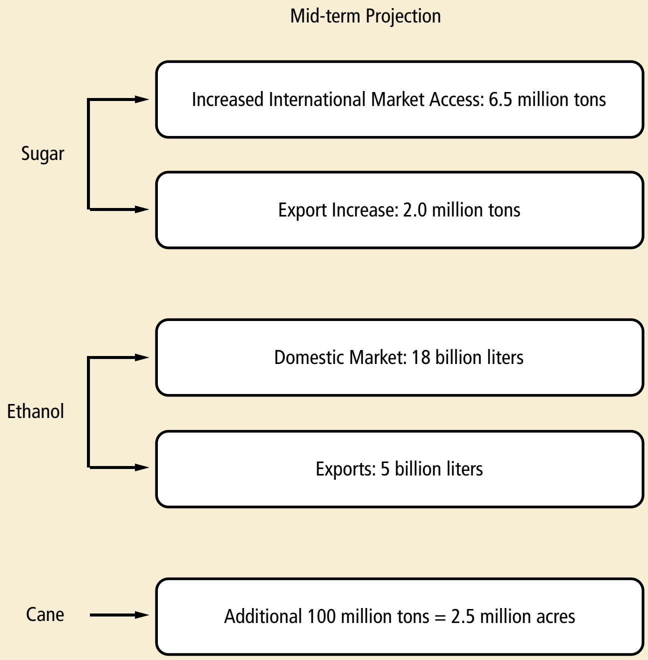
Since the beginning of 2005, there has been increasing attention in the media about expanding production of alcohol and sugar. The real number of new mills under construction is not available, but it is commonly assumed to be around 40 to 60 units with an average capacity to process 3 million tons of sugarcane per year. Of these, probably 30 will be sited in the state of São Paulo, where the environment authority has received almost 30 environmental applications. Other mills are planned in Mato Grosso, Minas Gerais, and Parana states. Some investors are traditional sugar/ethanol producers from the Northeast region. The total cost, including sugarcane area expansion and new industrial processing to sugar/ethanol, should be around $4 to $8 billion. Investors are expecting BNDES (the National Development Bank) financing and have already raised the necessary amount for equity. This behavior is very unusual for developing countries, and seems to confirm that sugar/ethanol production in Brazil is highly profitable.

Figure 14. Projected Ethanol Demand in Brazil



Source: Pereira de Carvalho (2004)

Figure 15. Futures Perspectives for Britain



Source: Pereira de Carvalho (2004)

6. BIOFUELS AND CLIMATE

The energy balance of the Brazilian biofuels programs is in principle neutral in terms of CO_2 emissions. In practice, however, planting, transporting, and transforming energy crops to biofuels uses external energy, sometimes derived from fossil fuels. A life cycle assessment is therefore needed to calculate the net effect on GHG emissions.

6.1 General Overview

The Brazilian sugar industry is almost energy-self-sufficient due to the use of bagasse, a process byproduct. The food and beverage sector in Brazil is highly dependent on sugarcane bagasse that is exported from the sugar mills and on other renewable energy sources (see Table 4).[15]

A detailed life cycle analysis shows how ethanol and bagasse from sugarcane have been contributing to the reduction of GHG emissions in Brazil by substituting for fossil fuels. The results are presented in Table 5.

Table 4. Energy Consumption of Brazilian Food/Beverage Industry, 2003

	1,000 toe/yr	%
Natural gas	432	2.6%
Coal	58	0.4%
Wood	1,720	10.4%
Bagasse	11,938	71.9%
Fuel oil	849	5.1%
Electricity	1,612	9.7%
Total	**16,609**	**100%**

Source: BEN (2004). Toe is tons of oil equivalent.

Table 5. Energy Balance of Ethanol Agroindustrial Process in São Paulo, Brazil

	Energy flows (megajoules per ton of sugarcane)			
	Average		Best case	
	consumption	production	consumption	production
Agricultural activities	202		192	
Industrial process	49		40	
Ethanol production		1,922		2,052
Bagasse surplus		169		316
Total	**251**	**2,090**	**232**	**2,368**
Energy output per unit of energy input	8.3		10.2	

Source: Macedo et al. (2004)

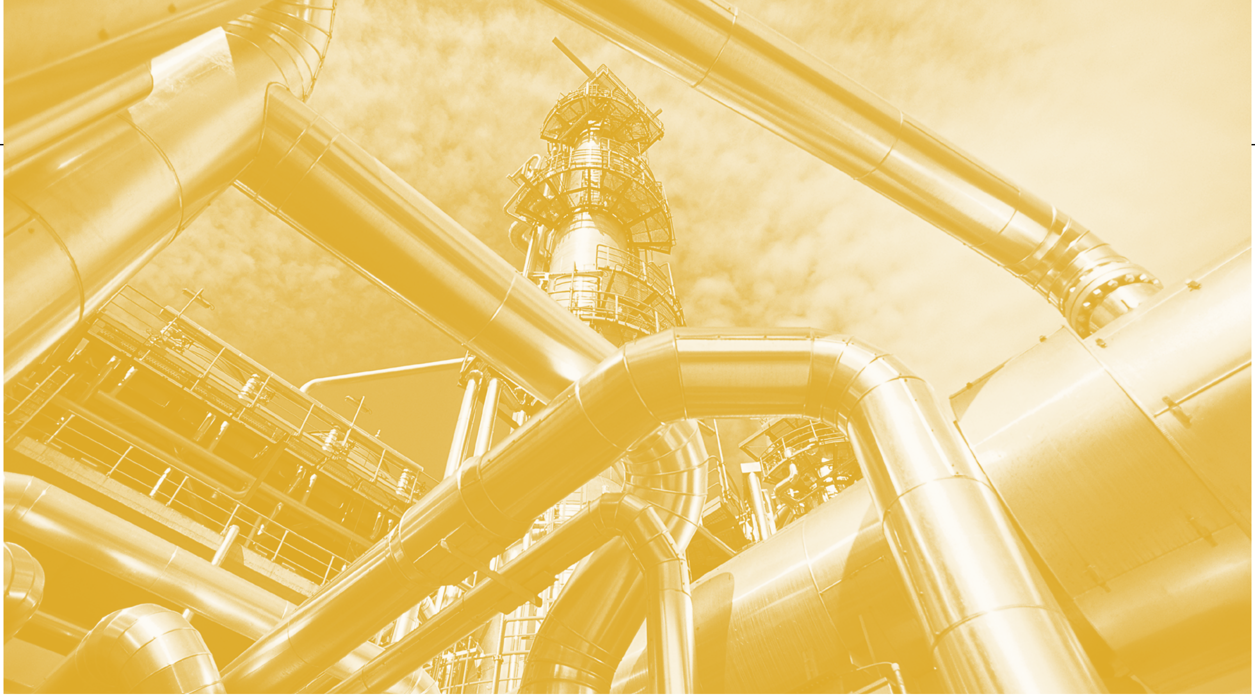
The use of biomass energy in the production process, as well as process efficiencies, mean that Brazilian biofuels are highly effective at displacing fossil fuel use, and therefore at avoiding GHG emissions. GHG sources may be divided into two groups: emissions derived from the use of non-renewable energy (diesel and fuel oil) and emissions from other sources (cane trash burning, fertilizer decomposition). For the first group, the calculated values were 19.2 and 17.7 kilograms of CO_2 equivalent per ton cane (kg CO_2/t) for average and best case scenarios, respectively. For the second group, the values were 12.2 kg CO_2/t for both scenarios. The emissions avoided due to the substitution of ethanol for gasoline and surplus bagasse for fuel oil, deducting the above values, gives a net result of 2.6 and 2.7 tons of CO_2 per cubic meter (tCO_2/m^3) anhydrous ethanol and 1.7 and 1.9 tCO_2/m^3 of hydrous ethanol for average and best case scenarios, respectively.

Brazilian fuel ethanol consumption in 2002 was around 12 billion liters, reducing GHG emissions by 25.8 million tons CO_2, assuming emissions are proportional to the amount of anhydrous and hydrous ethanol. This is approximately the same level of avoided CO_2 emissions as in 1995 (based on results from Macedo et al., 2004).

Sugarcane crops for ethanol production, which covered 2.5 million hectares in Brazil in 2002, abated 11.0 tCO_2 per hectare per year. Assuming the production of ethanol remains stable, in a time span of 100 years 1,100 tCO_2 per hectare will be avoided, showing that in the long term ethanol is more effective, strictly in terms of CO_2, than the preservation of native forests[16] or production of charcoal from plantations (Fearnside, 1995).

An additional climate benefit comes from the export of surplus biomass-generated electricity to the grid (see section 1.2). The 60 kilowatt hours (kWh) of electricity that can be generated from a ton of sugarcane could replace 0.65 gigajoules (GJ) of fuel oil (assuming 33 percent conversion efficiency to electricity). This amount of energy represents 52.3 GJ per hectare (for a yield of 80 tons of cane per hectare annually) abating 4.0 tCO_2 per hectare annually. Factoring in this abatement from biomass-generated electricity increases the total CO_2 savings by about 37 percent, from 11.0 (quoted above) to 15.0 tCO_2 per hectare annually. There is considerable scope for improving this performance; as discussed in section 1.2, use of barbojo and improved technology can raise electricity production from 60 kWh per ton to 500 kWh per ton.

According to the Brazilian National Communication, the biofuels program has displaced the emission of 403 million tons of CO_2 from 1975–2000 (MCT, 2004). Based on our figure of 11.0 tCO_2 per ha per year, and taking the production figures in Annex 1, our estimate is somewhat higher, at 574 million tons of CO_2 up to 2004.



6.2 Rewarding climate protection

Finding the carbon price that could lead to further expansion of biofuels is a challenging task. The Brazilian government has supported ethanol use in the country through reduced taxation. One of the most significant federal taxes, the CIDE[17] tax, only applies to fossil-fuel use. Total taxes are highly variable with time, but are known (see for example Figure 5) and can be calculated. Taking an annual production of 6.1 million cubic meters of hydrous ethanol (average annual production for the 1998–2004 period), the total revenue foregone from this exemption is $710 million per year. On average, a cubic meter of hydrous ethanol displaces 1.7 tons of CO_2 (when used in flexfuel engines) (Macedo et al., 2004), which yields an estimated loss of tax revenue of $65.30 per ton of CO_2 emissions avoided.

Thus, in most years, real alcohol prices (corrected for lower energy content and potentially uncollected taxes) were higher than gasoline. The average difference in price was around R$0.27/liter after 1998, when price liberalization was implemented. This figure ($0.074) means that a carbon credit equivalent of $36/t$CO_2$ added to hydrous ethanol would offset the price difference. However, with the increase in oil prices in the last two years, no further carbon credit would be necessary to offset the price difference. While this difference may vary with the price of gasoline, in general ethanol use results in some loss of revenue to the government. Use of a carbon price in some form may offset this burden.

7. BIOFUELS IN THE INTERNATIONAL CONTEXT

7.1 What lessons can other countries learn from Brazil's case?

Since the 1970s, many countries—notably Brazil and the United States—started to put ethanol programs in place. Argentina, Paraguay, and Zimbabwe also launched important programs. As oil prices dropped, government support waned and, by the end of the last century, only Brazil and the United States still maintained those programs. The programs in Argentina, Paraguay and Zimbabwe were too small to survive when oil prices declined in the early 1980s. However, China, India, Colombia, Thailand, and Australia have started their own programs, which may trigger large-scale use of ethanol worldwide.

The Brazilian experience demonstrates that it is possible to quadruple sugarcane production in less than a decade and that public acceptance for a new liquid fuel can be secured through appropriate government policies. Nevertheless, it is important to recognize the following constraints:

- Since sugarcane is a tropical crop, it requires appropriate levels of warmth and rainfall.
- Biomass energy, mainly when derived from crops, requires large amounts of labor. This has the advantage of job creation, but is a disadvantage if labor costs are high.

- Despite the advantages of sugarcane in both primary energy productivity and high conversion efficiency, land requirements are high. A country wishing to make a significant impact on its fuel consumption will require large amounts of available land.

These constraints mean that, as with oil, relatively few countries can be major producers, although, again like oil, many countries may produce on a smaller scale. With these constraints in mind, a series of experiences tested successfully in Brazil could be transferred to some dozen countries. They are, according to Morris (2003):

- Support for renewable electricity, which has been a major component of the biofuels business model. This can be done through measures such as Renewable Portfolio Standards (RPS), which mandate specific numerical goals for renewable energy.
- Mandated levels of ethanol blending in gasoline. This might be termed a Renewable Fuel Standard (RFS) to complement RPS standards. These could begin with a 10 percent level, and should encompass all renewable fuels—including renewable electricity for electric cars as well as biofuels.
- Moving beyond a 10 percent blend will necessitate the wide availability of vehicles with flexible fuel capability.[18] This capability could be mandated. It would need to be tied to the rapid construction of a nationwide infrastructure of appropriate fueling facilities.
- The success of biofuels in Brazil was tied to the rural economy. Encouraging smaller, locally owned biorefineries and creating new, more flexible markets for agricultural crops offers great potential for countries that might be poor in fossil fuels but rich in sunlight and plant matter, as well as in rural labor.

In addition, some recommendations should be considered by most of the developed countries that face significant limitations in the use of sugarcane.

- To enable biofuels to move beyond a 10 percent blend, policy makers should accelerate the commercialization of cellulose-to-ethanol plants. This involves financing of commercial-sized facilities testing different technological approaches. It also involves research and development into low cost and environmentally benign ways to collect and store cellulose. Production of ethanol from cellulose is welcome not only for economic reasons, but as a way to guarantee low carbon emissions from renewable energy. As discussed earlier, ethanol from sugarcane displaces a considerable amount of CO_2 emissions, since its energy balance is between 8 and 10. This means that for each unit of fossil fuel invested in all phases of ethanol production, it is possible to get 7 or 9 units of fully renewable fuels created by photosynthesis. Unfortunately, the same record for maize and wheat is much lower.

Ethanol from maize produced in the United States has an energy balance of around 1.3 (Shapouri et al., 2002). This implies very modest CO_2 abatement capability of the alcohol program, which can be a barrier for its future expansion as global climate change gains social importance.

- On the other hand, although sweet sorghum has never been commercially used as a source of alcohol in Brazil,[19] it could be a good candidate for temperate countries. The primary product (juice) and main byproduct (bagasse) are similar to sugarcane, and the available technologies and policies already developed could be used for sweet sorghum.

7.2 Lessons learned that may be applied elsewhere

We can identify several relevant drivers that explain the significant amount of ethanol being used in Brazilian cars. Nevertheless, it is necessary to ask why, after 30 years of use, its share only represents one third of all liquid fuel used for passenger cars. The first explanation is the difficulty of competing with low oil prices. During the first ten years, production costs were not a major concern of alcohol producers because of subsidies and the decline in production costs. In the next decade (1985–95), support provided by subsidies and regulations started to be reduced, while economic efficiency in alcohol processing continued to occur but not at a pace sufficient to justify further private investment. The most important barrier appeared in 1989 when there was a mismatch between supply and demand. Considering Brazil was the only fuel ethanol producer,[20] the shortage of supply could not easily be compensated by imports. The neat ethanol car driver was exposed, for several months, to a real fuel shortage. This was minimized by reducing the amount of ethanol blended in gasoline, blending of imported methanol to gasoline, and importation of out-of-specification ethanol. This crisis immediately pushed down neat ethanol car sales, which resulted in declining demand for ethanol as the old cars retired.

After 1995, it was clear that only ethanol blended in gasoline would survive since it was set by legislation. Consequently, ethanol production would decline; by 2010, it should return to the 1997 peak level, when the growth in car sales would guarantee an increase in ethanol consumption. Internal economic crises occurred in the period 1999–2001, and the further devaluation of national currency in 2002 (due to political changes in the country's leadership) revived interest in neat alcohol cars. Only by 2003—with the launching of flexfuel cars—was there a recovery in ethanol consumption. Already in 2004, oil price increases pushed up sales of flexfuel cars further. It is thus clear that shortage of supply postponed the interest in alcohol use by more than a decade. By 2005, investors announced the construction of around 50 new sugar mills (with an average capacity of 3 million tons of sugarcane per year), which is under way having had little difficulty in securing investment.

The oil industry

The participation of the oil sector is a real necessity, since only through them is it possible to distribute a blended liquid fuel. However, this sector also has powerful interests that can be threatened by the widespread use of biofuels. Alcohol stock storage and management, and the collection of subsidies designed for alcohol, was also transferred to the oil sector. These activities should be the responsibility of private and/or another government organization. Poor stock management was the major reason for the alcohol shortage in 1989 and delayed the success of Proalcool for almost a decade.

Technology development

Due to the immediate demand for neat alcohol cars set by government institutional measures, there was little time for performance testing of the new fuel. Neat alcohol automobiles built in 1979 and 1980 suffered excessive damage to some parts that were in direct contact with the fuel. These mistakes have since been completely addressed. This does not preclude difficulties for newcomers; it is possible that the main problems for some countries will arise from an inadequate agronomic basis (sugarcane varieties, agricultural processes and logistics, management) rather than from lack of industrial technology, which can be more easily transferred.

Power production

Until 1997, the electric sector was in the hands of public companies without any opportunity for small producers to sell electricity to the grid. As soon as new legislation allowed electricity producers to deliver energy to the grid and forced utilities to acquire and transport it, the sugar-mill sector started to retrofit their energy-producing plants to generate surplus electricity. Considering the significant potential of surplus electricity and the environmentally safe opportunity of co-production of ethanol and electricity, we strongly recommend that such experience be implemented in any other country seeking to produce liquid fuel from sugarcane.

7.3 Valuing international coordination on biofuels promotion

Coordinated efforts between countries to promote biofuels are already in effect in the European Union (EU) through the acceptance of renewable fuel targets and timetables. The effort could be more effective and its target improved if taken one step forward through the involvement of biomass-rich countries in an international agreement. As already stated, large production of biofuels will only be possible in some 10 or 20 developing countries. These countries probably will produce biofuels at lower cost than the EU and could help provide enough biofuels for more ambitious targets. With long-term agreements in place, such biomass-rich countries would be motivated to develop their biomass potential. On the other side, the EU would be able to combine internally produced high-cost biofuels with low-cost imported biofuels, reducing the average price and minimizing the economic burden for its citizens. With more ambitious biofuels consumption targets, there is room for increased Brazilian production, keeping opportunities for local farmers and for imports. With consumption level of biofuels around 20 to 30 percent of all liquid fuels, it is clear that a real alternatives for oil exists, finally setting an economic ceiling to the international oil price.

Although this would entail dependence on imports for some countries, the large number of potential biofuels suppliers means greater diversity of supply and therefore supply security. Such trade would also promote sustainable development by improving economic conditions in the biomass-rich countries. Essentially, there would be transfer of a share of revenues from oil-rich to biomass-rich countries, though it would be a long time before losses to oil exporters became significant. From previous experiences in the ethanol area, it is possible to establish initial guidance to set such international cooperation. Examples are the Ethanol Governors Coalition in the United States and the Ethanol Coalition in India. Such national efforts have, at least, the following purposes (Winrock, 2000):

- To serve as a source of reliable information for members, media, and other interested parties on renewable fuel usage and development.
- To provide information to policy makers, government officials, the media, and other key individuals and organizations, which will promote policy initiatives beneficial to ethanol fuel development and usage.
- To represent and promote fuel ethanol interests at meetings of government task forces, commissions, committees, and other related events/initiatives pertinent to this industry.
- To organize seminars and meetings across the country to present and discuss fuel ethanol usage and development, and to encourage market expansion.
- To generate and maintain consumer interest in renewable fuels.
- To help keep members abreast of new technological developments on renewable fuels abroad.

8. CONCLUSION

Biofuels are responsible for a large and growing share of Brazil's energy mix. After decades of development the ethanol program can be considered a mature and proven renewable option to supply automotive fuels. This clear success can be observed in the large and indisputable interest in flexible fuel cars in Brazil, which are using almost exclusively ethanol. Brazilian ethanol has several relevant characteristics, including current prices at the producer gate of about $ 0.25 per liter, removal of all subsidies, the very positive energy balance (8 to 10 energy units for each unit of energy put in the agroindustrial system), and beneficial impacts for air quality, jobs generation, electricity production, and national economic growth. These factors explain the strong support of Brazilian society for sugarcane biofuel. In any foreseeable future, ethanol will be an important fuel in Brazil. The next stage will be to see how many countries can reap similar benefits in the future.

Annex 1.

Table A. Sugarcane, Sugar, and Alcohol Production in Brazil

		Alcohol				
Season	Sugarcane (1000 tons)	Anhydrous (1000 m^3)	Hydrous (1000 m^3)	Total (1000 m^3)	Sugar (1000 tons)	TRS (1000 tons)
1970/1971	79,753	525	385	910	5070	6458
1971/1972	79,595	390	23	413	5081	6437
1972/1973	95,074	389	292	681	5926	7441
1973/1974	91,994	306	260	566	6680	8021
1974/1975	95,624	217	409	626	6673	8113
1975/1976	91,525	233	323	556	6017	7304
1976/1977	103,173	300	364	664	6851	8375
1977/1978	120,082	1177	293	1470	8306	11388
1978/1979	129,145	2096	395	2491	7476	12392
1979/1980	138,899	2712	671	3383	6980	13498
1980/1981	148,651	2104	1602	3706	7844	14935
1981/1982	153,858	1413	2750	4163	7912	15772
1982/1983	166,753	3550	2274	5824	8843	19837
1983/1984	197,993	2469	5392	7861	9086	23637
1984/1985	202,765	2102	7150	9252	8849	25832
1985/1986	224,364	3208	8612	11820	7819	29386
1986/1987	227,873	2168	8338	10506	8157	27338
1987/1988	224,496	1983	9474	11457	7983	28833
1988/1989	221,339	1726	9978	11704	8070	29345
1989/1990	223,410	1341	10557	11898	7301	28857
1990/1991	222,163	1309	10474	11783	7365	28718
1991/1992	228,791	1984	10768	12752	8665	31845
1992/1993	223,881	2216	9470	11686	9249	30581
1993/1994	216,963	2523	8774	11297	9326	29990
1994/1995	240,869	2867	9825	12692	11696	34973
1995/1996	251,346	3040	9631	12671	13235	36558
1996/1997	285,664	4600	9634	14234	13467	39681
1997/1998	302,169	5688	9720	15409	14845	43282
1998/1999	315,641	5692	8236	13928	17961	43916
1999/2000	310,049	6134	6934	13068	19380	43907
2000/2001	257,969	5616	4998	10615	16221	36216
2001/2002	291,924	6440	5062	11502	19096	40850
2002/2003	320,683	7010	5628	12638	22533	46182
2003/2004	356,079	8790	5839	14629	24860	52226
Yearly Growth Rate (%)						
1975/1985	9.4	30	38.9	35.8	2.7	14.9
1985/2003	2.6	5.8	-2.1	1.2	6.6	3.2
1985/1993	-0.4	-3.0	0.2	-0.6	2.2	0.3
1993/2003	5.1	13.3	-4.0	2.6	10.3	5.7
1990/2003	3.7	15.8	-4.4	1.7	9.8	4.7

Source: Datagro (2004) nº 06; Datagro (2002) n.º 05. TRS is Total Reducible Sugars.

ENDNOTES

[1] CENBIO - Centro Nacional de Referência em Biomassa, R. Álvaro Rodrigues, 283, Sao Paulo, SP, Brazil, 04582-000, bun2@tsp.com.br.

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[3] Energy Program, Instituto de Eletrotécnica e Energia, University of Sao Paulo (IEE/USP), Av. Prof. Luciano Gualberto, 1289, Sao Paulo, SP, Brazil, 05508-900, vparente@iee.usp.br.

[4] Total external debt at the end of 2004 was $221 billion, including loans from the World Bank. This is a significant burden compared with Brazil's GNP of $604 billion. Not only is the amount of debt large, but the schedule of payments is short; total debt service in 2004 was $53 billion (World Bank, 2005).

[5] Instituto Nacional de Tecnologia, Primeiro Congresso Nacional de Aplicações Industriais do Álcool, Rio de Janeiro, 1903.

[6] Cubic meters of ethanol produced per cubic meter of fermentation tank capacity per day.

[7] An increase in mechanization would be useful, for example by promoting the need to stop sugarcane burning (particularly in many areas of São Paulo near towns and roads). Increasing employment opportunities outside the sugarcane industry and the low prestige of some jobs (such as cane cutters) has resulted in shortages (or high costs) of labor in some areas.

[8] Governmental Decree 2166-67 of August 24, 2001, Brasilia Brazil. Available in Portuguese at: http://www.planalto.gov.br/ccivil_03/MPV/2166-67.htm.

[9] Total aldehyde emissions from alcohol engines are typically higher than from gasoline ones, but they are predominantly acetaldehydes, not formaldehydes. Acetaldehyde emissions produce less harmful health effects than the formaldehydes emitted by gasoline and diesel engines. In 1993, CETESB obtained the concentration ratio of acetaldehyde/formaldehyde based on ambient air monitoring data. The results were in the range of 1.7–1.8 and in 1996/97, 1.6–2.1. Comparing these figures to the typical values encountered in Los Angeles, Atlanta, and Chicago (0.18–0.96), the higher concentrations of acetaldehydes were observed in São Paulo due to the intensive ethanol use as an automotive fuel. It must be emphasized that during this monitoring campaign period, only a very small portion of the Brazilian light-duty fleet was equipped with catalytic converters, which help significantly in the reduction of aldehyde emission.

[10] Currently, light-duty vehicles in Brazil use predominantly two major types of fuel: gasohol, which is a blend of 22 to 25 percent of dehydrated ethanol and 75 to 78 percent gasoline, or neat ethanol (hydrated form, which contains 4 percent water).

[11] All prices mentioned here are in current US$.

[12] The London Interbank Offered Rate, an international benchmark rate for interest charged on loans.

[13] The conversion factor was 1.3 liters ethanol/liter gasoline, taking into account the lower heating value and the higher efficiency allowed by ethanol in engines.

[14] Vânia Beatriz R. Castiglioni, EMBRAPA, 2004. Personal Communication.

[15] Around 90 percent of electricity generation in Brazil comes from hydro sources. This means that around 90 percent of the total Brazilian energy consumption in this sector is renewable.

[16] Protection of native forests does of course bring other benefits.

[17] Aiming to simplify the federal tax structure, since 2002 the Brazilian government has imposed a value-added tax on fossil fuels, which is used to finance roads and fuel logistics.

[18] The limit of 10 percent ethanol blend in gasoline is debatable. In Brazil, more than 15 million cars have used ethanol blends of around 25 percent for more than a decade. Brazilian-made cars are already manufactured for such fuel, and a few parts are designed to be more resilient to alcohol corrosion. But it is worthwhile to mention that a few percent of the cars are imported. Some imported car dealers claim that the car is adjusted to Brazilian fuel through minor retrofit. As a conclusion, we can say that there are few indications that a 20 percent alcohol blend imposes a real difficulty for car owners.

[19] Although several international studies found that sweet sorghum could replace sugarcane used for the production (see, for instance, report prepared by the Hindu Line at http://www.blonnet.com/2004/08/13/stories/2004081301211200.htm or article "Beyond Corn: Alternative Feedstock for Ethanol production" at http://www.ksgrains.com/ethanol/Altfeedstocks.pdf), experimental tests in Brazil before the implementation of the Próalcool program found that sugarcane was more suitable in alcohol production (Serra,1977). Another factor is that once the commercial sector selected sugarcane, interest in sweet sorghum disappeared.

[20] The United States had already started alcohol production, but the volume produced was too small to mitigate Brazil's internal shortage.

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Editor's Note

Almost every achievement in development, and every challenge surrounding it, is writ large in China. The country's spectacular economic growth during recent decades has pulled hundreds of millions out of poverty, but has also produced wrenching social changes and environmental challenges.

Few sectors demonstrate this achievement and this challenge more clearly than transport. Famed barely two decades ago for their streets overrun by bicycles, China's major cities are now increasingly dominated by private cars. Though car ownership is very low compared to rich countries—the total number is about 9 cars per 1,000 people, as compared to over 700 per 1,000 people in the United States—it is growing at impressive rates, as China's urban middle class embraces the automobile just as Americans did in the 1930s. This growth is symptomatic of China's economic success, but the authors argue that this success can only be sustained through creative policymaking, as this rapid growth in car ownership is being accompanied by local, national, and global problems.

Within China, the growth in mobility faces two major constraints. First, locally, the rapid growth in car use is leading to gridlock in cities that were not designed, and cannot be easily adapted, for such traffic. Second, nationally, China's rapidly growing oil demand is making the price and provenance of its imported oil an increasing concern. After being a net exporter a decade ago, China now imports about one-third of the oil it consumes, a figure that is poised to continue rising.

At the global level, the manner in which China's transport sector develops over the coming decades has worldwide implications for the climate system. The future CO_2 emissions growth will depend on vehicle efficiency, the choice of fuels, and the distance driven per vehicle. These factors are also important for addressing China's congestion and oil security constraints. This is fortunate, because these constraints, having more immediate influence on policymakers than climate change, will be the decisive considerations in China's evolving transport policy.

The authors consider the impact of policies and measures designed to anticipate and avoid congestion and oil security concerns. These policies lead to more efficient engine types (hybrids, compressed natural gas); smaller vehicles to adapt to constrained road and parking space; and lower vehicle mileage as people use public transport alternatives. The authors are at pains to point out that these measures do not amount to reduced mobility for urban Chinese; to the contrary, by avoiding or at least deferring the constraints mentioned above, mobility will be increased. The results are striking. Compared to a "business-as-usual" scenario, energy use (and, therefore, to a rough approximation CO_2 emissions) is 78 percent lower with a policy mix designed to save the cities from a congestion crunch and avoid excess oil dependence.

SD-PAMs seek to find climate benefits from meeting non-climate development goals and, as such, this is a fascinating case. China is already aware of the constraints it faces, and has taken action—witness its recently applied vehicle efficiency standards, more stringent than those in the United States. But the scope to do more is large indeed, and the benefits to China of reducing its growing dependence on expensive and volatile oil supplies and keeping its cities moving are obvious. Anything that can be done to accelerate measures to address these challenges is clearly important both for China and for the climate. Finally, the economic sectors that will play a vital role in making these responses work (including most notably the auto sector) are international in scope and develop their products for global markets. A coordinated effort between China and other major markets to favor the introduction of more efficient vehicle technologies would be far more effective than countries acting in isolation.

CHAPTER IV

China Motorization Trends:

Policy Options in a World of Transport Challenges

Wei-Shiuen Ng ▪ Lee Schipper

1. INTRODUCTION

As the fastest growing large economy in the world, China is experiencing a rapid increase in motor vehicle ownership and use, in the process gaining immense economic and personal mobility benefits. However, this explosion in car ownership is unsustainable, as evidenced by the impacts of rising congestion, increased air pollution, increased oil consumption, and high rates of traffic fatalities. A sustainable transportation system would meet the increasing demand for private motorization without compromising the economic and welfare gains from greater mobility. The rapid growth of private vehicles in China, which will no doubt increase in ownership and use, threatens this sustainability, even though private vehicles currently contribute as little as 10 percent of the total daily trips in most cities.

Scenarios are used in this chapter to illustrate, but not predict, how a series of assumptions can lead to different outcomes. The scenarios show how effective mobility management, with the aid of advanced and alternative fuel vehicle technologies, could reduce oil consumption and many of the impacts of rapid private motorization that threaten sustainability. In addition, advanced fuel and vehicle technologies and approaches could help reduce the conflict between the economic development and environmental sustainability goals of the country by providing relatively smaller, safer, and cleaner vehicles to meet the growing demand. The forecasts of high private motor vehicle ownership and the subsequent oil demand imply enormous strains on urban infrastructure, as well as energy imports. These strains would be much easier to avoid with sustainable transport policies enacted now, rather than being rectified one or two decades later.

This chapter explores existing and potential Chinese transport and energy policy options related to private individual motor vehicles that have been or may be implemented in response to energy security, air pollution, and other challenges associated with motorization. It develops three different personal mobility scenarios that project oil and energy demand outcomes in 2010 and 2020, revealing a wide range of future oil demand levels and potential oil imports. The results also translate into a wide range of future carbon emissions from personal transportation. These outcomes depend primarily on choices Chinese policymakers make now. Different policy options are linked to the scenarios, suggesting how different policies could affect vehicle use, as well as how advanced and alternative fuel vehicle technologies could reduce some of the negative impact of motorization and improve energy efficiency.

Section 2 describes motorization trends in China and the energy and environmental consequences that follow. Section 3 reviews current transport-related policies, targets, and standards in China. The scenarios and key results are explained in sections 4 and 5. Policy options that could create the optimal transport scenario are presented in section 6. Section 7 provides the final discussion and conclusion.

2. TRANSPORT TRENDS AND CHALLENGES IN CHINA[1]

2.1 The rise of the transport sector

Transportation in China today is dominated by public transit and traditional transport modes. Public transport carries approximately 50 percent of all urban trips in China, with cycling and walking carrying another 40 percent (Schipper and Ng, 2005). Most Chinese cities have good transport systems built on buses, metros, and local rail systems that are extended to a greater region. Virtually all intercity (long-distance) travel is by rail or air. The average Chinese person travels about 1,000 kilometers (km) per year, compared with averages of 15,000 km per year for Europeans and over 24,000 km per year for Americans. Although mobility in China (measured in annual personal travel) still has a long way to grow, increases in travel distance do not always imply social benefits, as the benefits of private motorization could be easily exceeded by its incurred high costs (The National Academies, 2003).

One reason for low mobility is the low number of motor vehicles. In 2004, there were only 27 million privately owned motor vehicles in China (Brown, 2004), with most of them concentrated in large Chinese cities. The total number of cars—private and state-owned—was approximately 12 million, or 9 cars per 1,000 people, far below the global average (He et al., 2004). By comparison, there are over 700 cars (including personal vans, light trucks, and SUVs) per 1,000 people in the United States, 400 in Japan, 350–500 in Europe, and 150–200 in middle-income countries like Mexico, Brazil, and Korea. Motorized mobility in China, however, is set to change significantly as private car ownership takes off.

The growth of the transport sector in China accelerated markedly after 1978, when the country underwent massive policy reforms leading to significant economic development, industrialization, and urbanization. These changes have resulted in rapid increases in motorization and urban mobility. If lessons from the rest of the world apply to China, existing transport modes will face increasingly stiff competition from individual cars. With an increasing number of middle-class families, car ownership is no longer restricted to a selective group of governmental officials and high-income families. National passenger car sales increased by 76 percent from 2002 to 2003 while, over the same period, passenger car production increased by 86 percent (CATARC, 2004).

Given its large population and the small absolute number of vehicles in China, present trends point to enormous increases in motor vehicle ownership and fuel use. China appears to be following a path defined by other diverse nations. Figure 1 portrays motorization in relation to income. On a per capita basis, China's motorization in 2003 (the point farthest to the right and highest for China) is comparable to the U.S. in 1907, though China's per capita GDP in 2003 was only half of U.S. levels in 1907. The last dozen points for China in Figure 1 (bottom left) are very close to the first dozen points for Korea (from the 1970s), which fall somewhere between those of West Germany and Japan, when Korea was at income levels that those countries achieved in the 1960s and 1970s.

Rapid growth in motorization is bringing both costs and benefits to Chinese societies (Schipper and Ng, 2005). Benefits include economic growth—due to better accessibility for commercial, public, and private transportation—and improved social welfare as a result of increased flexibility and mobility. Costs are incurred in areas such as energy consumption and security, environmental and health impacts, congestion, and traffic fatalities.

2.2 Energy consumption and security

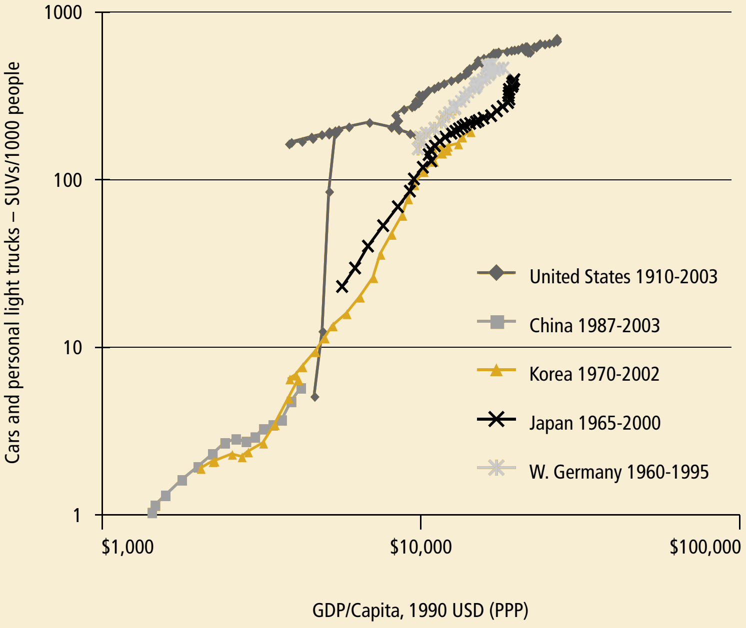
Energy consumption and oil imports, which are increasingly driven by the transport sector, have raised concerns over energy security. In 2003, China consumed approximately 275 million metric tons of oil, of which 30 percent was imported (BP, 2004) (Figure 2). The increase in energy consumption has resulted in China's transformation from an oil exporter prior to 1993 to a large net oil importer. Absent specific measures, the demand for crude oil is expected to increase by 12 percent annually until 2020 (He et al., 2004).

The Chinese transport sector, which is almost entirely dependent on oil, is increasingly a leading driver of overall consumption increases, contributing more than one-third of China's total oil consumption in 2002 compared to about 16 percent in 1980 (IEA, 2004b). From 1990 to 2002, gasoline and diesel consumption in the transport sector increased 157 percent (IEA, 2004b). Within the transport sector, it is notable that private car use constitutes a relatively small share of China's oil consumption—about 10 percent in 2001 (Figure 3). In the ensuing three years, however, the number of cars in China increased by 75 percent. As motorization trends continue, the share of oil consumption from cars will quickly become dominant.

2.3 Environmental pollution

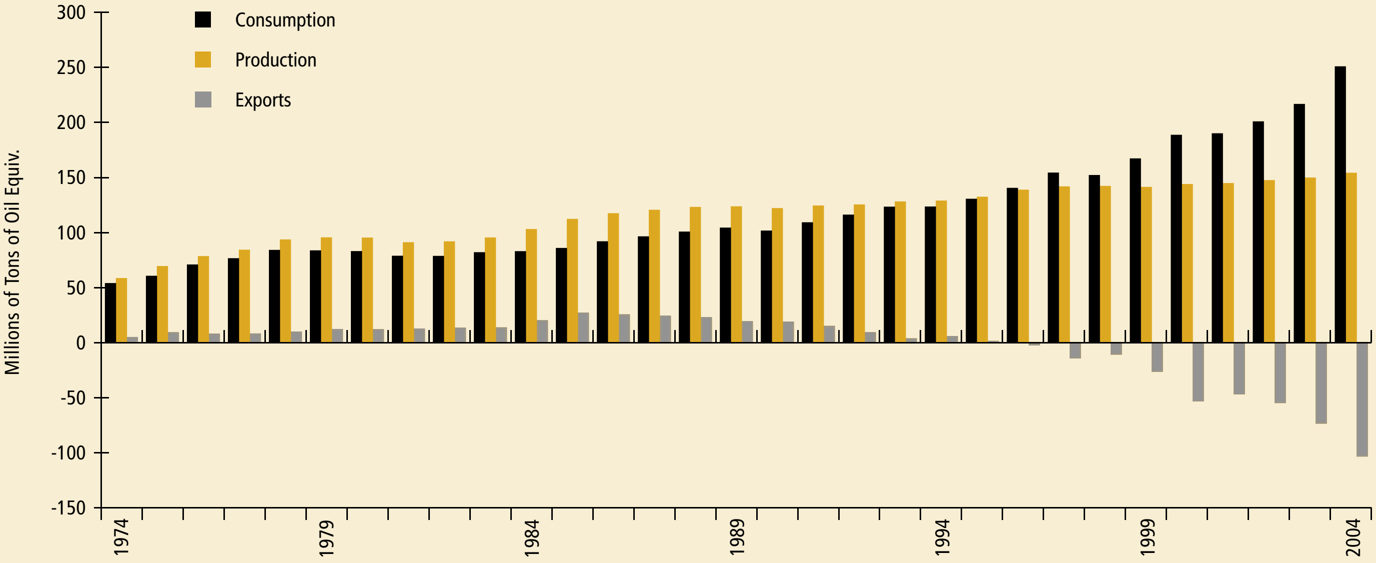
Pollutants produced during the combustion of gasoline or diesel fuel in vehicle engines have major environmental impacts. Such pollutants include carbon monoxide (CO), ozone (O_3), volatile organic compounds (VOCs), nitrogen oxides (NO_x), and fine particulate matter (Walsh, 2003a). Respiratory diseases such as infections, asthma, and decreased lung efficiency are common in polluted urban cities (Stares and Liu, 1996), in addition to reduction in

Figure 1. Comparison of Car/Light Truck Ownership in U.S., China, Korea, Japan, and West Germany



Notes: The horizontal axis shows per capita GDP converted to US$ at purchasing power parity (PPP). The range of years for each country covered by this GDP range is shown in the legend.
Source: U.S. Federal Highway Administration (various years), National Statistical Abstracts and Transportation year books (vehicles), International Energy Agency Energy Indicators Data base (vehicles for West Germany and Japan) and OECD (for PPP conversions, GDP, and population data).

Figure 2. Oil Production, Consumption, and Exports in China



Source: IEA (2004b) with estimates for 2003 and 2004 based on BP (2004 and 2005). Negative values indicate imports.

pulmonary function. These public health impacts will not only lead to losses in individual welfare, they could also inflict substantial economic costs upon the society.

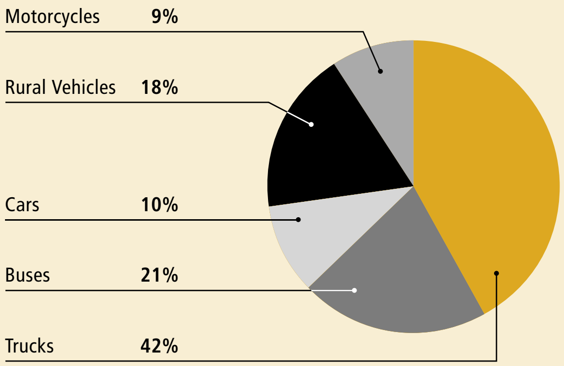
Air pollution from industry and households is gradually declining; as a result, vehicular emissions comprise a high and rising proportion of total urban air pollution in many Chinese cities (Table 1). Studies have shown that 45-60 percent of NO_x emissions and 85 percent of CO emissions are from mobile sources in most Chinese cities (Walsh, 2000). It is estimated that by 2010 in Shanghai, vehicular emissions will produce 75 percent of total NO_x emissions, 94 percent of total CO emissions, and 98 percent of total hydrocarbon (HC) emissions (Wang and Wu, 2004). Even with improved emissions controls and cleaner fuels, mobile-source pollution in Chinese cities is likely to continue rising due to increased use of individual vehicles and the total distance traveled.

Table 1. Motor Vehicle Shares of Criteria Pollutants in Chinese Cities

City	CO (%)	HC (%)	NO_x (%)
Beijing (2000)	77	78	40
Shanghai (1996)	86	96	56
Guangzhou (2000)	84	50	45

Source: Adapted from Mao et al. (2001)

Figure 3. Shares of Oil Consumption in Road Transportation in China, 2001



Source: Adapted from An (2003)

3. CHINA'S TRANSPORT-RELATED PRIORITIES AND POLICIES

The Government of China has enacted various policies and regulations relating to transportation and fuel use. These are targeted at improving ambient air quality in urban cities, reducing congestion, and improving transport energy efficiency. Many of these policies will reduce the impact of each kilometer driven or traveled in China. Policies are also targeted, however, at promoting the development of the automobile industry and greater domestic consumption of motor vehicles. The challenge for China is to resolve the tensions between these competing priorities and policies.

3.1 Developing the automobile industry

The Chinese automobile industry has been one of the most rapidly growing in the world; China now ranks as the world's third largest automobile producer. Over the 1999 to 2004 period, Chinese production of motor vehicles increased by 177 percent, from about 1.8 to 5.7 million vehicles per year (OICA, 2005). China's share of global production in terms of quantity has risen from 3.3 percent to almost 8 percent in five years. The automobile industry has been a "pillar" of economic development since 1988; this role has been reaffirmed by the government in preparing its 11th 5-year plan (2006-2011).

The development of the Chinese automobile industry has resulted in significant economic benefits. The sector has employed 1.8 million people and has total assets of $61.3 billion (The National Academies, 2003), as well as receiving significant levels of foreign direct investment (Gallagher, 2003). Total investment in new automobile manufacturing capacity in China is projected to reach $25.5 billion by 2007 (Xinhuanet, 2004a).

The rapid growth and development of the Chinese automobile industry has resulted in a new auto industry policy, which was launched by the National Development and Reform Commission in June 2004 (Xinhuanet, 2004b). This policy is aimed at slowing investment and consolidating the auto industry, which has been one of the most over-invested industrial sectors in China—mainly because of massive investment from foreign automakers and domestic state and private enterprises. New restrictions will include the regulation of new foreign investors entering the market. Nevertheless, foreign investors will still play an important role in the production of vehicles in the Chinese automobile industry.

Another goal of this policy is to further develop an automobile market largely dominated by private consumption, rather than state-owned vehicles. As the benefits of worldwide production practices and lower-priced advanced automotive technologies are now available in China, cars have increasingly become more appealing to Chinese consumers. However, the type of vehicle technologies likely to dominate the market is still uncertain. The 2004 auto industry policy also supports alternative fuel and advanced vehicle technologies, and it is expected that research and development in these areas will increase.

3.2 Saving transport energy

The need and urgency to restrain the growth in energy demand has become a national priority in recent years, mainly due to the experience of frequent energy shortages since 2000, brought on by China's booming economy. China, which now ranks as the world's second largest energy consumer after the U.S., has introduced energy conservation plans and increased public awareness of energy conservation. The recently agreed Chinese 11th 5-year plan national plan has restated and strengthened this commitment to improved energy efficiency.

Premier Wen Jiabao has announced that China will build an energy-saving society and implement state policies to promote efficient technological processes and encourage sustainable consumption through economic restructuring (Xinhuanet, 2004c). Accordingly, energy-efficiency policies for industry and the transport sector are expected to increase. Overall, energy demand will still rise with China's near double-digit economic growth, but economic growth could continue to outpace energy demand if energy conservation policies increasingly take hold. This has generally been the case since the 1980s, largely as a result of industrial modernization.

Policy changes are reflected in the 2004 National Energy Policy, which has shifted the focus from energy exploitation to energy conservation and improving energy efficiency, when compared with the previous energy policy implemented in 1998. The National Energy Policy launched a long-term energy-saving plan and is currently the biggest and most ambitious energy-saving plan in China's history (Mai, 2004). The burden to reduce energy consumption will no doubt be distributed across all industries and sectors, including the transport sector, which, as noted, is becoming a significant oil consumer.

The fuel economy standards announced in October 2004 are a key regulation to aid energy security. These standards require the auto industry to produce more fuel-efficient vehicles, which could include cleaner advanced vehicles or alternative-fuel vehicle technologies. The first phase of the standards will be implemented for newly introduced vehicles sold from July 1, 2005. For continued vehicle models, vehicles sold must meet the same standards by January 1, 2006. A stricter second phase for new car models entering the Chinese market will be in effect by January 1, 2008 (An and Sauer, 2004).

These standards establish maximum fuel intensities (fuel per km) for new vehicles, which are a function of weight and transmission type. For passenger vehicles weighing less than 750 kilograms, the maximum new vehicle fuel intensity is 7.2 liters of fuel per 100 km (equivalent to 33 miles per gallon [mpg]) for a vehicle with manual transmission and 7.6 liters/100 km (32 mpg) for vehicles with an automatic transmission. Permitted fuel intensity then rises with new vehicle weight in 15 additional weight classes.

Future uncertainties regarding consumer preferences and vehicle weights make it difficult to evaluate the overall likely impact of the fuel economy standards. A shift toward lighter cars could lead to lower average fuel intensity than those required by the standards alone.[2] The 2003 average new vehicle weight in China was about 1,500 kilograms (Sauer and An, 2004), which is considered heavy by international standards. The prominent share of large imported cars and SUVs in the sales mix over the past five years may contribute to this high average vehicle weight. As seen in many other countries, the weight and engine size of new vehicles tends to increase as income rises. Because China's fuel economy standards are weight-based, they would not inhibit such a trend. However, it is unclear if this will apply to China, as an increasing number of smaller vehicles are being purchased by the growing group of middle-class households.

3.3 Reducing air pollution

Through a series of legislative acts, regulations, and standards, the Chinese government has responded to the growing air pollution and public health risks described in section 2.3. These include national ambient air quality standards for different air pollutants, emission standards, and fuel quality standards. Generally, the established legislation states that the national government is responsible for measures to control air pollutants, while local governments have the responsibility for implementation and enforcement (Wang and Wu, 2004).

The 2000 Chinese Clean Air Act requires motor vehicles to meet emission standards and prohibits the manufacture, sales, or import of motor vehicles that have levels higher than the standards set by the State Environmental Protection Administration (SEPA). The 2002 Clean Air Act also encourages the development and sale of clean fuels for motor vehicles. The enforcement of the Clean Air Act and other requirements, however, is still weak, especially when certain regulations are not comprehensive enough.

Because air pollutants from mobile sources are highly dependent upon fuels, improving fuel quality is an important approach to reducing mobile source emissions. The "Emission Standard for Exhaust Pollutants from Light-Duty Vehicles" was implemented in 1999 by SEPA and went into effect in January 2000. This law set emissions standards equivalent to Euro I standards (He and Cheng, 1999).[3] Increasingly, China is following emission standards regulations from the United States, Europe, and Japan, even though the level of control (i.e., grams per km permitted) and enforcement is still less stringent in China. The government nevertheless recognizes the need to improve its air quality and has implemented Euro II equivalent fuel quality standards in Beijing and Shanghai in 2003. SEPA in Beijing has also charted emission standards that are equivalent to Euro III and expects the entire country to adopt the Euro III level by 2008 (Li, 2004). Table 2 shows the European Union emission standards for passenger cars and their year of implementation. Other transport policies, such as those that restrain automobile use, will of course also have air pollution benefits.

Table 2. EU Emission Standards for Passenger Cars (grams per km)

	Date	CO	HC	$HC+NO_x$	NO_x	PM
Diesel						
Euro I	1992	2.72	–	0.97	–	0.14
Euro II	1996	1	–	0.7	–	0.08
Euro III	2000	0.64	–	0.56	0.5	0.05
Euro IV	2005	0.5	–	0.3	0.25	0.025
Euro V	mid-2008	0.5	–	0.25	0.2	0.005
Petrol (Gasoline)						
Euro I	1992	2.72	–	0.97	–	–
Euro II	1996	2.2	–	0.5	–	–
Euro III	2000	2.3	0.2	–	0.15	–
Euro IV	2005	1	0.1	–	0.08	–
Euro V	mid-2008	1	0.075	–	0.06	0.005

Source: Adapted from the European Commission Directive 70/220/EEC (2002) and Diesel Net (2005).

3.4 Public transportation

According to the 2004 National Energy Policy, public transportation—buses and taxis—should be the main access method in big cities, with rail transportation supporting the transport network, while personal cars and bicycles should be used as supplements. In medium and small cities, public transportation will be developed, as well as the use of personal cars.

Public transport systems are in high demand in megacities, as well as middle-sized cities, where some are already actively adopting urban transport policies that encourage public transport. For instance, municipal authorities in Shanghai are now putting a high priority on buses and are seeking to increase public transport travel volume (People's Government of Shanghai Municipality, 2002). Overall, the Government of China is publicly encouraging the construction of bus rapid transit (BRT) and other public transit modes. Beijing is projected to have an increase of 100 kilometers in BRT bus routes, leading to a total length of 360 kilometers for the entire network by 2008. Kunming, Shanghai, Xi'an, Chengdu, Chongqing, Tianjin, Hangzhou, and Shenyang are either already in the process of developing BRT systems, planning BRT designs, or awaiting approval for their BRT proposals.

3.5 United Nations Climate Convention commitments

As a party to the 1992 Framework Convention on Climate Change and 1997 Kyoto Protocol, China has also committed to taking steps to limit greenhouse gas (GHG) emissions. Developing countries do not have quantified emission limitations under these agreements, though all countries have committed in the Convention to implement policies and measures to mitigate climate change (UNFCCC, 1992, Art. 4.1b). The Kyoto Protocol affirms these obligations for developing countries and also adds some additional detail by specifying particular sectors—including transport—where measures might best be targeted (UNFCCC, 1997, Art. 10b).

In 1990, China set up a National Climate Change Coordination Committee—composed of 15 government departments and institutions—to look at policymaking and scientific research (Qin and Zhu, 2004). China has also completed and submitted its first national communications to the UNFCCC, which includes a GHG inventory, and is increasingly engaged in emission-reducing projects through Kyoto's Clean Development Mechanism. With respect to policies, a number of existing policies and measures in the transport sector, such as the fuel intensity standards for new vehicles, are likely to have beneficial effects on CO_2 emissions. Many of the policy approaches outlined in the sections that follow would likewise contribute significantly to China's national priorities on energy security and air pollution, but also to China's obligations under the UNFCCC.

4. FUTURE MOTORIZATION AND MOTOR VEHICLE USE TRENDS IN CHINA: THE SCENARIOS

The future of the Chinese transportation sector is difficult to model or predict. There is inadequate data on fuel use, car ownership, fuel economy, and driving habits, among other parameters. Even when data is available, it may be unreliable, in part because future car owners in China will be different from today's. Historically, the majority of car owners and users were taxi and professional drivers, high functionaries, and company employees. Modeling their future behavior tells us little about how the average Chinese family will behave. Furthermore, discontinuities are expected, in part due to newly imposed fuel economy and emissions standards, policies to encourage alternative fuels, and other policies and conditions that could strongly reshape and regulate car use.

To better understand the future of the transport sector and the influence of policies, this chapter develops three scenarios that use different assumptions about the level of transport activity,[4] vehicle size/characteristics, and vehicle technology. The scenarios are constructed in a bottom-up fashion, in part using parameters and extrapolations based on experiences in two countries, Japan and Korea (South). Each scenario is accompanied by policies (or lack of policies) that could plausibly lead to the outcomes we describe. These scenarios are accounting, not behavioral, models.

The main input assumptions for the scenarios are shown in Table 3. Fuel taxes, vehicle use fees, and other policies are not quantitative and are simply used as qualitative measures to trigger the other input assumptions in

Table 3. Transport and Technology Scenarios Assumptions

Scenarios	Road Ahead (Baseline)	Oil Saved	Integrated Transport
Assumptions in the scenarios			
GDP and Population	GDP projected to increase at 6% annually	GDP projected to increase at 6% annually	GDP projected to increase at 6% annually
Motorization Rate of Increase	By 2020, China reaches the car/GDP ratio that Korea had in the mid-1990s	With higher oil prices and taxes, the number of cars in 2020 is 10% lower than it is in "Road Ahead"	With space being a severe constraint in Chinese cities and the implementation of parking charges, fees, and taxes, the number of cars in 2020 is 50% less than in "Road Ahead"
Total Number of Cars (Millions)	**2010:** 22.8 **2020:** 145.7	**2010:** 20.5 **2020:** 131.2	**2010:** 18.2 **2020:** 72.9
Car Characteristics (Weight)	Average weight falls to 1,200 kg	Average weight falls to 1,200 kg and power is lower than in "Road Ahead"	Average weight falls to less than 1,000 kg as mini-cars become popular
Car Utilization - Distance Traveled (km/vehicle/year)	**2010:** 14,496 **2020:** 12,484	**2010:** 13,466 **2020:** 10,238	**2010:** 12,948 **2020:** 8,775
Fuel Choices	Almost all cars run on oil, with 1% of total motor vehicle fleet based on CNG in 2015 and 2% in 2020	20% of motor vehicles use conventional gasoline; 15% of vehicle share are HEVs in 2010 and 50% in 2020; 10% of vehicles are CNG in 2010, 20% in 2020, and 10% are electric in 2020	In 2020, 30% of total motor vehicles are gasoline vehicles, of which 15% are small vehicles; market penetration of HEVs is 25%, small electric cars 25%, and CNG cars 20%
Assumptions made but not quantified in the scenarios			
Fuel Taxes (Crude oil price in 2005 assumed to be approximately $50 [2005] per barrel)	U.S. level of taxation, i.e. approximately $0.20 (2005) per liter	Japanese/European level of taxation, i.e. approximately $0.70 (2005) per liter	Japanese/European level of taxation, i.e. approximately $0.70 (2005) per liter
Vehicle Use fees	None	None	Significant charges on vehicle use in cities such as road pricing and parking charges
Other Policies	None	Encouragement of alternatives to traditional gasoline cars (hybrids, CNG, mini-cars)	Urban transport policies actively promoting the use of public transportation systems

Acronyms: GDP (gross domestic product); HEV (hybrid electric vehicle); CNG (compressed natural gas).

Box 1. Introduction to Advanced and Alternative Fuel Vehicle Technologies

1. Hybrid Electric Vehicles (HEVs)
HEVs are a cross between conventional automobiles and electric vehicles, combining an electric drive (motor and electricity storage) and an internal combustion engine. HEVs consume less energy by regenerating energy while braking, using smaller engines, allowing the engines to be turned off during stops, braking or coasting, and in some configurations, the motor alone can be used to accelerate from a stop (Santini et al., 2001). Apart from energy and oil savings, HEVs will also improve air quality and reduce CO_2 emissions. HEVs are relatively less expensive to introduce to the market than other technologies such as fuel cells, as they do not require new infrastructures for fuel production and distribution (Wang, 2003). Plug-in hybrids are not considered in this chapter.

2. Compressed Natural Gas (CNG)
Vehicles powered by CNG, as an alternative fuel, could reduce air pollution and reliance on oil. Per vehicle-kilometer traveled, CNG vehicles could emit 25 percent less carbon dioxide, 90-97 percent less carbon monoxide, and 35-60 percent less nitrogen oxide than conventional gasoline vehicles, depending on the engine design (US EPA, 2002). Other than being a cleaner fuel, CNG also has potential advantages with respect to cost, performance, and durability (due to a clean combustion process of natural gas) (US EPA, 2002). On the other hand, its fuel economy could be lower or identical to conventional gasoline vehicles (US DOE, 1999), and such vehicles generally have higher vehicle capital and infrastructure costs.

Natural gas is currently used for public vehicles, including buses and taxis in about 11 cities, including Beijing, Shanghai, Chongqing, Xi'an, and Sichuan. There are currently 50,900 natural-gas-fueled vehicles in China (He, 2003). When compared with the United States, which had about twice as many natural gas vehicles in 2003, the market penetration of natural gas vehicles is relatively higher due to China's significantly lower number of total vehicles. Since CNG offers the most engine and vehicle diversities (Rubin, 2003), this market is likely to further expand as China searches for sustainable energy resources.

3. Small Conventional Gasoline Vehicles
For many decades, "mini cars" with displacement of less than 600cc were common in space-constrained Japan (Schipper and Kiang, 1995). More recently, a number of major companies, notably Mercedes Benz, have begun to develop somewhat larger "mini-cars." Created by the stylish "smart" of Mercedes Benz and Swatch Group Ltd., these cars are popular for their small size and are fitted for urban parking and driving. At 40-60 mpg, these are some of the most fuel efficient internal combustion cars in the market and, at eight feet in length, small enough to back into a parallel parking spot, with two fitting in a single parking space. With aluminum engines weighing only 60 kilograms and a curb weight of about 730 kilograms (SMART, 2004), its light weight contributes to excellent fuel economy.

4. Small Electric Vehicles
Electric cars tend to have lower overall primary energy requirements per kilometer than gasoline cars of the same size (Delucchi, 2005), depending on primary energy sources. However, their lower speeds and performance means they will not be driven as much or as fast as conventional gasoline cars, thus indirectly contributing to energy savings. Small electric vehicles are most suitable for urban low-speed driving environments and could form a key component in creating a sustainable transport system. Electric vehicles are emissions-free at the point of use and could potentially transfer emissions to less populated and polluted areas (Lave et al., 1995), reducing transport emissions in urban cities. If the electricity used to recharge such vehicles is produced using efficient technologies and renewable energy resources, pollution and energy-saving benefits would increase. Likewise, with future advancement on alternative battery technologies, energy and cost-efficiency would improve.

the scenarios. Box 1 includes summaries of the different vehicle technologies. A more complete description of the assumptions can be found in Appendix 1. The outputs of the scenarios—measured in energy and oil consumption, and resulting carbon emissions—are of course only as robust as the parameters and policies applied to the scenarios. These outcomes are not predictions, but by setting up three possible futures, we provide a picture of the potential impact of various technologies and other options that could significantly affect personal automobiles and their use.

4.1 Road Ahead

The "Road Ahead" (baseline) scenario assumes that the current growth rate of motorization continues. Conventional gasoline vehicles are the dominant vehicle technology, car use is not restricted, and no significant fuel taxes are implemented through 2020 as Chinese policymakers follow a pricing policy with minimal taxes. It is also assumed that no other vehicle or fuel policies other than fuel economy standards will be implemented and enforced. In this scenario, the market penetration of HEVs is 5 percent, CNG 2 percent, and small electric cars 0.5 percent by 2020. China's level of motorization is derived from Korea's, as suggested by Figure 1. China, in this scenario, reaches the same number of cars per unit GDP in 2020 as Korea when Korea had China's projected 2020 per capita GDP in 1993. The best estimate of China's on-road fuel economy today is 9.5 liters/100 km. In the Road Ahead scenario, this figure improves simply because of improved technology and the likely rise in demand for smaller cars (i.e., under 1,500 kilograms).

4.2 Oil Saved

"Oil Saved" is driven by a clear move to save oil, backed by phasing-in of fuel taxes until they reach the level of those in Japan in early 2005, at approximately $2.70/gallon (Oil Market Report, 2005). Apart from conventional gasoline vehicles, CNG fuels 20 percent of cars by 2020, obtaining 5 percent better fuel economy (US DOE, 2005), and small electric vehicles power 10 percent, using less primary energy than gasoline or even CNG vehicles. In this scenario, there are 10 percent fewer cars than in Road Ahead, consistent with the small effect of higher fuel prices on car ownership observed by Johansson and Schipper (1997). Spurred by higher fuel prices, fuel economy improves much faster than in Road Ahead. This encourages a market share of 15 percent HEV by 2010 and a more significant 50 percent by 2020. The hybrid vehicles use only 80 percent of the fuel per km of conventional gasoline cars, a figure that falls to 75 percent by 2020 as technology improves. Higher oil prices will push car use downward, implying that 25 percent of all vehicles sold in the 2006–10 period are hybrids.

The assumptions used are consistent with experience in Europe, where the price elasticity of car use is within the range from -0.2 to -0.3 (Johansson and Schipper, 1997). Since real fuel prices in Oil Saved are roughly 2 to 3 times higher than in the Road Ahead scenario, which used 2003 prices, annual distance traveled is reduced by roughly 40 percent over its initial value, arriving at 10,238 km per vehicle by 2020. The fact that car use does not further decrease is a reflection of an improvement in fuel economy.

4.3 Integrated transport

The “Integrated Transport” scenario is a result of thoughtful and successful resistance to congestion by the Chinese authorities. The outcome is bolstered by the popularity of very small gasoline and electric cars whose required road space is less than that of conventional cars, and parking space significantly less. Additionally, such small cars are not as fast as conventional cars; hence, the overall utilization per car in this scenario is the lowest in all three scenarios. In this scenario, small and highly efficient vehicles will play a considerable role in reducing fuel consumption. Hybrids—together with small gasoline, electric, and CNG vehicles—dominate the market, with conventional gasoline vehicles constituting only 30 percent of the total market by 2020. With the general reduction in congestion time, hybrids have less of an advantage under Integrated Transport than they do in the urban traffic conditions illustrated in the first two scenarios.

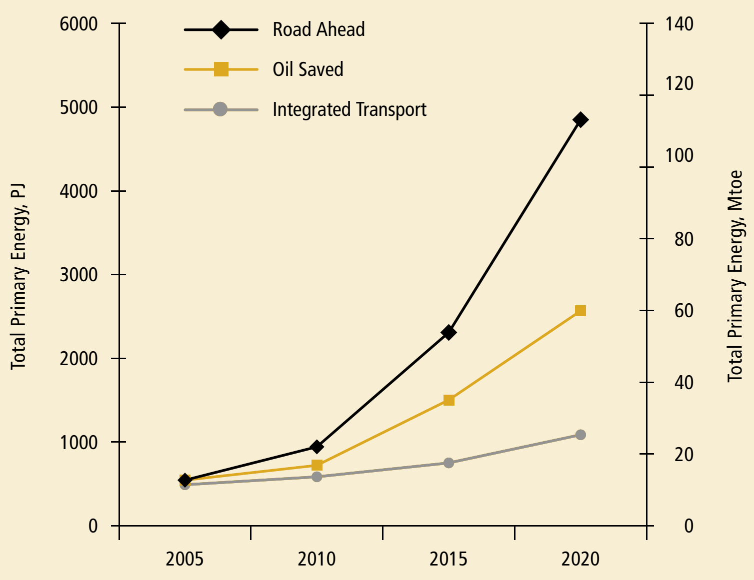
Congestion, parking and access difficulties, as well as the implementation of European-level fuel taxes and different transport policies, suppress the total number of cars to approximately 50 percent of what is estimated in Road Ahead in 2020. Similarly, annual distance traveled plummets to 9,000 km per vehicle by 2020 because of the high costs of driving and the extra advantages of public transport, such as bus rapid transit (BRT) and metro systems designed to give alternative high speed travel.[5] Higher oil prices support better fuel economy together with the popularity of very small cars, which are assumed to be 25 percent gasoline and 25 percent electric by 2020.

5. SCENARIO RESULTS

5.1 Energy consumption

The Road Ahead scenario demonstrates that if car ownership and use is unconstrained, oil consumption will continue to increase rapidly as the number of automobiles increases in China. The two other scenarios offer considerably contrasting results and present important alternative outcomes led by policy options that are worth considering (Figure 4).

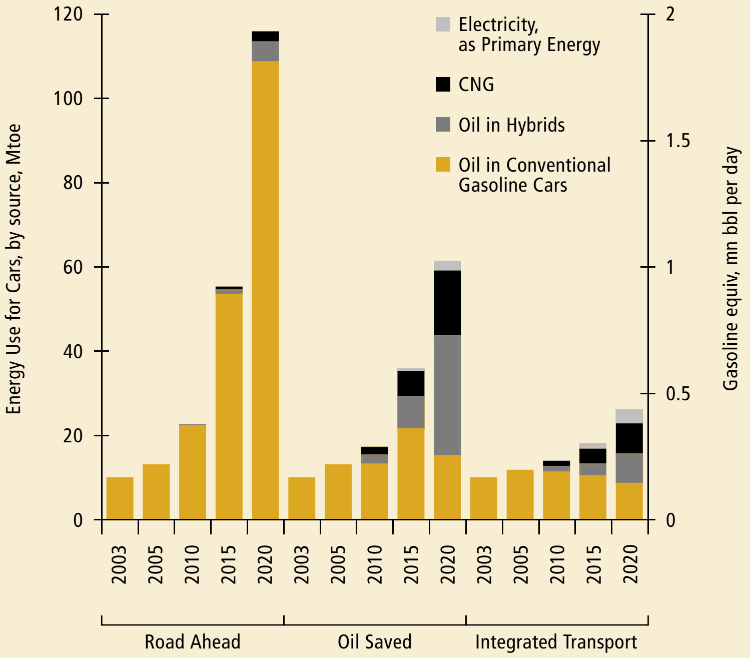
Figure 4. Energy Consumption Levels in the Three Scenarios



Energy use in each scenario is broken down by vehicle and fuel type in Figure 5. Compared to Road Ahead, energy use is 38 percent lower by 2010 and 78 percent lower by 2020 in the Integrated Transport scenario, assuming that strong transport policies and measures are implemented. Total 2020 oil use in Oil Saved is approximately 55 percent less than in Road Ahead, but it is still more than two times higher than oil use in Integrated Transport. Additionally, the total oil consumed in 2020 in the Integrated Transport scenario is only marginally higher than in 2003. This distinction, while fully a consequence of our assumptions, shows how powerful transport policies can be in leading indirectly to huge oil savings and increasing energy security.

Oil consumption comprises most of the transport energy use in Road Ahead at 450 thousand barrels per day (kbpd) in 2010 and 2,500 kbpd in 2020. Oil use in 2010 in Oil Saved is 300 kbpd and rises to 800 kbpd by 2020. In Integrated Transport, oil use is a mere 300 kbpd by 2020, 12 percent of its value in Road Ahead.

Figure 5. Energy Use for Cars, by Fuel and Propulsion



Note: Primary energy required for electricity generation and transmission is included, but no primary adjustments were made for production, transmissions, or distribution of gasoline or CNG.

5.2 Carbon emissions

Using our input assumptions, we estimated 2003 carbon emissions from cars in China at around 8.8 million metric tons of carbon (MtC).[6] Emissions grow to 20 MtC in 2010 and 102 MtC in 2020 in Road Ahead, assuming that no additional policies other than existing fuel economy regulations will be implemented (Figure 6). The only boundary condition for our base case is that imposed by the existing fuel economy standards. For comparison, IEA (2004a) foresees China's transport-related CO_2 emissions at 162 MtC by 2020, up from 67 MtC in 2002. The share from cars, while small now, rises rapidly.

In the second scenario, Oil Saved, improved fuel economy, largely due to a high penetration of hybrids and restraints in the size and power of cars (aided by reduced driving distances), could reduce carbon emissions in 2020 by 50 percent (Figures 6 and 7). One of the driving forces for this decrease in carbon emissions is a shift from present fuel pricing to the Japanese or European level of fuel taxation, which would boost prices by a factor of three.

In Integrated Transport thoughtful transport policies, listed in Section 6, have a profound impact on energy use, leading to 40 percent lower carbon emissions in 2010 and 79 percent in 2020 compared to Road Ahead (Figure 7). Despite more than ten times today's number of cars, primary energy use increases by only a factor of 2.5, only 22 percent of the level in the unconstrained case in 2020. In Integrated Transport, distance traveled per vehicle is half compared to Oil Saved. This, combined with the important share of mini-cars, reduces overall oil use and carbon emissions significantly.

6. POLICY OPTIONS

China already has a strong set of policy measures that can assist in achieving its energy security, air quality, and other goals. This section proposes additional options that will have an impact on vehicle ownership, vehicle use, infrastructure use, infrastructure access, road space use, and fuel demand, leading to increased energy efficiency, increased mobility, and reduced transport emissions. Most of these policies are implied in the assumptions underlying our scenarios in section 4, where their impacts are reflected in the scenario results in section 5. The policies assumed in the scenarios and proposed to be implemented are discussed below and include technology requirements, motor vehicle taxation, fuel taxation, road and congestion pricing policies, and public transport system improvements.

6.1 Vehicle technology requirements

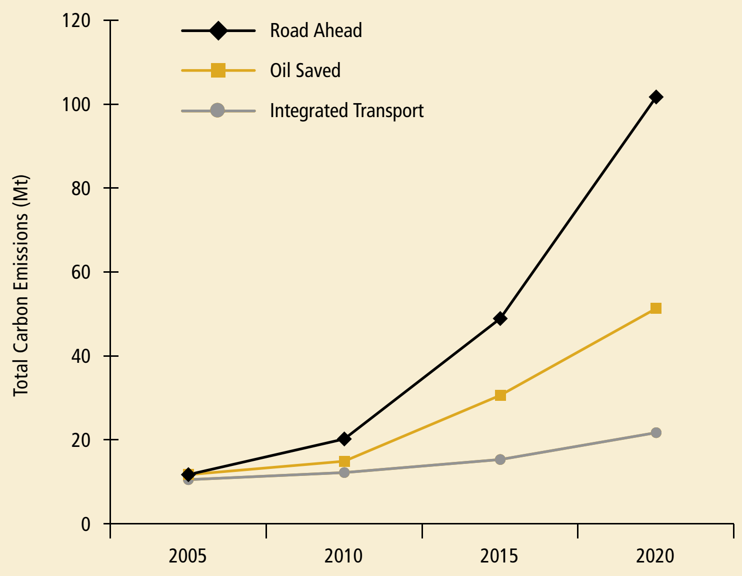
As described earlier, China has already started developing its advanced and alternative-fuel vehicle technologies. For example, HEVs will be available in the market by the end of 2005. Toyota has started building its Prius hybrid sedans in China with a Chinese partner (First Automotive Works). If this effort is a success, it will lead to greater availability of HEV technology in China and could lead to more HEV production. The Government of China has the option to continue attracting and encouraging such joint efforts, and to increase the diversity of advanced vehicle technologies in China.

Fuels other than gasoline and diesel have already been used in the transport sector. The two alternative transport energy sources discussed in this chapter are CNG and electricity. It is likely that the use of natural gas for transportation will continue to increase in order to meet the growing need for clean transport fuel. Natural gas is now used in approximately 110,000 vehicles (mostly buses and taxis) in 12 Chinese cities (Walsh, 2003b). However, this fuel is constrained by the supply of natural gas, and the fact that it is harder to transport than oil. Therefore, despite it being a relatively clean fuel, CNG-operated vehicles might be limited to a smaller role in the transport sector, but could be used in public vehicles in polluted urban areas.

Electricity is another clean transport energy source with minimal emissions impact. It is important to note that although emissions may be produced during the production of electricity, depending on the type of electric power generation, electric vehicles are still effective when used for short travel distances, especially small electric cars used in urban cities. Since the main barrier to using electricity in motor vehicles is the storage of electricity (Walsh, 2003b), further vehicle technology development is required for greater battery storage systems.

Although most technologies are already available, China needs to create the right market for such technologies to be developed commercially. The demand for advanced and alternative-fuel vehicle technologies should also be encouraged.

Figure 6. **Total Carbon Emissions from Road Transportation in the Three Scenarios, 2005–20**



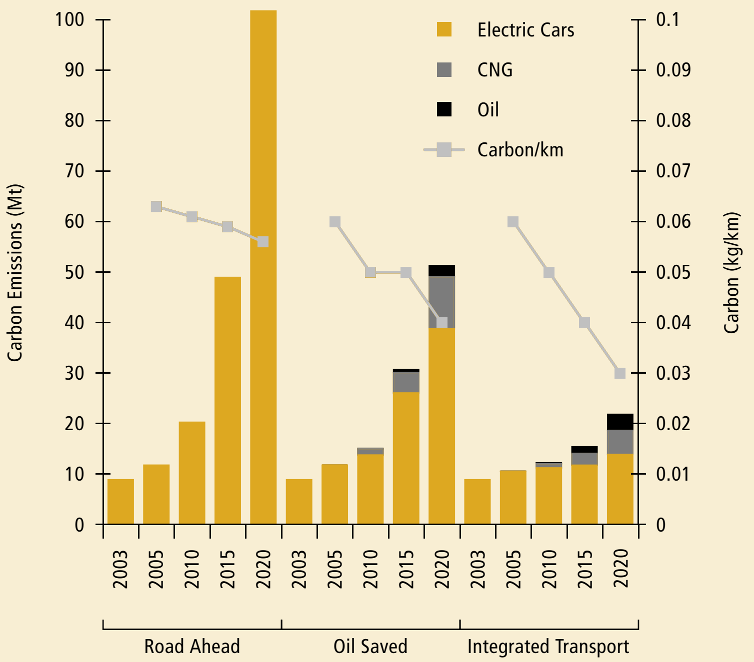
6.2 Motor vehicle taxation

Vehicle taxation has been implemented in many developed and developing countries. When integrated into transport policies, it may lead to improved transport demand management and be a good source of revenue. Vehicle taxation may also encourage demand to shift to other transport modes. Current taxes applicable to motor vehicles in China include value added (VAT), excise, vehicle acquisition, and vehicle usage taxes (Huang, 2005). A vehicle usage tax in China is collected on an annual basis and the amount of tax paid depends on the type of vehicle. An annual tax offers more flexibility than sales tax, as tax rates can be altered over time and the burden is distributed over a longer time period for vehicle owners (Schwaab and Thielmann, 2002).

Different features might be incorporated into vehicle taxation according to different transport strategies. For instance, taxation could be implemented by vehicle type, vehicle price, vehicle size, or test emission and noise levels. A differentiated system, as applied in Sweden and Germany, offers incentives for vehicle owners to switch to low emission vehicles (IEA, 2000; Breithaupt, 2002). This is often true when vehicle taxation is differentiated according to specific emission standards, where taxes are higher on more polluting vehicles. Vehicle manufacturers may also be encouraged to develop less polluting vehicles that could be preferred by consumers due to lower taxation (Schwaab and Thielmann, 2002). However, it is important to note that vehicle taxation, unlike other taxation options, does not contribute to variable costs of transportation and therefore is unlikely to influence vehicle miles traveled or other driving habits.

Vehicle taxation would be the highest in the third scenario, Integrated Transport, as authorities reduce congestion and private motorization demand by increasing vehicle costs. In the other two scenarios—Road Ahead and Oil Saved—the ownership and use of vehicles are not taxed as substantially.

Figure 7. Carbon Emissions from Motor Vehicles of Different Technologies by Fuel



6.3 Fuel taxation

Using fuel taxation as a policy instrument can recover the variable costs of driving by charging vehicle users for transport infrastructure indirectly through individual use. Since fuel is one of the highest and most visible variable costs of vehicle use, fuel taxes encourage drivers to make more efficient use of their vehicles, reduce trip frequencies, and even switch to less fuel-intensive vehicles. Most importantly, fuel taxes help reflect the real costs of dependency on foreign oil supplies, storing oil in the event of an interruption, and other externalities.

The level of fuel taxes imposed should be enough to abate vehicle emissions and serve as revenue for transport infrastructure and maintenance purposes. The revenues collected from transport fuel are usually allocated for transport purposes, as seen in many other developed, transition, and developing countries (Carruthers, 2002). Fuel prices should include taxes to reflect the perceived externalities and risks of foreign oil imports, and fees to reflect the environmental damages related to fuel quality. The latter was the goal of fuel taxation reform in Sweden in the late 1980s and early 1990s, as taxes rose on more polluting fuels but fell on cleaner fuels (IEA, 2000).

Fuel taxes in China are virtually nonexistent at present. If fuel prices continue to remain low, energy consumption and emissions from the transport sector could follow the projections in the Road Ahead scenario. If China wants to reduce its energy consumption to levels projected in the Oil Saved and Integrated Transport scenarios, a Japanese-equivalent rate of fuel taxes should be implemented in order to encourage less oil consumption by individual consumers. An increase in fuel taxes will lead to a stronger interest for advanced vehicles and alternative fuel vehicle technologies.

6.4 Road pricing

Road pricing is another demand management strategy through which drivers pay directly for utilizing public services. Some examples are toll roads, toll bridges, and congestion pricing systems, whereby drivers are charged when entering specific zones during certain time periods. Road pricing is usually implemented by public or private highway agencies or local authorities as part of transportation demand management programs; this would be the case for China as well. Revenue collected can be used to cover investment costs of transport infrastructure and maintenance, including alternatives to cars.

These approaches can reduce overall vehicle use and shift some travel patterns to less congested times. Since fuel use per kilometer rises with congestion, congestion measures tend to slightly improve fuel economy. Experience from London, for example, shows that the imposition of a £5 fee on bringing a car into a well-defined zone during business hours led to 15 percent fewer cars entering that zone. Singapore has also achieved similar results (Menon, 2000). Given the congestion in most large Chinese cities, the implementation of such systems is an option to consider.

Charging for scarce road space is an important strategy for Chinese cities, where central areas have as little as one fifth of the space per capita compared with even more traffic congested cities such as London, Paris, and New York (Mao, 2004). The Shanghai Metropolitan Transport White Paper (People's Government of Shanghai Municipality, 2002)[7] discusses electronic road pricing, which is a model that Singapore has followed in its general transport strategy for the past two decades (Menon, 2000). This pricing scheme is sophisticated, as vehicles are charged on a per entry basis and could vary depending on the day, time of day, the type and size of vehicle, congestion level, and the road and place of entry (Breithaupt, 2002). Here, public education was necessary before the implementation of the system to better inform motorists and to ensure a smooth transition.

A lesson that emerges from existing experience is that an effective road pricing system has to be designed specifically to a city's needs and to match the local traffic conditions. Applying one city's approach to another city without careful adaptation is risky. The Vehicle Quota System implemented in Singapore in 1990, for instance, could be applicable elsewhere but would require adaptation. This quota system determines the number of new vehicles allowed for registration, while the demand for new vehicle registrations determines the price to register. The vehicle quota for a given year is administered through the monthly release of Certificates of Entitlement, which may cost as much as a car.

Road pricing policies are extremely important in the Integrated Transport scenario, where congestion is largely avoided as a significant problem because of road pricing and other complementary measures to regulate car use. If this scenario is to be realized, it is important to announce and implement road pricing policies early, before too much investment in private automobiles and on infrastructure that is dependent on private vehicle use is made in the most congested zones. Of particular appeal for Chinese cities is the fact that with a few exceptions, private car ownership is low, hence the initial impacts will only be felt by consumers of relatively higher income levels. A major impact of the London scheme was the clearing of car traffic that otherwise slowed buses (and bicycles), even at a 20 percent reduction in car traffic. Therefore, the early imposition of congestion charging in Chinese cities would likely benefit the majority of present non-car users, as well as car users who do elect to pay car use fees.

6.5 Public transportation and non-motorized transport

To be an attractive alternative, a public transport system has to provide speed, convenience, comfort, and affordability. This requires policy changes and significant investment. If mass transit systems such as conventional buses, fast buses in dedicated corridors (i.e. BRT), metros, and other rail-bound systems are to compete with private cars or even motorbikes, they must improve with respect to speed and cost, as an increasing number of Chinese families will be able to afford private motor vehicles. Doing so would also deliver environmental benefits and transport efficiency benefits.

The most important and cost-effective way of promoting effective public transport systems in China is through BRT. These systems have high capacity volume, segregated bus lanes, rapid embarking and disembarking features, transit prioritization at intersections, and modal integration at bus stations and terminals. Such characteristics are appealing to passengers, and will aid in achieving sustainable urban transportation in high-population-density urban cities by reducing congestion, vehicular emissions, and by providing a cost-effective alternative transport mode.

Some of these benefits can also be attained by nonmotorized transport (NMT). Pedestrians and cyclists generate neither conventional air pollution nor CO_2. Pedestrians and cyclists are also more efficient users of scarce road space than private motor vehicles, along with being the most efficient and environmentally sustainable when making relatively short trips (Hook, 2002). In virtually every other country, however, NMT has yielded to motorized public transport and then individual vehicles. The most notable countries where NMT retains 20 percent or more share of all trips in urban areas are Denmark and the Netherlands, but the high share of NMT comes principally at the cost of bus travel and short car trips. High fuel taxes, careful urban planning, an integrated network of dedicated bike lanes, and a strong component of local commercial activities keep these alternatives to cars important.

The Government of China could continue to encourage public transport investments to enhance its quality and promote cycling and walking within urban cities. Good alternative transport modes provide options to private car ownership and use, and will limit congestion and transport pollution. This phenomenon is projected in the Integrated Transport scenario, where severe traffic congestion starts to restrict total car utilization and significant charges are added to increase the total cost of driving at the same time. In the Oil Saved scenario, the use of public transportation will also increase as higher oil prices and taxes will discourage private vehicle use. A good public transport system will hence aid in decreasing private vehicle use by being a more affordable and efficient alternative. The challenge for China is to increase the speed, reliability, and convenience of its public transportation systems before too many individuals choose to use private transport modes.

6.6 Parking charges

As urban land for parking becomes scarcer, parking charges should be increased as a measure to efficiently allocate parking spaces. Parking is free or charged at a subsidized rate in many countries (Breithaupt, 2002). However, as a demand side management measure, the costs of parking facilities or on-street parking should be distributed to motorists. Every motorist should know what it really costs to bring a car into a zone where land space is scarce. Parking charges can create substantial revenues for local municipalities and could be used for transport infrastructure maintenance.

The implementation of parking fees will increase the cost of driving in urban areas, which will make private car use less appealing. For China, this will certainly influence future patterns of car use. Congestion, as well as vehicular emissions, could decrease, especially when public transport modes are encouraged. Raising parking fees to reflect the real costs and value of space—and enforcing existing parking rules—discourages the use of cars in congested regions.

7. CONCLUSION

The trends and scenarios examined in this chapter illustrate important choices Chinese policymakers must confront. On a national level, China is in the "infancy" of personal motorization; Chinese authorities have nearly 100 years of experience to draw on from other countries on the positive and negative impacts of motorization. Given the rapidity of motorization growth in China, authorities have to act fast in order to avoid traffic safety, urban congestion, pollution, and energy problems that will increase together with continued rapid motorization. Cleaner, safer, rapid transportation systems that increase access to more people have to be developed, rather than following the narrower path of rapid individual motorization, as scenes from congested Beijing and other major Chinese cities already suggest. The sooner measures are considered, the more effective they will be. The longer policymakers wait, the more technologies, fuel choices, and travel patterns will be locked in by the fixed investments required to support them.

A key issue so far overlooked by Chinese authorities is that many motorization impacts depend not only on the emissions per kilometer, but also on the total distance driven. In the case of urban air pollution, the current focus on emissions per kilometer is proper, given the need to improve fuel quality and the enforcement of more stringent emissions standards. If the present trends in car use continue, the huge increase in distance traveled will increase emissions significantly, hence offsetting much of the promise of improved emissions control through current air quality and emissions regulations. Thus, there are good reasons for authorities to consider strategies that will slow the rise in total distance traveled, particularly in urban cities.

Similarly, the number of motor vehicles and the total distance traveled are the key factors in determining total energy consumption and carbon emissions. Nevertheless, since the growth of motorization in China is likely to continue to increase for the next few decades, the use of advanced and alternative-fuel vehicle technologies should also reduce the externalities of motorization while meeting the demands for private car use. With the appropriate policy actions, it is also possible to have widespread use of clean, small, and efficient cars in the future, especially if car use is regulated by both restraint policies and the strategic provision of alternative transport means.

Our third scenario, Integrated Transport, is driven by a vision of an ideal future Chinese city with minimal congestion delay. Oil is a limiting concern, but not the driving factor for the results shown in this scenario. The issues that decide the quality of life in Chinese cities—including population density and size, land use, and the structure of economic and cultural activities—are far too important to be determined solely by oil markets. However, Chinese authorities may recognize that a high-oil, high-car-use model of a city in China may actually leave most Chinese with fewer choices and a lower quality of life because of the constraints of space and air pollution.

Fuel taxation and road pricing play a major role in reducing vehicle use, energy consumption, and carbon emissions in Integrated Transport. The timing of fuel taxation is crucial, as early imposition gives the automobile industry more time to adapt to its growing production capabilities to produce vehicles that capture the desired social benefits of the taxes. The earlier policies are implemented, the larger the fraction of China's potential future drivers will have grown up under a policy with the goal of a sustainable transport system in mind. Since only a small minority of Chinese own private cars today, and most of them are from relatively well-to-do urban households, imposing fuel taxes and road pricing is likely to bring a net societal benefit. Private car users will bear the burden of increased taxes and charges, but the potential results of less driving and congestion will benefit the large majority of pedestrians, cyclists, and bus riders. The more revenue is channeled into infrastructure projects, congestion-alleviating projects, and alternative transport development, the more the public will accept the imposition of relevant charges. Finally, as such changes are introduced, it would be important for Chinese local and national authorities to measure the impact of pricing policies through surveys of car and fuel use, travel time, and other impacts of the policies, as has been done in London and Singapore in connection with congestion charging.

Advanced vehicles, alternative vehicles (such as minicars), and alternative-vehicle fuel technologies already exist and could be affordable if China creates a market for these technologies. Since the transport sector, in terms of private motorization, is still relatively young compared to most other countries, China has an opportunity to truly revolutionize its auto industry and private automobile market. It is important to note, however, that even if the entire Chinese fleet of motor vehicles is transformed to advanced or alternative fuel vehicles, the basic problems of motorization, such as heavy congestion and road traffic accidents, will still persist. Additionally, cleaner vehicles and fuels alone may not eliminate air pollution if the distance traveled per vehicle is not also reduced (Walsh, 1996).

Vehicle demand has to be optimally managed and regulated in order to reduce the adverse impacts of transportation, including energy consumption, congestion, air pollution, and ultimately GHG emissions. Advanced and alternative fuel vehicle technologies are part of the solution to reduce such adverse motorization impacts, but appropriate policy measures that could change travel patterns have to be implemented and enforced as complementary tools.

ENDNOTES

[1] Further background on trends and impacts of rapid motorization in China can be found in Schipper and Ng, 2005.

[2] Numerous press reports in the first third of 2005 suggest overall slowing of car sales, and a shift toward smaller, less expensive models as well. The 1,500 kilogram average should fall, at least during the present phase of market expansion. A tightening market for car loans is the principal reason for this market weakening.

[3] Euro emissions standards for passenger cars and light vehicles were implemented in the European Union as early as in 1993 (Euro I) to reduce air pollution from transportation. Vehicles must meet certain exhaust emissions standards before they can be approved for sale in the European Union. The Euro IV emissions standard is currently implemented in the European Union.

[4] "Activity level" includes the number of cars, the distances cars are driven, and the overall distance people travel in cars, on foot, and on all other modes, which is referred to as "modal split" as described in Schipper et al. (2002).

[5] Since bus travel, particularly by BRT, would only use 10 percent as much fuel/passenger-km as car travel, the incremental oil needs for shifts to buses indicated here are small.

[6] CO_2 from "road transport" in 2002, according to IEA (2004c), was about 41 MtC. Calculations here suggest that cars constitute just over 20 percent of this figure. Trucks, buses, two-wheelers, and other motor vehicles operating on roadways are likely to constitute the large (but declining) part of transport-related emissions from China.

[7] The Shanghai Metropolitan Transport White Paper is the first comprehensive transport plan for the city that outlines current and future transportation needs and sets specific objectives and actions for city planners and managers. The white paper was issued in April 2002, and is the first of its kind for any city in China. The white paper was created to respond to the transportation needs Shanghai will face as its population expands in the next 20 years and as private automobile ownership grows along with it.

[8] "Private vehicles," defined as cars and privately owned household light trucks and SUVs, numbered approximately 12 million in 2003, or 9.2 per 1000 population. The number of cars we have chosen for historical analysis is from a time series devised and used as the basis of the work in He et al. (2004).

[9] In addition to the key scenario assumptions noted here, the number of cars, share of cars by each fuel type, distance driven, fuel economy, and improvement in fuel economy from hybridization are just as important. Other assumptions made in the scenarios include the availability of natural gas used for compressing gas at filling stations, the exact fuel cycle carbon emission for gasoline, natural gas, and fuels used for electric power production. These minor assumptions differ very little among the scenarios and therefore do not "cause" the variations driven by the key assumptions.

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Appendix 1. SCENARIO AND TECHNICAL ASSUMPTIONS

The variables in this chapter include basic motorization factors and trends in China, estimates of car ownership, car use, and fuel economy. The number of cars in China in a given future year is the parameter with the greatest likely variation. This and other variables are projected into the future with trends derived from neighboring countries with higher income levels. Description of the assumptions include the following:

1. Car use: distance traveled per car per year

The current average annual distance traveled in China is 18,000 kilometers per car, excluding taxis whose annual usage is probably well above 50,000 kilometers (Chen et al., 2005). The 18,000 average distance is swollen by the large number of government and company cars with high usage. Since the private car fleet is expected to grow much faster than the taxi or government/company fleet, average use will fall. Indeed, as the number of cars grew from low numbers in Japan or West Germany, usage per car fell slowly. This reflected both fewer people "sharing" the same car, and more truly private cars as opposed to heavily used company cars.

2. Fuel consumption

For each scenario, fuel use is calculated as a product of the number of vehicles, distance traveled per car per year, and fuel per unit of distance (fuel economy), in accordance with the ASIF model of Schipper et al. (2000). With the introduction of gasoline hybrids, mini-cars, CNG vehicles, and electric vehicles, separate assumptions are made for fuel economy of each kind of vehicle. Fuel economy depends on both car weight/power and the efficiency of propulsion. We cannot separate these two variables, but we can estimate the range of fuel economy expected for a car of 3,000 kilograms (for example, a Hummer) in contrast to one weighing close to 750 kilograms (for example, a Mercedes Smart). Lying between these extremes is the average new Chinese car of 1,500 kilograms. Previous analysis (He et al., 2004) has used the road fuel economy at about 11 km/liter, or 9.1 liter/100 km. The best estimate of China's on-road fuel economy today is 9.5 liters/100 km.

3. Final and Primary Energy Consumption

Total energy use consists of the numbers of cars, distances cars traveled, and fuel economy values assumed, which will depend on the type of vehicles such as HEVs, conventional gasoline cars (including mini-cars), CNG cars, and electric cars. For electric power, the electricity per kilometer reflects what is put into the battery (Delucchi, 2005). Hence, total energy consumption (EN) is:

$$\mathrm{EN} = \sum (\mathrm{N}_e * \mathrm{FI}_e * D_e) \qquad (1)$$

where, FI_e is the fuel intensity (the inverse of fuel economy) for each car type e (in energy/km), N_e is the total number of cars of each type, and D_e is the average distance traveled by each type of car. Electricity is converted to primary energy using the figures modeled in World Energy Outlook 2004.

4. Carbon Emissions

Carbon emissions are calculated for each fuel using IPCC coefficients of CO_2 (converted to carbon) per unit of energy in fuel at the lower heating value. To model approximately the full fuel cycle emissions of each fuel, we have added 7 percent "overhead" to CNG and oil, and 5 percent to utility fuels. The lower figure for utility fuels reflects the fact that they are largely delivered in much greater quantities, and at least for oil, not refined as much as is gasoline delivered to vehicles. The overall results are not very sensitive to the assumed "overheads" we have added here.

Editor's Note

Rural electrification is a pivotal development issue in many parts of the world. Electricity provides a huge range of development advantages, facilitating better education, better health, and more economic activity. There are few higher priorities than providing modern energy services to the poor, mainly rural, populations around the world that lack them. But it is also very hard to deliver and requires the establishment of effective institutions, delivery mechanisms and policy incentives. Nowhere better illustrates these challenges than India. Despite repeated efforts, 56 percent of Indian households have no electricity supply, and the problem is growing worse as new connections fail to keep pace with population growth. The new government has set ambitious targets for providing full electrification, but it is far from clear that these goals can be met.

The authors consider three scenarios under which electrification goals could be met: an extension of the grid using India's existing generation mix; a scenario dominated by off-grid diesel generators; and one dominated by off-grid renewable energy generation.

It comes as no surprise that the scenario dominated by renewable energy results in significantly lower GHG emissions—depending on demand levels this approach saves from 14 to 100 million tons of CO_2 *per year compared to the grid-based model. The authors also point out that the longer-term effect could be more important still: if renewable energy is important in the rural electricity mix now it will probably remain so as demand grows in the future. However, the choices for India need to be taken primarily on non-climate grounds, and the authors consider a number of these: how fast electrification can be delivered, the quality of supply, cost issues, and implications for India's energy security.*

The authors express serious reservations as to whether India's creaking power delivery institutions can be expected to deliver grid electrification in rural areas before fundamental problems are solved. It is hard to envisage how a grid-based electrification can meet the government's targets. Dispersed diesel generation is far more promising, with entrepreneurial suppliers already springing to the aid of customers eager to escape erratic grid power, and in many ways it can be expected to play an important role. However, the authors point out that high levels of diesel use do present a significant import dependence and security problem for India. This "Diesel First" scenario leads to an increase in oil product imports of between 6 and 41 percent over 2004 levels, as opposed to between 1 and 11 percent in the other two scenarios. What this means in cost terms depends on the price of oil; the authors consider $30 and $70 per barrel as an indicative range. The Diesel First scenario under high demand assumptions adds $8.4 billion per year (at $30 per barrel crude) or $15.8 billion per year (at $70). The security implications of this additional dependence are well beyond the scope of this chapter to predict, but it is safe to say that such significant additional import dependence will at least be a concern.

A model based on off-grid renewable energy therefore offers considerable attractions, provided that appropriate delivery mechanisms and policy incentives can be developed. Although India already offers a range of support for renewable energy, it remains a relatively minor part of the energy mix. The authors suggest that the advantages they identify here partly make the case for a much more significant use of renewable energy technologies. But are these reasons enough? Although high fuel prices tilt life-cycle costs in favor of renewable energy, the relatively high capital cost of these technologies is a major barrier in a country like India where capital is expensive.

This is an interesting case in which framing the challenge as an SD-PAM may make a difference. India must reach its goal of providing electricity to all its citizens, and the international community has an interest in helping it meet this goal on a low-emission trajectory. India would see substantial benefits from having a high use of renewable energy in meeting rural electricity demand, but is hampered by the lack of low-cost capital. This is an area in which the international community is well-placed (through international lending institutions, export credit agencies and other financial support) to help.

Compared to the examples we have considered earlier in this volume, the degree of assistance is likely to be greater and will probably have a greater financial component. But the interests of both India and its international partners seem sufficiently well-aligned to make this an attractive area in which to explore the potential for SD-PAMs.

CHAPTER V

Pathways to Rural Electrification in India:

Are National Goals Also an International Opportunity?

Navroz K. Dubash ▪ Rob Bradley

1. INTRODUCTION

In the first decade of the 21st century, rural India remains in darkness. While the rest of the country debates whether or not India is shining (a catchy, but ultimately unsuccessful election slogan), whether 7 to 8 percent growth rates are sustainable, and whether or not India's creaky electricity infrastructure and cobwebbed institutions can support a 21st century economy, these questions are academic for more than half of India's poorest households. They have no access to electricity.

After a decade of inattention, however, rural electrification has slowly climbed up the political agenda. The Electricity Act, passed in 2003, promises a new approach to rural electrification. Support for rural areas, including electrification, was prominent in the electoral program of the governing "United Progressive Alliance," (UPA) which came to power in mid-2004. Following bold declarations of electricity for all within ambitious time frames, bureaucrats and technocrats have scrambled to prepare policies and plans to meet these commitments.

This chapter is an attempt to better understand how the country can best go about the enormous task of providing electricity to half its population. Our premise is that rural electrification is central to India's development efforts, and that achieving this outcome should be driven by national development goals, such as providing electricity rapidly, effectively, cheaply and securely. We evaluate—quantitatively where possible, otherwise qualitatively—a range of different approaches to rural electrification against these criteria. We add to this list the impact of electrification on India's national energy security and its dependence on fossil-fuel imports. Consistent with the approach of this volume, we also recognize that a major effort like rural electrification in India also has potential global climate implications—negative, if growing consumption rests primarily on fossil fuels, and positive, if electricity use displaces kerosene or reduces pressure on forests by reducing the need for unsustainably-harvested wood.

Regardless of the climate impacts, however, the development advantages of electrification should be pursued. Since there are active global negotiations and deliberations on addressing the problem of climate change, it is relevant to these global processes, and certainly to India's bargaining stance within them, to ask if those approaches to rural electrification that best meet national development goals are also those that minimize greenhouse gas (GHG) emissions. If the rural electrification option that best meets India's development goals is consistent with climate reduction goals, the country has a potentially strong case to make to the global community for international support for India's rural electrification. This chapter assesses the strength of this claim.

1.1 Importance of electrification for development

Provision of energy services is a central element of a development agenda. While electricity is by no means the only source of energy for rural populations, as a high quality source of energy, it is an important element in a larger development framework.[1] Electricity reduces household drudgery, frees up time, provides opportunities for economic entrepreneurship, supports education, supports health-enhancing efforts through refrigeration and pumped water, is critical for agriculture, and enables more effective communication with the world beyond the village. Rural electrification can particularly benefit women. Mathur and Mathur (2005) report that in households with electricity, women spend significantly less time collecting wood for fuel and, because of the availability of lighting, are able to spend a portion of their day reading.

Moreover, access to more efficient technologies such as electricity for lighting can actually save money, in addition to providing health and development benefits. In rural India, poor households spend 8 percent of their incomes (which are low in cash terms) on kerosene for lighting (Saghir, 2004), a proportion that is likely to fall with use of electricity for lighting.

1.2 India has a lot to do

Rural electrification is hard to accomplish. Rural households are remote and therefore costly to serve; they do not use much electricity, which makes them relatively unprofitable (under the prevalent tariff structure, they are loss-making), and they are poor credit risks. In the recent past, efforts at restructuring State Electricity Boards and attracting private capital to the electricity sector have contributed to the neglect of rural electrification (Singha et al., 2004). While 220,000 villages were electrified in the 1980s, just under 40,000 villages were electrified in the 1990s (Ministry of Power, 2003).[2]

India's record since independence has been poor. In 2001, 78 million of India's 138 million households (56 percent) did not have any connection to an electricity supply (Ministry of Power, 2003; World Bank, 2004). At the recent pace of a million households a year, India is actually seeing an annual increase in numbers of households without electricity, since the household population is growing even faster, at a rate of 1.85 million households a year (World Bank, 2004). India's performance also falls well behind international standards. China, for example, is well on its way to complete electrification (Figure 1 and Box 1).

In recent years, rural electrification has come back to political center stage, driven by the realization of its neglect and by a realignment of political forces. In mid-2005, the UPA government announced the "Rajiv Gandhi Grameen Vidyutikaran Yojana" or village electrification scheme to electrify 125,000 villages and 78 million households in five years. This ambitious scheme promises, in essence, to complete the task of rural electrification in one massive five-year push. The scheme is even more ambitious, promising electricity for rural industry and livelihoods on a 24-hour basis (Ministry of Power, 2005a). The backdrop for this announcement is the commitment to rural India in the UPA government's Common Minimum Program and subsequent pronouncements about providing electricity to all remaining unelectrified households by 2009. The previous National Democratic Alliance (NDA) government sought to reach this milestone by 2012.

The Indian government has a track record of underachieving on ambitious targets. Tongia (2003) notes that "unlike in China, where the planning mechanism is often gospel, in India actual plant constructions are typically about half the official Plan target, and in recent years the gap between Plans and reality has grown."

1.3 A New Political and Institutional Context

Although the chances that the government will redeem its promise in full remain slight, there are at least two reasons to expect a more serious effort at rural electrification than in the past.

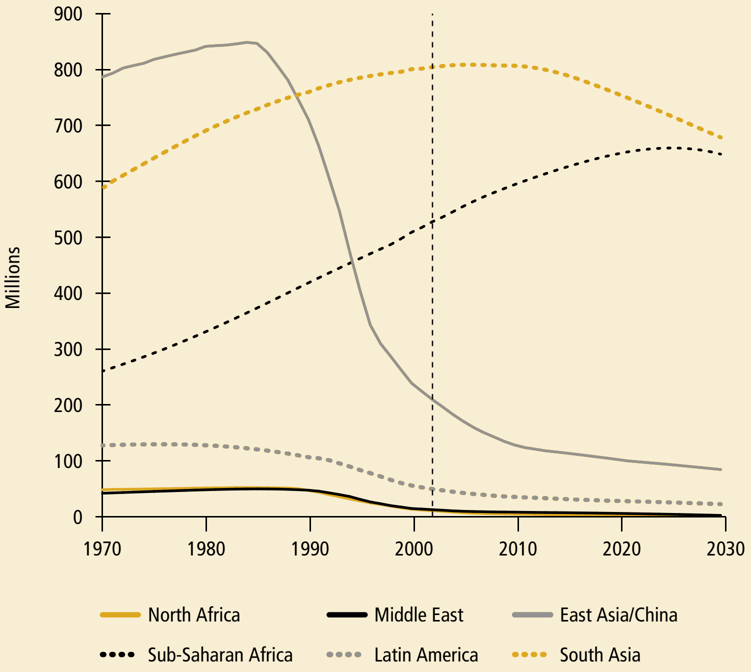
First, the UPA government's surprise victory in the 2004 general election is often attributed to a protest vote from rural constituencies who felt excluded from the image of "India Shining" portrayed by the then-governing NDA.[3] Whether this explanation is true or not, the perception is firmly rooted, and the UPA clearly sees its support as rural-driven. For this reason, rural development, including electrification, is central to its electoral platform and many of its policies in its year in government. The UPA's commitment to this agenda will help ensure that the spotlight remains on rural electrification at least through the electoral cycle.

A second reason is the Electricity Act of 2003. Previously, responsibility for electrification rested in the hands of various state institutions, notably the Rural Electrification Corporation in coordination with the State Electricity Boards (SEBs). Their performance was uneven, marked by relatively rapid electrification in some decades and extremely low levels of activity in others, notably the 1990s (see Section 2). Perhaps more significant than the pace of new connections, the level and quality of service has been poor, as rural electrification has been caught up in a larger malaise of inefficient administration, poor technology, and financial collapse that has afflicted the SEBs (World Bank, 2004). Rural electrification, which is heavily loss-making, actually has been an important contributing factor to this financial imbroglio.

The Electricity Act of 2003 opens the electricity market to new institutions and new thinking in rural electrification. It allows for decentralized provision of electricity without prior need for a license by, for example, Panchayats (village councils), user association's cooperatives, NGOs, and franchisees. The success of this approach remains to be tested, and it certainly brings its own risks and dangers, such as the potential for new unregulated entrants to unduly exploit rural consumers (Dubash, 2004). However, the change in approach certainly opens the door to a great deal more activity, ferment, and experimentation in rural electrification, and marks a departure from the past.

The existence of new political momentum and supporting legislation behind rural electrification by no means guarantees success in rapidly enhancing access to electricity in rural India. Indeed, there remain considerable obstacles, notably institutional and financial, to achieving rural electrification. For example, what service delivery mechanism(s) are most appropriate to deliver rural electricity services? How can electrification be sustainably financed, whether through cost recovery or public expenditures? Viably addressing such short- and medium-term issues is necessary to jump-start India's rural electrification. In this paper, we recognize these central and practical issues that stand in the way of rural electrification in India. These issues are extensively debated within India and elsewhere; we draw on these debates for portions of the analysis that follows.[4]

Figure 1. Population Without Access to Electricity



Source: International Energy Agency (2002b)

1.4 Framework and Approach

This chapter is focused on understanding the implications of alternative trajectories of rural electrification. We understand this exploration to be complementary to, and by no means a substitute for, work on the institutional and financial concerns that are the primary roadblocks to rural electrification. In assessing the promise of various approaches to rural electrification, we examine the potential

Box 1. The Chinese Success

China and India are in many respects very different countries, but over the last few decades they have faced similar electrification challenges. The difference in the levels of success at rural electrification between the two countries is striking. So how did China do it?

For the first decade or so after the revolution (1949), electrification in rural areas fell largely to the rural communities themselves. Increasingly aware of the advantages of electric power, such communities established off-grid generation using locally available fuels—coal, diesel, and hydropower. These efforts were small-scale, typically used only for lighting and food processing. By 1957, they still accounted for around 0.6 percent of China's power consumption.

Starting in 1958, the central government began to take an active role in promoting rural electrification, first for irrigation and flood prevention, and later for other productive uses. The dominant technology was small hydropower (SHP), an enormous resource in China. The central government supplied demonstration projects, workshops, and other encouragement, while the turbines were generally manufactured locally.

In 1979, the government established the National Primary Rural Electrification County Program (NPRECP), targeted at specific counties with low levels of electrification. Banks were instructed to give high priority to rural electrification in their lending. Even as investment in transmission infrastructure meant that new areas could be connected to the grid, the government recognized the importance of SHP in alleviating power supply constraints, and support was maintained. From the late 1980s on, the shift away from government control and toward a market economy gave rise to new sources of demand, and the NPRECP was expanded. Two codes for renewable energy were developed: one for systems in remote areas, generally based on SHP, and one for grid-based electrification. These are expected to produce the same standard of power supply. The results have been spectacular: by 1997, 96 percent of Chinese households had an electricity supply.

Since 1998, the focus has been on the reform of rural power markets. The government has also committed public funds (180 billion yuan, roughly $22 billion over three years) to strengthening rural electricity grids. Clearly there is much in the Chinese story that cannot be applied in India—the central government does not have equivalent powers to instruct banks to lend to certain sectors, for instance. Nevertheless, the fact that the electrification of rural areas was led by decentralized approaches, with central government policy supporting it, is noteworthy. It is also important that China was able to apply identical quality criteria to both on- and off-grid power supplies.

Source: Based on Yao and Barnes (2005)

of a range of approaches to meet national development goals. In brief, these three approaches are (1) largely grid-based electrification with conventional thermal sources, (2) largely off-grid electrification with diesel technology; and (3) off-grid electrification with renewable energy technology.

For the purpose of this study, the Government of India's stated goals in its proposed Rural Electrification Policies (Ministry of Power, no date) provide a starting point for developing a framework against which to assess rural electrification approaches. There are five components to the government's approach: (1) *accessibility*, or the speed and effectiveness with which access to electricity is provided to those that otherwise lack it; (2) *availability*, or the provision to each connection of the full power demand of the user; (3) *reliability*, or the proportion of time during which this power is available to the user (blackouts and brownouts are indicators of low reliability); (4) *quality*, or the consistency of such features as the voltage and frequency of the power—poor quality can both reduce the usefulness of the power and damage appliances and equipment, a major problem with rural electricity in India today; and (5) *affordability*, or the appropriate pricing of the power to ensure that those who need it can afford it.

For tractability, we combine availability, reliability, and quality, all three of which are closely related, into a single goal of quality supply. We also add another important, but often forgotten goal—ensuring energy security. While India has plentiful coal reserves, its stocks of other fossil fuels are limited. A massive future expansion of demand could become a factor in India's energy security and in related macroeconomic considerations. Consequently, the framework of national development goals against which we examine alternative rural electrification approaches is:

1. *Speed* at which access is provided
2. *Quality* of supply, including availability, reliability and consistency
3. *Affordability* or cost criteria
4. *Security* of supply

From a global point of view, climate impacts are also relevant. This is treated separately from the four "national" policy priorities, as India does not currently have specific commitments to abate GHG emissions, and is not expected to have such commitments in the foreseeable future. GHG emissions from rural India, certainly in per capita terms but also in absolute terms, are likely to be relatively minor in the short run. But it is important to keep in mind a longer timeframe, when "lock-in" to particular technologies and forms of electrification may result in a tighter than necessary linkage between economic development and electricity consumption one the one hand, and GHG emissions on the other (see Section 3.2.5 for further discussion).

While India has no specific obligations to reduce GHG emissions, it is in the nation's long-term interest to understand the congruence (or lack thereof) of national goals and global climate protection goals. A country of India's size, representing around one sixth of the world's population, will surely be drawn into climate policy in the long run as its development permits. Furthermore, India with its many vulnerable ecosystems and poor communities is expected to suffer significant impacts from climate change.[5]

To anticipate the conclusions of this study, we find that there is at least a case to further explore renewable energy-based rural electrification as a way to meet the four national development goals outlined above, and, unsurprisingly, it is also the clear winner from a climate point of view. A lynchpin of our argument is the likely value of renewable energy in ensuring energy security, a criterion we have added on to the government's own goals. While this conclusion rests on assumptions and judgments that are certainly open to question and comment, we have attempted to lay these assumptions out clearly. The assumptions and the ensuing analysis will, we hope, serve as the basis for a broader discussion about alternative trajectories for India's rural electrification, and specifically about the appropriate role of renewable energy.

Section 2 undertakes the task of defining reasonable demand parameters for rural electrification.

Section 3 spells out three pathways to meeting demand, and assesses these pathways against the framework of national goals and global climate goal spelled out above. Section 4 provides some concluding observations.

2. ESTIMATING RURAL DEMAND: HOW MUCH POWER TO THE PEOPLE?

How much electricity do people need? It is notoriously difficult to identify the latent demand for electricity in rural communities (ESMAP, 2000). In most cases, actual consumption is constrained by the quantity or quality of supply, as well as the ability to pay for both the power itself and the appliances that use it. This section will consider what an aspirational goal might be for a government determined to provide adequate electricity supply to its rural populations.

Between 2003 and 2005, a blizzard of ever more challenging rural electrification pronouncements and targets were put forward by two different governments. The most recent such target calls for the government to provide electricity to 78 million households—all the remaining unelectrified households—in a short five-year span; that is, by 2009 (Ministry of Power, 2005a). The description of the target in terms of households is significant, since past targets have been in terms of villages that are provided access and were based on an incomplete and misleading definition of what constitutes an electrified village (Box 2).

From a range of perspectives, the timescale applied to the targets is highly infeasible.[6] To achieve the more modest target of village electrification in five years would require connecting 20,000 villages a year—based on the definition in Box 2 (Rejikumar, 2005). This pace was achieved during the 1980s, but only according to the old, far more modest definition of village electrification. In fact, the pace has slowed down in recent years (See Figure 2). Based on the new definition, only 2,626 villages were electrified in 2002–03 and 4,589 in 2003–04. To achieve the target would require accelerating the pace by a multiple of four or five. If anything, the task is even harder at the household level. Electrifying all households by 2012 would require connecting 10 million households a year, ten times the recent pace of household electrification (Dubash, 2004). To imagine that full electrification can be achieved within this timeframe has to be regarded as framing an aspiration rather than as a realistic plan.

Box 2. Changing Definition of Village Electrification

Figures for the extent of electrification in India can be confusing. Government figures have reported 87 percent of Indian villages as being "electrified." However, this is based on the very modest definition that a village is electrified if electricity is used for *any* purpose *anywhere* in the village. In recognition that this is an inadequate definition that fails to capture whether electricity is actually being used, by whom, and how, a proposed revised definition enumerates multiple criteria that collectively would define an electrified village:

1. Basic electricity infrastructure is available within the village, including in adjoining hamlets occupied by disadvantaged groups.
2. Electricity is available in public places such as schools, the *Pandhayat* office, and health centers.
3. At least 10 percent of village households have access to electricity.
4. The voltage is sufficient to enable lighting during peak evening hours.

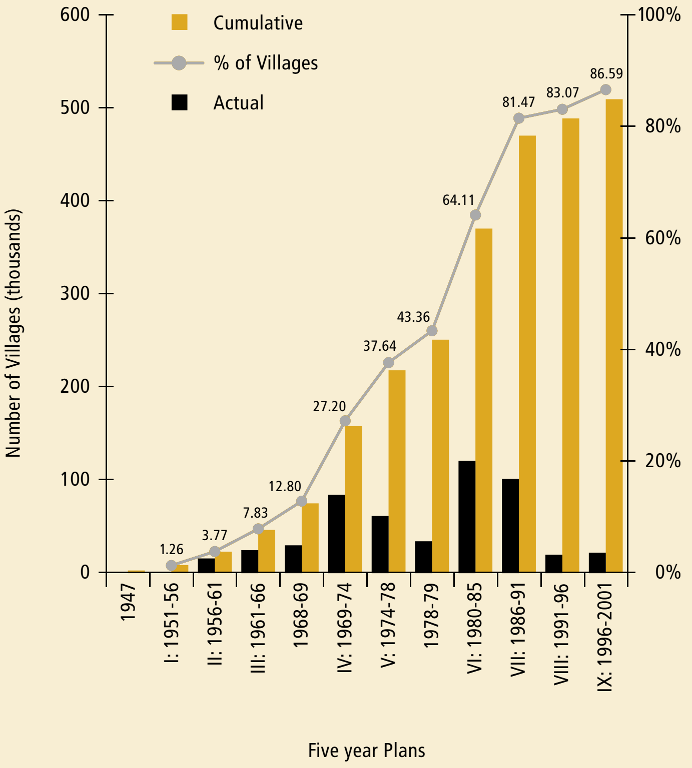
These criteria seek to articulate a definition of electrification that encompasses actual use rather than simply theoretical availability, making it a far more satisfactory definition of electrification. Moreover, the government's target for 2009 extends beyond this more ambitious definition of village electrification to aim at full household electrification.

Source: Ministry of Power (2005b)

These observations suggest that making significant progress toward meeting the government's targets will mean a quantum leap in the rate of electrification. It may equally imply a change in the approach to electrification. For the purposes of this study, we assume that 2020 is a more realistic date by which to achieve the government's targets, and will use this date in further analysis.

Connecting households is only part of the challenge; the capacity must exist to serve newly connected households. How much power will be needed to serve rural India? While demand will rise over time as households become more affluent, some near-term idea is needed for

Figure 2. Villages Electrified (Old Definition) by 5-Year Plan



Source: Sinha (2005)

planning purposes. Whether extending transmission lines or installing distributed generators, the specifications need to be as accurate as possible to avoid either frustrating demand or adding to the cost by over-engineering.

The aim of this study is not to make detailed predictions of future demand, but rather to illustrate the scale involved in meeting certain future standards of service. We have therefore made simplifying assumptions in each case, which are discussed in the remainder of this section. Village electricity consumption can be divided into three categories: (1) consumption in households, for lighting, television and other domestic appliances; (2) consumption in communal buildings, such as clinics and schools; and (3) consumption for productive applications, such as machinery and agricultural pumping.

2.1 Household demand

To what uses do rural, typically low-income, users put electricity? Electricity's first role is almost always lighting. This displaces kerosene, which is generally the first commercial (and expensive) form of energy used in poor households. Electricity provides a much higher quality light, without the problems associated with kerosene, which include indoor pollution and safety issues. Second, it allows several appliances that cannot be powered without electricity—radio, television, electric irons and refrigeration, electric fans (in hot climates), and eventually computers and associated technology and services.[7] Electricity for poor users does not replace traditional fuels for cooking and heating until a number of these high-value services have been provided. For cooking in particular, many people prefer to use traditional fuels even at quite high income levels (ESMAP, 2000; Victor, 2002).

Rural electricity demand is shaped by a range of factors, all of which are uncertain and contingent. Household income levels are one important factor. Rural households are unlikely to spend more than about 5 percent of their household budget on electricity. The cost of electricity is certainly also relevant to translating household budget figures into demand estimates. One often-used composite way of examining household use is to scrutinize households' "willingness to pay" for electricity. Willingness can be high for the first few units of electricity, which are invariably used for lighting (ESMAP, 2000). However, assumptions about the reliability and quality of supply certainly affect estimates of willingness to pay; households are hardly likely to buy electricity to power a refrigerator for two hours a day. In a climate of unreliable and subsidized electricity, demand projections are at best informed guesses.

The question of demand estimates is further confused by underlying assumptions about the efficiency of use. Rural populations ultimately care about electricity services, not the amount of electricity delivered. For example, the same amount of light could be provided by a 60-watt incandescent bulb or an 18-watt compact fluorescent bulb. The latter will rapidly pay for its higher price through savings in operating cost, and use a fraction of the electricity, although for rural populations the up-front cost can be hard to pay, even if it saves money later. Since every unit saved is at least one less unit generated, investment in end-use efficiency can be a substitute for investment in generation capacity and, in the case of grid-connected electricity, in transmission capacity as well. In the Indian context where rural electricity is loss-making, energy efficiency can also reduce utility losses. While the demand estimates derived below are based on household electricity consumption, it is important to keep in mind that in reality, effective service delivery for each unit of electricity consumed will be much higher if accompanied by a deliberate effort at enhancing end-use efficiency.

Turning to demand estimates, we start with actual demand from poor rural households that receive grid electricity. Although data from India are difficult to obtain, studies of "low demand households" in Senegal, Brazil, Indonesia, and Vietnam suggest a consumption range of 91 to 182.5 kWh per household-year (Gabler, 2004). In this study, we use the upper end of this estimate as the low-demand scenario.

The National Electricity Policy (Government of India, 2005) also prescribes a minimum of 365 kWh per household per year as a "merit good," or basic entitlement. This is two to four times higher than the actual low-demand consumption recorded from the countries noted above. This is intended as a minimum, not as a target for mean household consumption. We use the figure of 365 kWh per household-year as the medium-demand scenario for this study.

Rural electrification should aspire to more than minimal service. Victor (2004) advocates a benchmark minimum consumption of 1000 kWh per person-year (equivalent to about 5,000kWh per household-year), noting that average per capita consumption is already higher than this in 50 percent of Chinese provinces.[8] However, if heating and cooking needs (which are generally met with other fuels in India) are excluded, 250 kWh per person-year would cover the "core" electric services for which electricity is the strongly preferred or only choice. This would include such services as lighting, television and/or radio, an electric iron, and a limited amount of domestic refrigeration. Although all of these appliances are not in reach of the rural poor today, the example of China suggests that as purchasing power increases the appetite for such appliances grows rapidly. If India continues to grow at 4 to 6 percent per annum, the economy in 2020 will be 75 to 150 percent larger than in 2005. At least some of this increased wealth will likely be reflected in the consumption power of rural households. As a result, we consider 250 kWh per person-year as a reasonable aspiration for the rural electrification program, and we use this figure as a plausible high-end demand for our purposes. As Indian households average over five people,[9] a target of 250 kWh per person-year is roughly equivalent to 1,250 kWh per household-year. For comparison, a typical U.S. household consumes 25 to 40 kWh per day (Byrne et al., 1998), some 7 to 12 times more than our high-end scenario.

How many households will require electrification? In 2001, India had 137 million rural households (Census of India, 2001), of which 57 percent lack electricity (UNDP, 2003). By 2020, the number of rural households is expected to grow to 161 million.[10] Projections do not allow us to say how many of these new households will arise in areas already served by the grid and how many will require new connections. For simplicity we assume that the current ratio of 57 percent persists. By 2020, India will have to provide new grid connections or off-grid electricity supply for 57 percent of 161 million, or 91 million households. These simple calculations should be refined with more detailed future analyses; here the aim is only to establish the order of magnitude of the challenge.

2.2 Non-household demand

Aside from households, villages have two other main sources of demand.

- Public buildings, such as schools, Panchayat offices, health centers, dispensaries, and community centers.
- Water pumping: Here we consider pumped water for drinking and domestic use—not for agriculture, which is considered a productive use (see below).

Few data exist for average village requirements of these services. For the purposes of this study we use the electricity requirements of a minimal set of applications for an "electrified" village (Box 3). The one area this leaves unexamined is the use of electricity for productive purposes such as machinery.

Box 3. The "Model Village"

Under the new definition of rural electrification adopted by the Ministry of Power, a village will only be considered "electrified" if, *inter alia*: "public places like Schools, Panchayat Offices, Health Centers, Dispensaries, Community centers etc. have available power supply on demand." Additionally, power to pump water for domestic purposes (that is, not including irrigation) is an important development benefit of electrification.

Few data exist to estimate the likely addition these village public utilities will make to electricity demand. In order to get a reasonable approximation, we have made a "reasonable guess" list of applications for an average village (roughly 250 households). To estimate power consumption from specific applications, we have used a case study by NREL (1998). The applications are:

Refrigerator
Vaccine refrigerator/freezer
Lights (10)
VHF Radio (2)
Centrifuge
VCR
Vaporizer
Oxygen concentrator
Overhead fan (4)
Water pumps
TV (one big, one small)
AM/FM stereo

This includes both the essential equipment for a clinic, lighting and entertainment for a community center, and pumping for the village's domestic water demand. The total demand for these amounts to 5.47 TWh per year and is assumed to be constant across all the household demand scenarios. These communal facilities constitute between 5 and 30 percent of the electricity demand in an average-size village, depending on the household demand scenarios.

2.3 Productive use demand

A third, and vital element of electricity demand in rural villages is the use of electricity for productive applications. By far the most important of these is water pumping for agriculture, which remains the underpinning of the rural economy, but other applications include rice and flour milling, metal working, machine tools, and large-scale refrigeration.

One reason that productive use is important to these scenarios, as well as to the development of rural electrification in general, is that the growing use of electricity in households and villages presupposes a greater ability to pay for the power, and thus increasing economic growth. Much of the growth in rural economic activity will require power.

This is an area in which data are scarce and difficult to compare across states. The range of different applications and the different economic conditions in different parts of the country make it difficult to extrapolate from existing case studies.

For tractability, we base our productive demand estimate solely on the use of electric pumping for agriculture. This is by far the most significant productive use of electricity in rural areas; in states where mechanical pumps are widely used, they are a major source of energy demand. There are few studies of agricultural pumping that offer comparable data and methodologies across multiple states. The broadest of these (ESMAP, 2002) covers six of India's 25 states, although pumping data was only available for five states, and these states differ widely in their use of pumped irrigation.[11] We adopted the figures from this study as the basis for our estimates, but we avoid drawing detailed conclusions about precise demand levels.[12]

In the sample, an average of 14 percent of farming households use electric pumps, and these consume an average of 4,579 kWh of electricity each year. In addition, about 10 percent of households on average own a diesel pump for irrigation, mostly because of lack of availability of electricity. Assuming that at least half of these would switch to electricity pumps with lower running costs if the option were available, we assume that 20 percent of households are likely to own electric pumps for irrigation. Based on these assumptions, each rural household can be said to demand on average 918 kWh per year.

This estimate may be high for newly electrified areas for at least two reasons. First, investment in new wells and irrigation equipment follows the availability of electricity with a time lag. Hence the demand in newly electrified areas will take some time to build up to levels comparable to the areas surveyed by ESMAP. Second, many areas where electricity has long been available have suffered from falling water tables, which requires extracting water from greater depth and therefore higher energy demand (Dubash, 2002). Newly electrified areas will likely have more shallow water levels and lower demand per unit water consumer. To account for these factors, here we assume that electricity demand for irrigation in newly electrified areas will be about half that in areas with long-standing access to electricity, or about 457kWh/household-yr. Given the enormous variability in economic, hydrologic, and agronomic conditions across states, this estimate should be seen at best as an order-of-magnitude approximation.

In summary, Table 1 shows the average household demand predictions used for this study. None of these is intended to be predictive, but rather to provide a reasonable indication of the scale of the new demand that will have to be met.

Table 1. Summary of the Demand Scenarios

Scenario	Low Demand kWh/yr	Medium Demand kWh/yr	High Demand kWh/yr
Household Demand	182.5	365	1250
Communal Demand	34	34	34
Productive use			457
Total	**216.5**	**409**	**1741**

3. MEETING THE DEMAND

This section will consider and describe three broad approaches to satisfying demand for rural electricity:

Grid First: Extension of the grid, and expansion of on-grid generating capacity

The first scenario takes as its starting point the Ministry of Power's approach, which aims to provide electrification on the grid except where the remoteness of the community or the low population density make this infeasible. The Ministry estimates that 78 percent of the remaining village electrification can be achieved on the grid.[13] We assume that for off-grid electrification, the balance between diesel and renewable energy-based generation remains constant at today's level of 77 percent diesel and 23 percent renewable.[14]

Diesel First: Off-grid generation based on diesel

The second scenario is based on a much more rapid penetration of off-grid diesel generation in response to the removal of licensing requirements under the Electricity Act 2003. Since inexpensive diesel gensets are a readily available and well-known technology, if electricity is to be privately supplied in rural areas with minimal further government intervention, it is likely to be based on diesel technology. Indeed, there is some evidence that entrepreneurs are already operating diesel-based electricity provision in small towns as a back-up supply to the grid (Kishore, 2003). This market may well expand to larger villages before long. We assume therefore that the assumptions of the Ministry of Power are reversed, and that 78 percent of household electrification takes place off the grid. We further assume that 80 percent of this off-grid generation is based on diesel technology and the remainder on renewable energy in communities where remoteness prevents diesel supply at acceptable cost.

Renewables First: Off-grid generation based on a range of renewable energy sources

The third scenario presents an option that favors renewable energy technologies. Implicit in this scenario are policies and other measures that help jump-start the use of renewable energy in off-grid applications. The assumption for the use of off-grid generation is 78 percent, as in Diesel First. But in this instance 80 percent of the off-grid power is generated from renewable sources and only 20 percent from diesel.

Each of these cases considers a technology mix rather than an institutional or financial model for delivering the power systems. Finding and deploying such models is essential for the success of any of the technology mixes discussed in this section, but the question is beyond the scope of this report. The range of approaches is briefly discussed in Box 4.

Box 4. Institutional and Business Models for Rural Electrification

It is beyond the scope of this report to consider in detail the implementation of rural electrification projects and systems, but it is worth bearing in mind the variety of available approaches. These approaches can be broadly categorized according to two factors: (1) the amount of government involvement, and (2) the degree of centralization. Like any categorization, this risks being simplistic—for instance, the central government might apply a subsidy to equipment that is then bought and installed by individuals on a cash basis. But it is a reasonable way to look at some institutional structures.

A centralized, governmental approach involves support from either national or state governments. This support can be passive, providing subsidies, tax incentives or technical support and leaving project implementation to other actors, as in many countries. It can also be more active, with the central government a major partner in project implementation; an example is the Chinese Township Electrification Program.

India has a number of centralized governmental initiatives: the Ministry of New Energy Sources (MNES) is involved in both grid-connected and off-grid renewable energy, as well as the Rural Electrification Corporation and the Indian Renewable Energy Development Agency.

Centralized, nongovernmental actions are less prevalent in India. This category might include regional concessions, under which (sometimes in exchange for given levels of subsidy) private companies, cooperatives, or other operators are awarded the provision of electricity for everyone within their concession area. In Brazil, for instance, dispersed off-grid diesel generators are owned and operated centrally by regional concessionaires. Similar models have been applied in the United States, Argentina, and South Africa.

Decentralized, governmental models are common in many countries. Local governments, municipal councils, and panchayats often play a crucial role in either supporting electrification projects or even implementing and managing them. Many early electrification projects in China fall under this model (see Box 1).

In decentralized, nongovernmental models the main actors can be highly varied, including cooperatives, private sector entrepreneurs, and nonprofit associations. India’s Electricity Act of 2003 created significant new opportunities for this kind of structure. The opportunity has been opened up for small-scale enterprises that provide energy services. Examples include the diesel generators discussed in Box 5, but India already has some small enterprises providing renewable energy systems and mini-grid installations. Cooperatives are equally important in providing these kinds of services, both in India and elsewhere such as the United States and the Philippines.

Just as the institutional approach varies, a range of financial models are used. A surprising number of energy markets operate on a cash basis without subsidies: PV systems sales in Africa and Western China are good examples: consumers purchase equipment outright and install it themselves. In some cases consumers purchase energy equipment with low-interest financing. In other models, some companies offer lease finance, and some act as mini-utilities, owning and operating generation equipment and financing through power sales on a local level.

None of these categories is exclusive. Entrepreneurs will frequently take advantage of central government subsidies, local government initiatives may use private sector turnkey operators, and so on. The important point in India, particularly following the Electricity Act, is that we are likely to see considerably more variety in the business models employed.

Source: Based on Zerriffi & Victor (2005)

3.1 Quantitative and qualitative aspects of options

3.1.1 Grid electricity

India’s grid electricity system is in a chaotic state and seemingly defies a range of different strategies adopted over the years to fix it.[15] By 1999–2000, revenues generated by state electricity boards were 26 percent lower than their costs, and in 2000–01 accounted for 23 percent of the combined fiscal deficit of state governments (Planning Commission, 2002b).

The problem manifests itself in periodic electricity crises in state after state. A recent example is India’ s most heavily industrialized state, Maharashtra, and its commercial

capital, Mumbai. In May 2005, advertisers across Mumbai were instructed to turn off their neon billboards as a small gesture of electricity conservation (Hindustan Times, 2005). Meanwhile, its heavily industrialized hinterland was suffering rolling blackouts of 3 to 12 hours per day. Small businesses were devastated. Large ones, generally, were not; major companies increasingly generate their own power on site. As the Maharashtra experience testifies, the Indian grid system has not come close to providing quality and reliable power to citizens.

In Indian debates over rural electrification, it is commonly assumed that centralized electricity provided through the grid is the first choice, and that decentralized, or distributed, generation is suitable only for remote areas. Yet the electricity grid throughout India promises more than it delivers. According to the IEA (2002b), “the duration and number of blackouts and brownouts are beyond acceptable limits, leading to shortfalls of up to 15 percent of demand.”

The grid is also prone to losses. With technical and, more important, commercial losses (or theft) accounting for about 25 percent of generated electricity, India has one of the highest rates of electricity losses in the world (Figure 3). Indeed, recent estimates, including those by State Electricity Regulatory Commissions, suggest the actual loss levels, including theft, could be even higher, in the range of 30 to 40 percent. This means that if this dismal performance continues, to meet a rural demand of 100 terawatt hours (TWh) on the grid India would have to generate some 143 to 167 TWh.

Fixing the technical losses and quality problems in the grid will take money—after being relatively neglected in public spending, transmission now requires, though it does not receive, as much public investment as generation (IEA, 2002a; Planning Commission, 2001). Fixing the nontechnical losses, which make up the bulk of the losses from the grid, requires more fundamental reform. The greatest losses come from theft by those who have no legal electricity supply, and from farmers and others that are not billed (Ministry of Power, 2003).[16] Enforcing bill payment, charging farmers for power, and stopping physical theft are all high priorities, but politically daunting.

The necessary changes to India’s grid system need to be viewed in the political context framed by the new Electricity Act. A plausible interpretation of the likely impact of the incentives embedded in the act is that it will result in a fragmentation into four consumer classes (Prayas, 2004). First, large industrial and commercial consumers, who tend to bear high electricity costs due to a cross-subsidy to household and rural consumers, will likely gain from the benefits of shopping around for electricity and from efforts to reduce the cross-subsidy. Second, urban high consumption and wealthy consumers are likely to be taken over by dedicated urban utilities and will also be gainers. Third, existing consumers from small towns and rural areas will continue to be captive consumers, but will be starved of resources as the cross-subsidy tap is turned off. With no replacement sources of revenue, they may fall deeper into a spiral of low quality, low revenue, no investment, and bad performance leading to ever-lower revenue. The fourth category are those who are unserved; under current conditions, they are most likely to move into the third category of electrified users with declining prospects. It remains to be seen whether the effect of new market entrants, and possibly re-targeted subsidies, can alter this gloomy scenario.

It is worth looking in more detail at the third category. Across India, farmers and rural areas receive electricity at a price well below average cost, although they pay for this with poor quality electricity, often for only a few hours a day and often in the middle of the night. Nonetheless, the policy of cheap or even free power to farmers is jealously defended by politically powerful farmer lobbies. While many consider this a necessary subsidy, it is also true that the form and administration of this subsidy—through cross-subsidies rather than transparent allocations—has negative spill-over effects for the sector as a whole. For these reasons, the provision of electricity to farmers is a political hot potato in India, and for many is the single biggest obstacle in the way of reforming the power sector. Notwithstanding the rhetoric about rural electrification, many are quietly leery about a dramatic effort to expand the grid to rural areas, since it will expand the number of low-paying customers without bringing more revenue, placing an even greater fiscal burden on states (Godbole, 2002). This conundrum seldom gets openly discussed in the recent feel-good climate of India's rural electrification efforts.

3.1.2 Off-grid electricity

Given the chronic problems of grid-based electricity in India, off-grid solutions are increasingly attractive. By generating electricity close to its point of use, distributed generation eliminates transmission losses. The scope for theft may also be reduced, particularly if small-scale generation is mated with local-level distribution through panchayats or franchisees, although this proposition is yet to be tested. Finally, given the poor state of the grid, distributed generation may actually lead to more reliable and dependable supply than grid-connected supply.

The Electricity Act of 2003 opens the door to off-grid generation to a much greater extent than before. Some of the most significant changes from this viewpoint are:

- Most licensing requirements for generation are removed (the one exception is for hydropower).
- Licensing requirements are also removed for entities such as cooperatives, rural distributors, and nonprofit associations, which are allowed to directly purchase power in bulk.
- Provision of electricity to "notified" rural areas, from generation through to distribution, is allowed with no prior need for a license, opening the door to dedicated rural electricity businesses.

The term "off-grid generation" is taken here to mean any power generation that does not depend on connection to the high-voltage transmission network. This may include mini-grids set up to serve isolated communities as well as single installations to serve individual buildings, such as domestic photovoltaic systems.

A range of technologies can be used for off-grid generation. In keeping with our scenarios, here we will consider two main groups of technologies: diesel engines, and distributed renewable energy sources.

Diesel generation

Diesel generation sets are in widespread use for off-grid power around the world. They offer some important advantages:

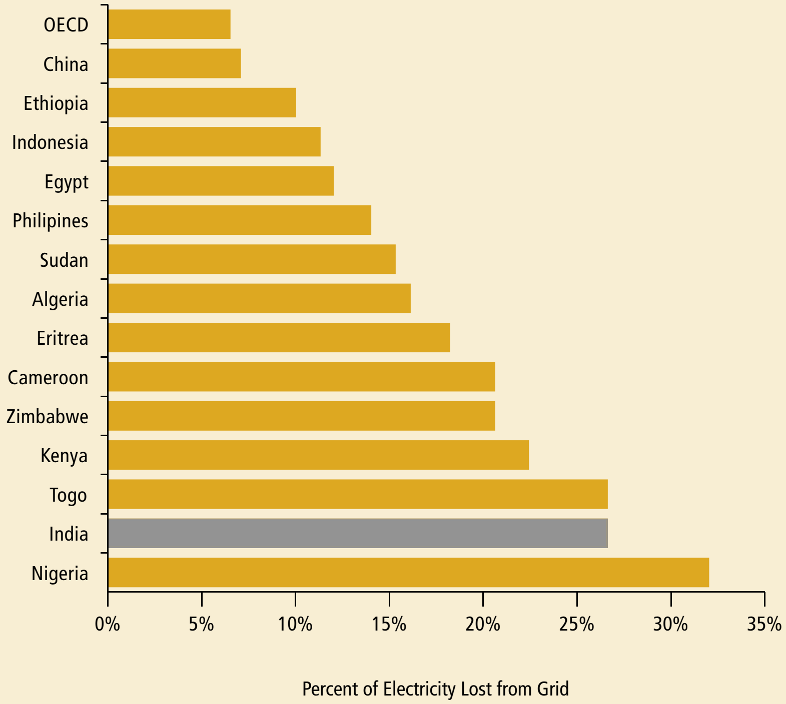
- The technology is a familiar one, with large established vendors for both the generators and the fuel.
- Compared with alternatives such a renewables, a relatively low proportion of the life cycle cost is upfront capital.
- Maintenance and repair skills are widely available in both cities and rural communities.
- They can provide high-quality AC power on demand.

To weigh against this, diesel presents a number of challenges:

- The fuel is increasingly expensive, particularly in cases where it must be transported long distances, as in much of rural India, leading to higher life-cycle costs in many cases.
- Large-scale use adds to India's growing dependency on oil imports.
- Diesel engines emit noxious fumes, as well as CO_2.

There is some preliminary evidence that small-scale diesel-based power systems are expanding rapidly in small towns, particularly in states where grid power is unreliable and poor (Box 5).

Figure 3. Losses from the Electricity Grid by Country



Source: IEA (2002b)

Box 5. The Diesel Entrepreneurs

In the small town of Muzaffarpur in the northern state of Bihar, private entrepreneurs have seized on consumer discontent as a massive business opportunity. Starting with generators purchased to supply power to parties during the "marriage season" but that otherwise lie idle, entrepreneurs have expanded to full backup and even 24-hour supply to hotels and other commercial establishments. Old generators phased out from industrial units provide a cheap and ready, if inefficient and dirty, supply of capacity. Kishore reports generators striving to capture enough of the market to reach scale. Electricity is often distributed using the poles and lines of the SEB, with SEB employees receiving a cut of the profit. There is evidence of further collusion, with private entrepreneurs paying SEB employees to keep the lights off for as long as possible to maximize their market! Prices are as high as Rs. 7 to 10 per kWh (US cents 15 to 22), more than double rates paid by households and considerably higher than commercial rates. While rural areas offer a smaller and less dense market, the rapid saturation of the small urban market could see an expansion to at least the larger villages. Muzaffarpur could be the shape of things to come in rural India.

Source: Kishore (2003)

Renewable energy

The term "renewable energy" covers a wide range of technologies and applications. Four seem particularly promising for rural electrification in India: small hydropower, wind, solar, and biomass. These will be discussed individually below, but they share several characteristics:

- They are capital-intensive, with low running costs. Relatively high capital requirements are a major obstacle in India, where finance is expensive. All except biomass have no fuel costs at all, so running costs are essentially just maintenance. While biomass does require fuel, much of this is available on a non-cash basis (see below).
- They are relatively unfamiliar technologies. While many of the technologies, particularly in the case of hydro, have existed for a long time, they tend to be less familiar and are thus seen as more risky. In addition, this lack of familiarity means that the relevant maintenance skills are less common.
- They do not rely on outside fuel supply. While perhaps obvious, this is an important advantage, especially for more remote applications.
- In some cases they are relatively benign in terms of local impacts on the environment, though some hydro and biomass use can have significant impacts.
- They produce very low GHG emissions, even considered over the whole life cycle.[17]

Renewable energy sources have tended to be more expensive on a per kilowatt hour (kWh) basis than conventional energy sources. However, technology improvement and economies of scale have brought costs down dramatically over recent decades (WEA, 2000; G8, 2001).

India may be the only country to have a ministry specifically dedicated to renewable energy promotion—the Ministry for Non-Conventional Energy Sources (MNES). Unless stated otherwise, information on renewable energy in India below is derived from MNES (2005).

Small-scale hydropower

Hydropower as a whole plays a significant role in India's electricity mix, at around 11 percent of power generation. The great majority of this comes from large dams. However, small hydropower—defined in India as installations rated at under 25 megawatts (MW)—accounts for some 1,519 MW in total, with just over 55 MW more under construction. MNES estimates an economic potential for 15,000 MW of small hydropower, and offers incentives to encourage their development. In China, about 20 percent of rural electricity is provided from small hydropower installations, amounting to 28,500 MW of installed capacity in 2002 (Tong, 2004).

Hydropower can be used to support mini-grids covering one or more villages, as well as working well at a small scale.

Biomass

Biomass can be converted to electricity with a range of technologies. These can involve gasification, charcoal production, or simple combustion. Biomass power offers a number of advantages in many parts of rural India.

First, unlike some renewable sources it does not suffer from intermittency and can therefore be used as a basis for power on demand without need for additional storage or backup technology.

Perhaps more importantly, it offers substantial advantages for rural communities, which are mainly engaged in agriculture. Most villages have a ready supply of agricultural residue that can be used as fuel, although there are complex social questions of ownership of this resource, particularly where village commons are involved. Agricultural residue can be traded on part-barter basis for electricity: an important advantage over commercial fuels in communities that are poor in cash. By adding value to rural farming, this also creates economic opportunity. The Indian Planning Commission (2002) notes that biomass has "the added advantage of potentially creating millions of rural employment opportunities and contributing to higher rural incomes, rather than higher outflows of foreign exchange."

MNES (2005) estimates the potential for power generation from fuel wood, crop residues, wood waste, and bagasse at about 19,500 MW. The Planning Commission goes further and estimates that "establishment of 40 million hectares of energy plantation would be sufficient to generate 100,000 MW of power and provide year-round employment for 30 million people." As of March 2003, India had just under 500 MW of biomass power generation capacity, so this resource is clearly at an early stage of exploitation.

Wind power

Wind energy development is a significant domestic industry in India, which is currently the world's fifth largest wind market.[18] Viable potential for power generation is estimated at around 13,000 MW (Bakshi, 2002), of which around 3,000 MW (Global Wind Energy Council, 2005) have been exploited to date both on and off the grid. Over half of the current total is in Tamil Nadu. Small systems can use battery storage to provide power on demand, but larger applications off-grid will use some combination of solar, biomass, and/or diesel to ensure a more consistent output.

One appeal of wind power is the high level of productive capacity within India. An estimated 80 percent of the value chain is located in the country, and the Indian wind industry has an annual production capacity of about 500 MW per year, including all but the largest turbine sizes (MNES, 2005).

Solar photovoltaics

PV cells, which produce DC power directly from sunlight, have an obvious appeal in a country as drenched in sunshine as India. The power they produce is relatively expensive (typically 20 to 24 US cents per kWh). However, for small-scale applications, particularly in remote areas, this becomes cost-competitive. Their lack of moving parts also means that they require little maintenance, though they do require batteries in order to deliver power on demand.

3.2 What are the impacts of the rural electrification scenarios?

Here we examine the impacts of the scenarios in terms of the four criteria discussed in section 1.4: (1) the speed at which access is provided; (2) the quality of supply, including availability, reliability, and consistency; (3) affordability or cost criteria; and (4) security of supply.

In addition, we examine the implications for GHG emissions of each scenario.

Table 2 summarizes the additional electricity consumption from rural electrification under the three scenarios.

3.2.1 Speed at which access is provided

The Indian government has set hugely ambitious goals for accelerating the rate of new electricity connections. If the timeframes recently being discussed are to be taken seriously, grid-connected electricity will face formidable challenges. These are in two areas: (1) generation, and (2) transmission and distribution (T&D).

Generation

The requirement for new generation capacity is enormous. Our scenarios suggest that grid-dominated rural electrification will require the delivery of 23 to 157 TWh of power to newly electrified rural areas. According to India's Planning Commission, capacity utilization for thermal plants is 70 percent (Planning Commission, 2002b), but rural power is "peaky" (that is, demand is concentrated in small time periods during the day), and thus capacity factors[19] are much lower. Using a rate of 30 to 50 percent, between 6 and 65 gigawatts (GW) of new

Table 2. The Three Scenarios under Different Demand Assumptions

Scenario	Grid First			Diesel First			Renewables First		
Demand	Low	Medium	High	Low	Medium	High	Low	Medium	High
Grid elec. consumption (TWh)	22	38	157	6	11	44	6	11	44
Diesel elec. consumption (TWh)	4	7	27	14	24	100	4	6	26
Renewables Consumption (TWh)	1	2	8	4	6	26	14	24	100

Note: Grid losses are assumed to fall to 20 percent. The CEA estimates that technical losses can be reduced to 10 to 15 percent. Given that this does not include losses from theft and non-billing, this means that our 20 percent estimate for total losses assumes considerable reduction in grid losses of all types.

capacity will need to be built to supply the grid. At an approximate capital cost of $1 million per MW, this means from $6 billion to $65 billion, and may be significantly higher depending on the technologies used.

Traditional generation technologies have long gestation times—three to five years for a coal-fired plant and 10 to 15 years for a hydro plant (see Table 3). Smaller-scale power plants are generally less challenging in terms of their local impacts, and require shorter lead times. Most distributed generation technologies operate on much shorter time-scales of one to two years, bringing realization of ambitious political targets closer to the bounds of reality. Transmission lines are obviously not necessary, though low-voltage distribution infrastructure may be. It is important to note that the implementation rate of generation capacity is driven by a range of factors, which may vary over time. These include the institutional capacity for delivery (which we discuss briefly below) and the ability to mobilize capital. While a full treatment of these issues is beyond the scope of this study, it is reasonable to expect that introducing new types of providers in addition to the SEBs will increase the overall institutional capacity for delivery. Although new market entrants often have a hard time accessing capital, their freedom from the chronic financial problems of the SEBs may even give them an advantage in this area.

There is a question, however, regarding whether the respective industries would be able to respond quickly enough to such a rapid increase in demand. Assuming a capacity factor of 30 to 50 percent for off-grid diesel, generating 100 TWh per year implies new installed capacity of some 23 to 38 GW by 2020, or roughly 1,500–2,500 MW per year. This is equivalent to adding 15 to 25 percent of India's present installed capacity of distributed diesel generation each year. This is significant growth, but the rapid response of entrepreneurs to the Electricity Act and the relative abundance of diesel engine suppliers give some reason to think that it is plausible.

Table 3. Typical Unit Size and Construction Time for Selected Technologies

Type	Typical unit capacity (MW)	Construction time (years)
Large Hydro	30–250	10–15
Micro Hydro	0.01–1	3–5
Coal	60–700	3–5
Gas combined cycle	100–300	1–2
Diesel	0.5–10	1–2
Wind	0.25–1	1–2

Source: Prayas (2004)

For renewable energy the picture is not quite so clear. Using a generalized load factor for renewable energy systems is difficult, since the various technologies this includes vary widely—from a typical capacity factor of 25 percent for solar PV to around 70 percent for many biomass applications (Banerjee, 2006). Assuming an average capacity factor of 30 to 40 percent, meeting demand of 100 TWh per year in 2020 would imply installing some 29 to 38 GW over 15 years, or 1,900 to 2,500 MW of off-grid renewable energy capacity per year. While this is not overwhelming in terms of the technology—Spain alone installs almost twice that amount every year—further work needs to be done to evaluate the potential to install large numbers of dispersed renewable energy projects. India has a significant domestic manufacturing base in most of the renewable energy technologies, but an expansion of this scale would almost certainly require the active involvement of international providers as well.

Transmission and distribution

India's T&D infrastructure already suffers from underinvestment, with blackouts and brownouts common across the country. Rural electrification, which by definition means less dense populations and thus greater T&D needs, may well place too much demand on India's creaking grid.

Exactly how much transmission infrastructure investment will be needed will depend on a range of factors, but we can consider the scale of the challenge with some rough calculations.

A general rule for capital investment in India's power infrastructure holds that investment in transmission and distribution should roughly equal that in generation (IEA, 2002a; Planning Commission, 2001). Assuming this ratio holds for rural electrification, and assuming an optimistic load factor of 50 percent, we would expect to see a $5 billion to $36 billion investment in T&D over 15 years in *addition* to investment needed to strengthen the grid and improve reliability in existing demand centers.

This is a tall order. For purposes of comparison, the 9th ten-year plan invested $1.2 billion in T&D over five years. Even under the lowest of our demand scenarios, India would need to maintain its recent level of T&D investment just to support rural electrification (see Figure 4)—without counting any further investment in its urban and other areas that already have some grid connection. At the high level of demand, annual investment in T&D would need to increase almost sixfold.

Based on the above, we make a qualitative appraisal of the scenarios in terms of the speed of provision of electricity (Table 4). Note that these assessments are based mainly on the capacity of the institutional and delivery frameworks in India, rather than on technology. There are some technological constraints—for instance the need for T&D

Table 4. Qualitative Assessment of the Speed of Electricity Provision under each Scenario

	Grid First	Diesel First	Renewables First
Speed	Low	High	Medium

infrastructure often adds to the time needed to provide new connections—but these are generally much less significant than those of institutional and delivery models.

3.2.2 Quality of supply, including availability, reliability and consistency

The grid-based approach is in some ways the most difficult to assess, since much depends on recent efforts to reform and fix India's grid-based supply. A grid can in principle be well-suited to the delivery of power with high levels of availability, reliability, and quality. With sufficient improvement, a grid connection offers the potential for "scalability"—that is, the ability to match increased demand with ready supply.

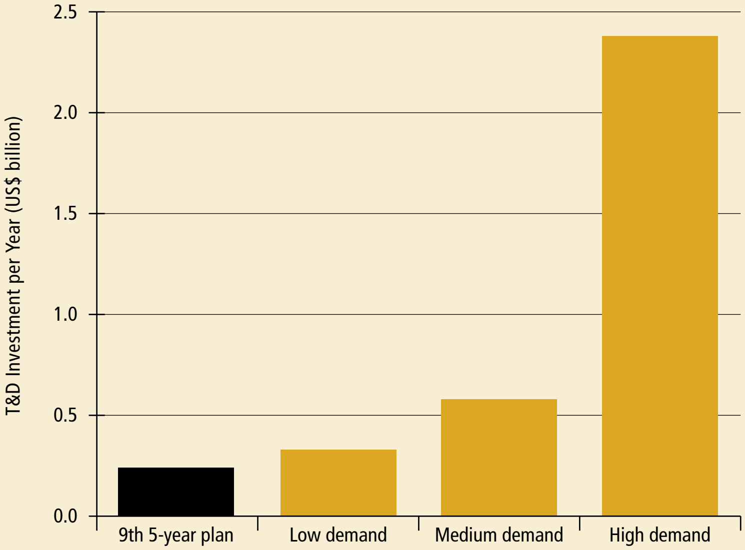
As discussed in 3.1.1, however, the obstacles that lie in the way of better grid electricity are formidable. The potential for cash-strapped SEBs to simultaneously expand connections and improve quality for the bottom two segments of the electricity market—current rural consumers and anticipated future rural consumers—is remote.

Only if serving the rural poor is no longer a loss-making proposition can this outcome be reversed. To do so will either require a steep increase in transparent subsidies from the state, or a steep increase in price, along with far greater collection efficiency. Neither seems likely. State governments are struggling to cover existing subsidies, let alone enhanced subsidies from an additional 161 million households. Since existing rural consumers are organized to prevent price hikes and are remarkably effective at avoiding collection, there is no reason to expect new, and likely poorer, users to be noticeably more pliant. These arguments suggest that for perhaps several decades, grid-based rural electrification will most likely be poor quality and unreliable electrification.

By contrast, distributed generation has the potential to break out of this cycle for at least two reasons. First, studies suggest that rural populations are willing to pay more if quality improves commensurately (World Bank, 2001). This leads to a chicken-and-egg situation, where rural users wait for service quality to increase, and the SEBs seek higher prices before investing in service quality. New distributed generation providers have the opportunity to establish greater trust and credibility than the SEBs. If they provide adequate quality and reliability, they may well be able to charge remunerative prices. Second, by introducing more knowledge of local context, decentralization in collection in conjunction with distributed generation may well help solve the collection problem. Although decentralized collection has been attempted for central grid power as well, notably in the state of Orissa, preliminary reports suggest that since the chain of command between local collection agents and the utility was unduly long, local collectors did not have the ability to provide quick solutions to local problems, undercutting the benefit of local knowledge (Mishra, no date). An integrated small-scale provider—whether using diesel or renewable technologies—would not have the same problem and may well be able to provide better service and extract a higher price.

From a technological point of view, diesel and renewable energy projects both offer potentially higher quality and reliability than the present Indian grid. However, this will depend in both cases on the existence of a sufficient workforce of competent project developers and associated experts. In general, diesel generators have the advantage of being familiar technology with a ready supply of mechanics to maintain and repair the generators. However, some field experience in China suggests that rural consumers prefer renewable energy systems for their greater reliability (Byrne et al., 1998).

Figure 4. Indicative Annual T&D Investment Needs under the Grid-Dominated Scenario Compared to the 9th 5-Year Plan



Source: Authors, based on parity with required generation investment.

Wind and solar technologies both depend on a variable resource, which adds an obvious challenge in providing a consistent and high quality supply. The solution to this problem varies with the scale of the generation. Small systems, particularly solar PV, tend to use batteries (WEA, 2000). For larger systems, to power mini-grids for instance, batteries can be uneconomic, and typically hybrid systems are used. These pair wind and/or solar technologies with diesel or biomass back-up supply. The solar and wind equipment, not requiring fuel, is used when the sun or wind is available; at other times the backup technology kicks in. Project experience suggests that well-designed systems can rely on the backup for as little as 20 percent of the power demand (Goldemberg and Johansson, 2004).

Based on the above, we make a qualitative appraisal of the scenarios in terms of quality of supply (Table 5). As in the case of speed of delivery (see preceding section) this appraisal is based on institutional factors. There is no technological reason why grid electricity should be of lower quality.

Table 5. Qualitative Assessment of the Quality of Electricity under each Scenario

	Grid First	Diesel First	Renewables First
Quality	Low	High	Medium

3.2.3 Affordability

A persistent criticism of off-grid electrification in general, and renewable energy technologies in particular, is that they deliver power at a considerably higher cost than the grid. In Cambodia, for instance, off-grid schemes charge an average tariff three times higher than that paid by customers on the grid (World Bank, 2004).

However, such comparisons can be misleading. Comparing costs on a per kWh basis between such different technologies and delivery structures as are considered here is not straightforward, since tariffs will depend on a wide range of technology factors or complex cross-subsidies. Whatever approach is used, providing electrification to dispersed rural populations is inherently more expensive than to concentrated urban populations. Conversely, urban populations are often richer than their rural counterparts. This provides a strong political rationale to subsidize rural electricity in the interest of equity.

Subsidies for grid-based technologies—which could just as feasibly be used for off-grid electrification—can be complex and hidden. Figure 5 shows the difference between the cost of providing power, the price set by the Regulatory Commission (RC), and the price after government subsidy for power to a range of sectors in the State of Andhra Pradesh.

In 2002, the average cost of supply from the grid was 3.5 rupees per kWh (7 cents), but the average tariff was 2.4 Rs (4.8 cents). The customer thus paid on average about two-thirds of the cost of supply—considerably less than this for rural customers. (Prayas, 2004).

Nor do these "cost of supply" figures properly reflect the total costs involved. The somewhat counter-intuitive figures above suggest that the cost per kWh of serving a large industrial consumer is higher than serving rural consumers—something that, if true, would stand in marked contrast to the experience in other electricity markets. The discrepancy seems to be due to the fact that commercial and industrial users require reasonably high levels of quality in the power they consume. Rural costs seem low because they reflect the cost of delivering low-quality, intermittent power. The true cost of rural electrification that meets the government's quality criteria would be far higher.

The cost estimates for off-grid sources vary widely across sources, and within each source because of location-specific factors (Table 6). Solar is the most expensive because of its significant capital investment. For this reason, it tends to be used largely for low-load applications, where it is better able to compete with other technologies. India has invested heavily in wind capacity, and has the 5th largest installed wind capacity in the world (European Wind Energy Association, 2003). Because of India's agrarian base, biomass is perhaps the most promising source for India (Pathak, 2004). Finally, diesel is the most tried and tested of the off-grid technologies. However, the cost depends considerably on the distance over which fuel has to be delivered.[20]

A first glance at Table 6 suggests that off-grid power sources deliver power at a higher price per kWh than grid power. However, this may well not be the case for at least three reasons. First, because of the heavy capital and operating subsidies for grid power, direct comparisons between these unsubsidized generation costs and subsidized grid prices are not meaningful. Second, much depends on the characteristics of the site. Variables such as remoteness (from the grid or fuel supply), availability of an appropriate renewable resource, and suitable operation and maintenance capabilities can all materially alter cost

Table 6. Indicative Prices for Off-grid Technologies

	Price per kWh (US cents)
Solar	20-94[21]
Wind	3.6-11.7[22]
Biomass	4-10[23]
Diesel	10[24]

comparisons of specific off-grid technologies with grid-based power. Third, the cost of relatively new renewable off-grid technologies, and wind energy in particular, has been steadily declining over time, and is likely to decline even further as scale economies of manufacture are realized. Over time, therefore, off-grid renewable technologies are likely to be ever more competitive (Goldemberg and Johanssen, 2004).

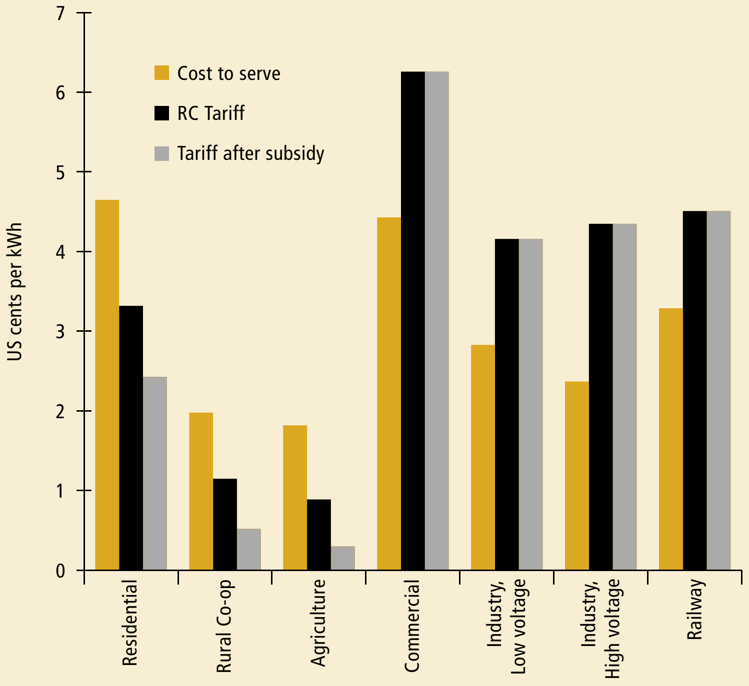
In sum, it is extremely hard to make general statements about cost comparisons across generation technologies. The economics of grid generation and transmission are extremely murky in India, and it is by no means clear that future rural users will have access to electricity at the costs that current users enjoy, especially if cost-recovery discipline is imposed in the sector. Among off-grid technologies, diesel generators are the most established, but costs depend on fuel availability and transport costs. Off-grid renewable energy sources range from high cost to costs that are competitive with grid sources, in the case of wind. In practice, there is unlikely to be a single winner from among sources. Instead, each of these technologies may be used, alone or in conjunction with other technologies (for example, wind-diesel), where conditions are ripe.

Based on this discussion, we make a qualitative appraisal of the scenarios in terms of affordability (Table 7). Note that no option is very affordable—in other words, the ability of rural households to pay for power is likely to be limited in all cases. Note also that the application of subsidies is likely to be the dominant factor in ensuring affordability, and these subsidies may be applied to any of the technology mixes considered here.

Table 7. Qualitative Assessment of the Affordability of Electricity under each Scenario

	Grid First	Diesel First	Renewables First
Affordability	Medium	Medium	Low/Medium

Figure 5. Price per kWh for Power to Various Sectors in Andhra Pradesh



Source: Prayas (2004)

3.2.4 Energy import dependence and security of supply

The phrase "security of supply" as often used conflates two distinct concerns for an energy-importing state. The first of these is import dependence. Large-scale dependence on imported fuels imposes a burden on a country's foreign currency reserves and balance of payments, and the volatility of international oil prices presents an unpredictable economic cost. This applies to all fuels that have to be imported. The second, security of supply, refers to a physical and political risk that supplies at bearable cost might become unavailable. Given the vital importance of energy supplies for all economies, the dependence on politically vulnerable or unstable regions for these supplies is worrying. This second consideration applies more to fuels such as oil and natural gas, which are generally found in less stable regions, than to coal, which comes from countries that present less political risk.

As governments become more concerned about the economic and political consequences of dependence on imports, embarking on an approach sure to increase that dependence looks imprudent. India is increasingly dependent on foreign supplies of oil, and this concern, as in many other countries, is growing.

It is not clear to what extent India would depend on importing refined diesel. At present, some diesel products are imported, though India has significant refining

Table 8. Oil and Oil Product Import Increases from the Scenarios, 2020

Scenario	Grid First			Diesel First			Renewables First		
Demand	Low	Medium	High	Low	Medium	High	Low	Medium	High
Diesel consumption (million barrels/year)	9	16	68	34	60	251	9	16	65
Percentage increase over 2003-4 imports	2%	3%	11%	6%	10%	41%	1%	3%	11%
Oil import increase (billion US$/year) at $30/barrel crude	0.4	0.7	3.1	1.5	2.7	11.3	0.4	0.7	2.9
At $70/barrel crude	0.8	1.4	5.8	2.9	5.1	21.3	0.8	1.3	5.5

capacity of its own. However, its oil resources are small and unlikely to rise significantly. Thus, the rise in diesel consumption will lead to increased imports, whether of crude oil or refined diesel. Here we assume for simplicity that the additional diesel demand is met with imports of refined diesel. As Table 8 shows, depending on the level of demand the Diesel First scenario raises India's imports by the equivalent of between 6 percent and 41 percent of those in 2003/4.[25] By contrast, the Grid First and Renewables First scenarios raise diesel imports by barely a quarter as much.

Such an increase in imports represents a significant financial burden, particularly as oil prices seem likely to remain high. Predicting oil prices is notoriously difficult, but to indicate a plausible range in Table 8 we consider the effects of the increase at crude oil prices of $30 per barrel and $70 per barrel.[26]

At $30 per barrel, the Diesel First scenario implies an increase in the import bill of $1.5 to $11.3 billion per year (depending on the assumed demand) over a 2003-04 import bill of about $17.4 billion. The Renewables First scenario (using the same oil price) raises imports by $0.4 to $2.9 billion, thus saving the country a net $0.9 to $8.4 billion per year. At $70 per barrel, this saving rises to between $2.1 and $15.8 billion. In terms of impact on oil imports there is little difference between the Grid First and Renewables First scenarios.

The import figures represent potentially significant costs. At the high end of this range (oil prices of $70 a barrel), $15.8 billion is equivalent to 90 percent of India's current import bill for oil and refined products, and 14 percent of the national external debt.[27]

In addition to the purely financial burden, another issue is the dependence on potentially volatile suppliers. While Indian refiners also buy on the spot market, their main sources of crude under term contracts are Saudi Arabia, Kuwait, UAE, and Iran (Ministry of Petroleum and Natural Gas, 2005). This concentration of suppliers in a politically volatile region leaves India more exposed to potential supply disruptions than it might wish.

Oil raises troubling dependency issues for India due to the sensitive security concerns it raises. However, coal imports may also have to rise. In the calculations presented here, we assume that the generation mix—that is, the share of the different power technologies on the grid—will remain broadly constant. However, "peaky" loads such as those in rural areas are not well served by baseload plants such as the large thermal generators in wide use in India. Hydropower and natural gas technologies are common for dealing with peak loads, but neither has large medium-term potential for expansion. This leaves the possibility that smaller coal plants will come online to deal with the more variable grid load. These smaller plants tend to be less efficient and more polluting, and will of course demand coal. India's coal industry faces major constraints in its ability to increase either production or transport of coal. However, even a doubling of India's coal output will not allow it to keep pace with spiraling projected demand for power *on the existing grid* (Planning Commission, 2002a). This raises the possibility that India, which has a large domestic coal resource, will become increasingly dependent on coal imports. This possibility is reflected in our qualitative assessment of energy security implications (Table 9).

Table 9. Qualitative Assessment of the Protection of India's Domestic Energy Security under each Scenario

	Grid First	Diesel First	Renewables First
Energy security	Medium	Low	High

Table 10. CO_2 Emissions Arising from the Scenarios

Scenario	Grid First			Diesel First			Renewables First		
Demand	Low	Medium	High	Low	Medium	High	Low	Medium	High
CO_2 emissions (Mt)	23	40	167	19	33	137	9	16	65

3.2.5 Greenhouse gases

As illustrated in Table 10, the three scenarios show marked differences in their resulting GHG emissions.

High dependency on the grid produces the highest levels of GHG emissions.[28] The Diesel First scenario produces slightly lower emissions, largely through reducing grid losses and thus lowering total generation required.

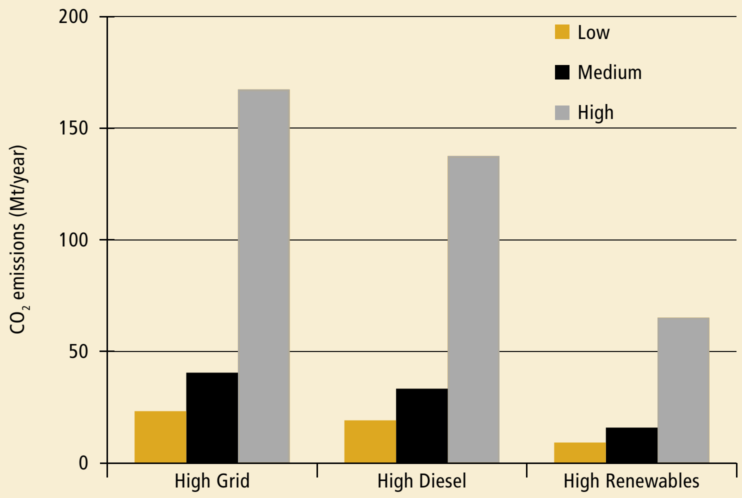
The Renewables First scenario leads to emissions roughly 60 percent lower than Grid First: a difference of 14 to 100 million metric tons of CO_2 per year depending on the demand level. The middle of this range is equivalent to almost twice as much as the yearly CO_2 emissions of Bangladesh.

The near-term significance of this impact should not be overstated. Even under the Grid First scenario, the impact of 500 million Indians gaining access to electricity for the first time leads to the equivalent of 1 to 5 percent of U.S. GHG emissions. This is hardly trivial, but it does not make rural electrification an obvious place to focus efforts at lower-carbon growth.

A potentially more important issue is the extent to which the technology and institutional choices made now will persist. For instance, high investment in grid infrastructure in the coming decade may make grid-based electricity delivery the norm and ensure the use of large, centralized thermal plants well into the future. In the case of large-scale T&D infrastructure and on-grid generation, the technologies themselves have long lifetimes. A large thermal generation plant can have a life of 50 years or more and, once the capital has been depreciated, can be hard to replace economically. Investments made now may last well into the second half of the century. This might be described as a technological, or infrastructure "lock-in."

Conversely, distributed or off-grid energy systems entail a set of institutional and business structures such as marketing, installation, maintenance, and repair networks that take time to develop. In addition, users need to accustom themselves to the idea of generating their power locally. A large-scale adoption of off-grid electricity technologies now by communities that are new power users might be expected to build a lasting set of institutional structures that will continue to facilitate the introduction of other off-grid generation in the future. Since these systems do not rely on large discrete capital investments, they allow new technologies to penetrate the market as they are developed. Thus the "lock-in" effect in this case is institutional rather than technological.

Figure 6. CO_2 Emissions under the Scenarios



Even after the heroic efforts needed to electrify all households by 2020, demand can be expected to grow substantially. There is some evidence of a substantial technological inertia in energy systems.[29] This inertial effect is an interesting area for further research, which is beyond the scope of this study. The salient point here is that the longer-term climate impacts of today's choices may be significant, and the interest in finding lower-carbon options is stronger than only the near-term emission reductions would suggest. Based on this discussion, we qualitatively score the various scenarios in Table 11.

Table 11. Qualitative Assessment of the Level of Climate Protection under each Scenario

	Grid First	Diesel First	Renewables First
Climate protection	Low	Low/Medium	High

4. CONCLUSIONS

This chapter has attempted to put some realistic contours on the task ahead for rural electrification in India, to construct three plausible pathways toward this goal, and to assess the pathways against five criteria for success—four development criteria of national interest and one global criterion of climate change. Such an exercise is intended to inform and stimulate debate rather than provide any definitive conclusions. In addition to the issues discussed here, there are important questions of institutional form of service delivery, local environmental impacts, and end-use efficiency that only receive cursory treatment here, but are deserving of further attention. Table 12 briefly summarizes the relative performance of our three scenarios against these performance criteria.

Table 12. Summary of Scenarios by Performance Criteria

Approach	Grid First	Diesel First	Renewables First
Speed of provision	Low	High	Medium
Quality of supply	Low	High	Medium
Affordability	Medium	Medium	Low/Medium
Security of supply	Medium	Low	High
Climate protection	Low	Low/Medium	High

Rural Electrification and National Development Goals

Grid-dominated rural electrification in India is likely to suffer the scars of Indian electricity's recent past. It is likely to take a long time, provide inadequate quality electricity, and while it may deliver cheaper electricity per kWh to existing users, it is not clear that the overall cost of the infrastructure involved makes this the cheapest approach. It may also exacerbate some intractable issues of coal supply.

Diesel-based electrification, helped by the Electricity Act 2003, appears to have considerable promise when viewed through the lens of speed and quality of supply. However, diesel-based electrification has one considerable flaw: it will almost certainly exacerbate India's long-term dependence on oil imports, increasing these imports in volume terms by 6 to 41 percent of current levels. This is a significant finding of the study, and potentially disqualifies diesel-based supply as the spearhead of a rural electrification strategy.

The third option, renewable energy-based supply, promises reasonable speed of installation and reasonably good quality. Both criteria are likely to be ever more comprehensively met as the technologies mature. However, in the short run renewable energy will be unlikely to provide electricity as fast as diesel and, depending on the specific technology, perhaps not as well as diesel. Compared to the other options, however, renewable energy dramatically strengthens India's energy security.

In the short run, the cost criterion is likely to have the heaviest weight in decision making. However, it is also the hardest to assess, because of differences in the technologies and the complexity of the underlying assumptions. Clearly, more detailed work needs to be done on this issue. Moreover, the discussion here suggests that a decision based on cost alone would be shortsighted. At minimum, an Integrated Resource Planning (IRP) approach that assesses the full lifecycle costs of alternatives, including end-use efficiency, and factors in real rather than subsidized prices would yield more complete results. Ideally, we suggest that considering a full range of criteria such as those described here, in addition to cost, yields valuable additional insights for policy makers to consider.

To summarize our results, we find strong reasons to doubt the success of a Grid First strategy on various criteria, notably speed and quality. It is also the most problematic from a climate perspective. A Diesel First strategy promises the best short-run outcomes, but exposes the country to a potentially crippling energy security threat. The Renewable First strategy is the most unknown, but on current evidence promises moderate results in the short run, while coming out strongest on long-term considerations such as security and climate protection.

This exercise does not anoint a clear winner, which is an argument for a more even-handed treatment across different rural electrification pathways than exists at present. Specifically, the analysis suggests there are convincing benefits to off-grid renewable energy within such an IRP approach that have not been explored in recent planning. At the moment, the Government of India's policy is based on an *a priori* judgment that renewable energy should be reserved for marginal areas where grid extension is a challenge. This runs counter to the findings of this study, which suggest that from the broader perspective of the four national development criteria examined here—speed, quality, cost, and security—renewable energy should be integral and not marginal to India's rural electrification.

Rural Electrification and Global Climate Goals

We turn now to the fifth criteria of global climate change, which we deliberately separated from the four national criteria. The decision on rural electrification should be based on national criteria; international criteria should play a role only if they can provide an additional strategic impetus for one pathway, and possible national benefits. That renewable energy is the clear winner from a climate perspective provides such an impetus. In the near-term—until 2020—GHG emissions from India's rural electrification are likely to be on the order of magnitude of 1 to 5 percent of U.S. emissions. However, the "lock-in" effect—the impact of near-term technological choices on future emissions—has the potential to contribute significantly to GHG emissions in the longer term, particularly if India's expectations of becoming a major economic power later this century are realized.

The importance of this "lock-in" will depend on the future evolution of India's power market and of energy technologies. Experience in OECD countries suggests that both generation and T&D infrastructure remains in place for many decades. Off-grid generation, which uses smaller generating units, may show less inertia. The security and climate implications of a grid-based approach may also be mitigated if on-grid renewable energy is rapidly adopted and accounts for the bulk of future growth past 2020.

Despite these imponderables, the discussion here suggests that the Government of India has an opportunity to seek international support for a more renewable energy-intensive pathway to rural electrification. To do so, the government will have to work to shape the next phase of international climate negotiations to better provide instruments for such climate friendly policy (rather than only project) choices.

To date, the Government of India has been a reluctant partner in these discussions, justifiably concerned that India might be saddled with emission limits that threaten its economic growth. But if more attention to renewable energy for rural electrification is in the national interest for domestic purposes, as this chapter suggests is possible, then Indian policy makers may be missing an opportunity to obtain broader international support for its rural electrification program. Given the potential advantages to both India's national interests and the broader concern of combating climate change, there is considerable scope to explore how—through political, technical, and financial means—India's ambitious electrification goals could be supported by sustainable development policies and measures aimed at increasing the role of distributed renewable energy.

ENDNOTES

[1] See Reddy (1999) for a larger conceptual framework within which to understand rural energy needs. See Das (2004) for a discussion of various linkages between electricity and rural development.

[2] This slowdown in pace may also be partially explained by the government's insistence, based on a very limited definition of rural electrification, that the task of village electrification is almost done, leaving only the most remote and inaccessible villages. As of March 2003, 87 percent of villages have been declared electrified (Ministry of Power, 2003).

[3] For a detailed political analysis of the 2004 general election see the collection of articles contained in the *Economic and Political Weekly*, Dec. 18, 2004.

[4] For a snapshot of the contemporary debates on rural electrification, see Ministry of Power (2003), World Bank (2004), Dubash (2004). For a discussion of institutional issues, see Rejikumar (2004) and Namashivayam et al (2004).

[5] See for instance IPCC (2001) Chapter 11.

[6] See for instance World Bank (2004).

[7] See for example Tuan and Lefevre (1996) for a breakdown of rural household demand in Vietnam.

[8] The Indian government's stated aim is to have an average available electricity supply of 1000 kWh per person by 2012, though it is reasonable to assume that this average includes higher consumption by urban individuals and lower in rural areas (Government of India, 2005).

[9] In 2001 (Census of India, 2001) India had a rural population of 737,283,492 living in 137,235,518 households, at a mean of 5.37 people per household.

[10] Population and household size projections from the United Nations Human Settlements Programme (UN-HABITAT, 2005). There is considerable uncertainty in such projections. The World Bank (2004) estimates 157 million rural households in 2012. This is broadly consistent with the UN-HABITAT projection, which has India's rural population declining from 2015 onwards as urbanization outstrips population growth.

[11] The six states are Andhra Pradesh, Himachal Pradesh, Maharashtra, Punjab, Rajasthan and West Bengal; no data was available for Himachal Pradesh.

[12] Other studies that document groundwater use and that we have used as a basis to cross-check the ESMAP study include World Bank (2001), Dubash (2002), and Dossani and Ranganathan (2004).

[13] The Ministry, using the old definition of village "electrification," estimates 80,000 villages remain to be electrified, of which 62,000 can be provided with connection to the grid (MoP, 2005c; Planning Commission, 2002a)

[14] Off-grid capacity in India today is around 13,000 MW, of which 10,000 MW is diesel and 3,000 MW is renewable energy (Banerjee, 2006).

[15] The recent literature on the Indian power sector is voluminous. See SL Rao (2004). For a comprehensive assessment of options, see Ruet (2003 and 2005). For a historical review of the political economy of the sector in the 1990s, see Dubash and Chella Rajan (2000).

[16] Recent studies suggest that agriculture consumes less than previously thought. Consequently, consumption formerly accounted for as agricultural use is most likely theft, which pushes up the real estimates of losses. For a review of studies by Electricity Regulatory Commissions, see Honihal (2004). Other studies of loss levels include Reddy and Simithra (1997), Dixit and Sant (1997), and World Bank (2001).

[17] The lifecycle GHG emissions associated with various energy technologies vary widely according to manufacture, location, and technology type. Some renewable energy sources can cause significant GHG emissions— for instance, biomass that is not replaced by new growth. However, if managed appropriately renewable energy sources have negligible lifecycle GHG emissions compared to their fossil fuel counterparts. Here we consider GHG emissions from renewable energy to be zero.

[18] By the end of the 1990s, 70 percent of wind turbines installed in India were manufactured domestically (European Wind Energy Association, 2003).

[19] Capacity factor represents the output of a plant as a proportion of what its output would have been if it had operated constantly at full capacity. Wind turbines (which only operate at full capacity when the wind is blowing at optimal speed) have relatively low capacity factors, fossil fuel and biomass relatively high. However, if the demand is highly intermittent all plants will have low capacity factors.

[20] One study of rural electrification in three western Chinese provinces found that the cost per kWh from diesel generators was $1.09 to $1.19, leading to the conclusion that in these regions renewable energy systems offered superior economic performance, without taking environmental or social benefits into account (Zhou & Byrne, 2002).

[21] The exact cost within the range depends on capital cost and load factor; range taken from Arizona Solar Center (2005), Banerjee (2006), Byrne et al (1998), Zhou & Byrne (2002).

[22] For wind regimes that allow capacity factors of 30 percent; price also varies depending on size and capital cost (Banerjee, 2006).

[23] Depending on the resource and technology (MNES, 2002). The cost is lower where there is cogeneration of heat and power.

[24] (Banerjee, 2006). This figure varies greatly depending on load factor, fuel price, and remoteness.

[25] In 2003–04 , India's net imports of crude and oil products totaled 614 million barrels, valued at $17.4 billion (MoPNG, 2005).

[26] Diesel (whether imported or domestic) costs approximately $15 per barrel more than crude. Assuming a medium-term oil price of $30 to 70 per barrel therefore, diesel costs $45 to$ 85.

[27] India's external debt in April-June 2004 was $112 billion (Ministry of Finance, 2005).

[28] This might be reduced by a decline in the emissions intensity of the electricity mix, for instance by a rising share of natural gas for power generation. Conversely, the result presented here assumes a reduction in grid losses—if this does not take place, then emissions would be higher still.

[29] See for example Lloyd (2001), who suggests that household conservatism is keeping South African users of kerosene from switching to demonstrably better alternatives.

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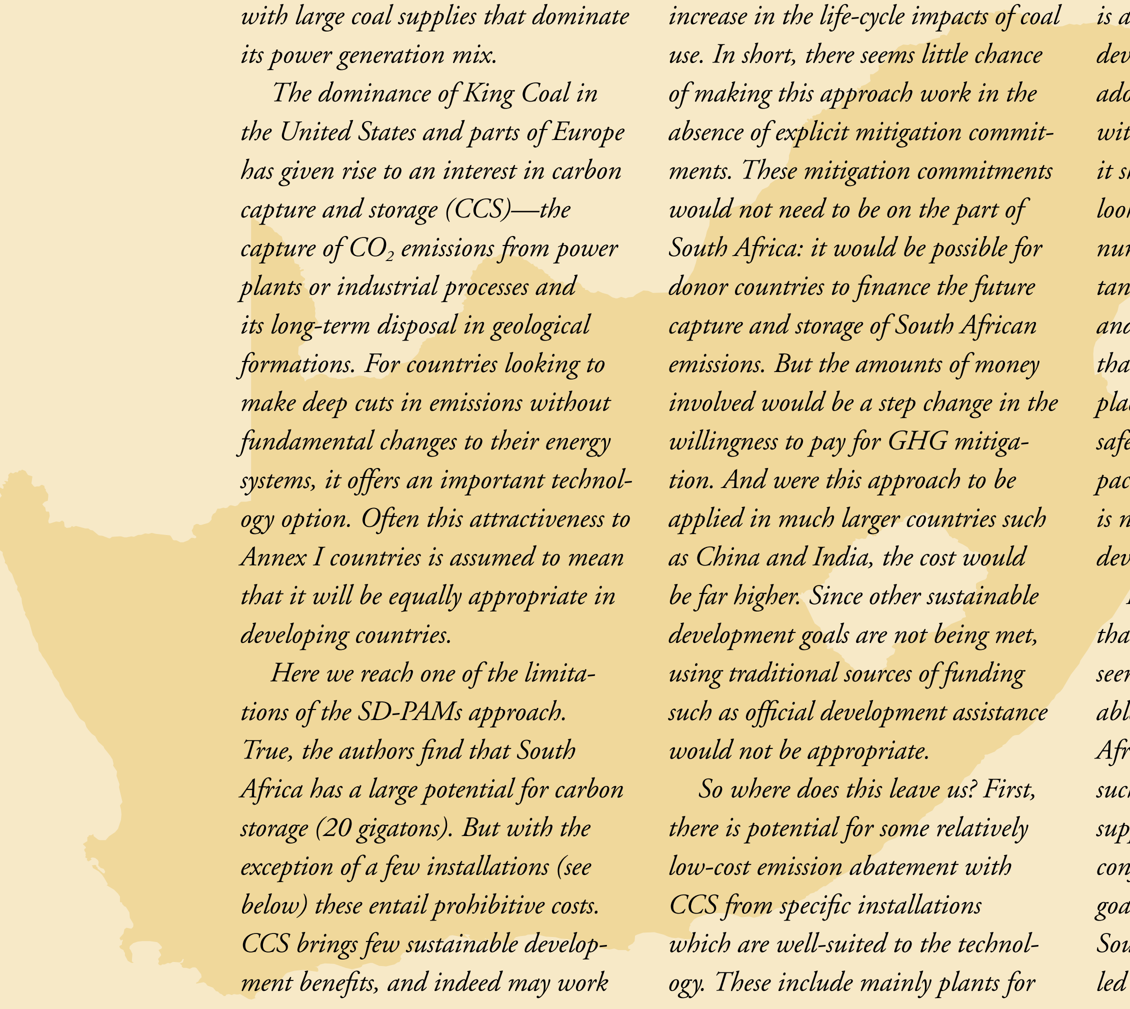
Editor's Note



South Africa has several features that it shares with countries such as India and China: it is poor but growing; it faces rising demand for energy and in particular electricity; and it is naturally endowed with large coal supplies that dominate its power generation mix.

The dominance of King Coal in the United States and parts of Europe has given rise to an interest in carbon capture and storage (CCS)—the capture of CO_2 *emissions from power plants or industrial processes and its long-term disposal in geological formations. For countries looking to make deep cuts in emissions without fundamental changes to their energy systems, it offers an important technology option. Often this attractiveness to Annex I countries is assumed to mean that it will be equally appropriate in developing countries.*

Here we reach one of the limitations of the SD-PAMs approach. True, the authors find that South Africa has a large potential for carbon storage (20 gigatons). But with the exception of a few installations (see below) these entail prohibitive costs. CCS brings few sustainable development benefits, and indeed may work against sustainable development goals. If South African resources were to be diverted towards CCS it would increase the cost of power significantly, slowing the increase in electrification (and the provision of some free power to households) that is a central aim of government policy. Although CCS may reduce some pollution from coal use by encouraging the use of more modern coal plants, it will also increase total coal demand, with a corresponding increase in the life-cycle impacts of coal use. In short, there seems little chance of making this approach work in the absence of explicit mitigation commitments. These mitigation commitments would not need to be on the part of South Africa: it would be possible for donor countries to finance the future capture and storage of South African emissions. But the amounts of money involved would be a step change in the willingness to pay for GHG mitigation. And were this approach to be applied in much larger countries such as China and India, the cost would be far higher. Since other sustainable development goals are not being met, using traditional sources of funding such as official development assistance would not be appropriate.

So where does this leave us? First, there is potential for some relatively low-cost emission abatement with CCS from specific installations which are well-suited to the technology. These include mainly plants for gasifying coal for the production of liquid fuels and synthetic chemicals—installations that may represent 30 million tons of CO_2 *per year that could be sequestered for around $20 per ton. This would not strictly be an SD-PAMs activity as it would be a "pure" mitigation measure, but is an important finding nonetheless. It is not impossible that in the future there will be sufficient international concern about runaway GHG emissions that developing countries, donor countries or both will find the resources needed to implement CCS in emerging economies. South Africa is a good example of an advanced developing country that may in time adopt CCS technologies, with or without international support, though it should be stressed that that time still looks far off. The authors identify a number of factors that mark important differences between developed and developing countries in the way that this implementation might take place, in particular in questions of safety standards and institutional capacity—though possibly South Africa is not a representative example of a developing country in this regard.*

Nevertheless, the final conclusion is that, for the time being, CCS does not seems to support the central sustainable development aims of South Africa in a way that other options such as gas and renewable energy supplies may, and CCS may even conflict with national development goals. While the dominance of coal in South Africa, China, and India has led some commentators and policymakers to put their hopes in CCS, the particular circumstances of developing countries may make other options more realistic.

CHAPTER VI

Carbon Capture and Storage in South Africa

Stanford Mwakasonda ▪ Harald Winkler

1. INTRODUCTION

Some three-quarters of South Africa's primary energy supply and 93 percent of its electricity are derived from coal (NER, 2002; DME, 2003b). Even in more optimistic energy policy scenarios (De Villiers and others, 1999; EDRC, 2003; Banks & Schäffler, 2005), coal continues to provide for the majority of South Africa's energy needs over the next 20 to 30 years. Almost 80 percent of GHG emissions come from the energy sector—both supply and use—and most of these are in the form of carbon dioxide (Van der Merwe & Scholes, 1998; RSA, 2004).

Making South Africa's energy system more sustainable is a transition that will take decades. Making energy development in South Africa more sustainable will require attention to solutions that deal with CO_2 emissions from coal. Together, these factors mean that an evaluation of the sustainability of carbon capture and storage (CCS) technologies is an important element of climate policy.

1.1 Context: climate change and sustainable development in South Africa

South Africa's development objectives have been shaped deeply by Apartheid—a history of racial oppression and patterns of economic exploitation. Apartheid systematically underdeveloped black working-class communities and left a deep legacy of backlogs of basic services in rural and urban areas. A central driver for policy since 1994 has been the redress of the imbalance of Apartheid and the promotion of the socioeconomic development of poor communities. A core document capturing the major objectives is the Reconstruction and Development Programme (RDP). However, the imperatives of reconstruction and development have been in tension with a macroeconomic framework that emphasizes economic growth as the driver of development—the Growth, Employment and Redistribution (GEAR) strategy (2002). The main feature of the vision of GEAR was a competitive fast-growing economy that creates sufficient jobs for all work-seekers. To achieve the GEAR employment goal, a minimum growth rate of 3 percent per year would have to be met.

Many of the detailed socioeconomic development objectives were set in the African National Congress' RDP (ANC, 1994). It outlined job creation through public works and meeting a range of basic needs as key priorities. Quantified goals were set for delivery of basic services, including (a) building 300,000 housing units each year for the first five years (to address a housing backlog of some 2–3 million houses); (b) redistributing 30 percent of the land; (c) providing 25 liters of water per person per day; and (d) providing electricity to 250,000 households per year (this target has actually been exceeded) (Borchers et al., 2001).

Relative to other sectors, the energy sector has performed well in meeting such targets. Significant progress has been made in extending access to electricity in particular, although affordability and productive use remain issues. Yet more remains to be done, and the challenge of delivering energy in a sustainable manner remains.

Energy makes a critical contribution to sustainable development by providing households with access to affordable energy services and contributing to economic development. However, it is important to manage the environmental impacts of energy supply and use. South Africa's national climate change response strategy, approved by the Cabinet in October 2004, is built around sustainable development; its point of departure is the achievement of national and sustainable development objectives while simultaneously responding to climate change (DEAT, 2004). Any technological option, including CCS, needs to fit within the broader South African approach to climate policy.

1.2 CCS and South Africa's commitments under UNFCCC

South Africa's climate policy is rooted in a firm commitment to the multilateral process under the United Nations Framework Convention on Climate Change (UNFCCC) and its Kyoto Protocol. South Africa is a signatory to both the UNFCCC and the Protocol.[1]

Being a signatory to the UNFCCC, South Africa has a general commitment to "implement … measures to mitigate climate change" (UNFCCC, 1992: Article 4.1b). As a non-Annex I country, however, it does not have a *quantified* emissions limitation or reduction target under the Kyoto Protocol. Nonetheless, the climate change response strategy recognizes that the country can benefit from moving to a cleaner development path. For example, one of the major objectives of the White Paper on Energy Policy is to secure the nation's energy supply through diversity (DME, 1998). The Clean Development Mechanism (CDM) and other climate funding opportunities are seen as key in driving this development. Domestic policy has also recently resulted in a voluntary renewable energy target of 10,000 GWh by 2013 (DME, 2003c).

At least in principle, CCS offers an option to use coal with lower GHG emissions than under a business-as-usual approach. Initial research into the potential of CCS (Engelbrecht et al., 2004) has focused on Sasol, the chemicals and synthetic fuels producing company, and the existence of pure CO_2 streams in the coal-to-liquids process, as the most promising option for capture. The potential to generate credits under the CDM has been highlighted: "At $10 per ton [of carbon CDM credit price], the sequestration of this 30 million tons per year could be worth $300 million per year" (Surridge, 2004). This assumes that suitable storage sites can be found at reasonable cost in environmentally acceptable conditions. A further question is how long this carbon storage avenue will exist, since Sasol is switching its feedstock from coal to gas piped from Mozambique (Poggiolini, 2001; ECON, 2004). The key sources of CO_2 in South Africa are shown in Table 1.

Any proposal to capture CO_2 for storage must take into account the fact that a number of sources—for instance, those involving transportation—are unlikely to be suited to the capture of their emissions, because they are generally too distributed. Table 1 provides the breakdown of sources of carbon dioxide in South Africa. Based on the source category technologies amenable to capture processes, the hypothetical maximum amount of capturable carbon dioxide in South Africa is about 212 Mt/a, or 58 percent of all anthropogenic CO_2 released (Lloyd, 2004). The distribution of sources is discussed further in section 3.

1.3 Purpose of this chapter

South Africa, a developing country with an energy economy dominated by coal, has potential for carbon capture and storage (CCS). Given its strong commitment to sustainable development, the country may want to understand the implications of this climate change mitigation option for local development—in its economic, social, and environmental dimensions.

South Africa is expected to remain dependent on coal for decades to come (DME, 2003a), but will increasingly be challenged to contribute to the global effort of climate change mitigation, or reducing emissions of greenhouse gases (GHGs). In this context, CCS might be attractive to South Africa's minerals and energy sector, with its high reliance on coal and the existence of pure carbon dioxide (CO_2) streams in the coal-to-liquid fuel process. Its "minerals-energy complex" (Fine & Rustomjee, 1996) has already become involved in exploring CCS[2] through participation in the Carbon Sequestration Leadership Forum (CSLF) and the Intergovernmental Panel on Climate Change (IPCC) processes. This report seeks to understand the broader implications of CCS for sustainable development, and how it compares to alternatives: CCS might make sense as pure climate policy, but how does CCS line up alongside other mitigation options with respect to development?

The report considers the political, technological, and institutional prerequisites for making CCS work in a developing country, and the discussion of its potential to become an important component of a coherent climate strategy. Given that climate policy has low priority relative to development for basic human needs, the report tries to address the question of whether (and to what extent) CCS can contribute to *local* sustainable development.

Research on CCS has been receiving much attention recently; for example, the IPCC is preparing a special report on the subject. While there has been increasing interest in CCS in the developed world, its only serious consideration in developing countries has been in locations where international energy companies are active.

Table 1. Sources of Carbon Dioxide in South Africa, 1990

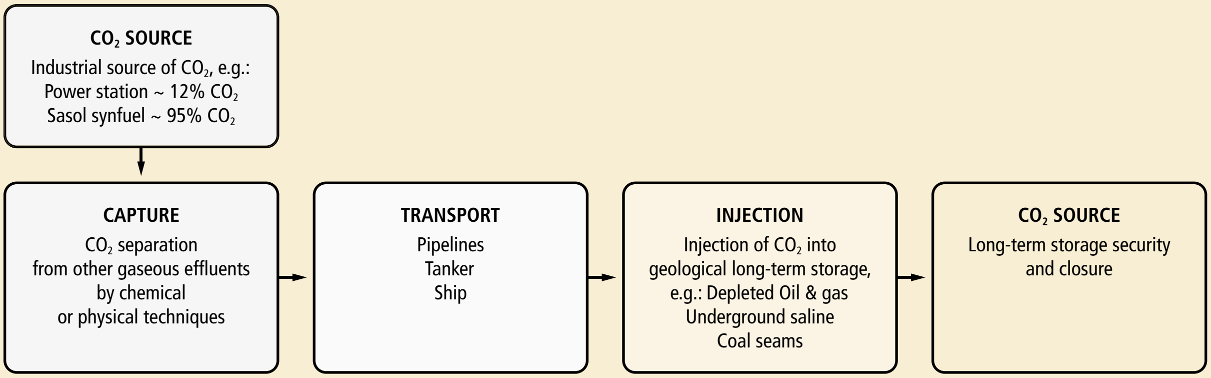
	CO_2, Mt/a		CO_2, Mt/a
Likely to be capturable		**Unlikely to be capturable**	
Electricity generation	137	Waste	9
Industry	24	Agriculture	41
Other energy production	26	Fugitive	36
Manufacturing	26	Transport	34
		Heat production	32
Total capturable	**212**	**Total non-capturable**	**152**
Total Emissions (capturable & non-capturable)	**364 Mt/a**		

Source: Lloyd (2004), drawing on Engelbrecht et al. (2004)

2. WHAT IS CARBON CAPTURE AND STORAGE

Carbon capture and storage is a technology envisaged to mitigate GHG emissions by producing a concentrated stream of CO_2 that can be transported to a storage site. It is most likely to be applicable in large centralized sources, including power plants, other energy industries (oil refineries, synthetic fuel plants), and fossil-fuel-intensive industries (iron & steel, cement, chemicals). Four stages of the process are identified in Figure 1. After initial capture of the gas, the CO_2 needs to be transported to a suitable storage site for injection. Monitoring CO_2 after injecting it into a storage area (geological formations) is important to ensure permanent storage and safety for human health and the environment.

Figure 1. Process of Carbon Capture and Storage



Source: Surridge (2004)

2.1 Carbon capture

In some existing processes, CO_2 is separated from other gases routinely, such as in natural gas processing and ammonia production (Kohl & Nielsen, 1997). In South Africa, Sasol produces pure streams of CO_2 in the process of gasifying coal.[3] These streams of CO_2 can be captured at minimal additional cost, although they still need to be transported and stored appropriately.

Alternatively, capture of CO_2 will depend on the combustion technology. There are three classes of combustion technologies under consideration. First, the oxy-fuel combustion technology, in which a hydrocarbon or carbonaceous fuel is combusted in either pure oxygen or a mixture of pure oxygen and an inert gas rather than in air (which is 79 percent nitrogen) (Lloyd, 2004). The major drawback to oxy-fuel combustion is the cost of oxygen separation.

Secondly, separation can be carried out before combustion. Pre-combustion processing of the primary fuel in a shift reaction[4] could separate CO_2 and H_2, with the former stored and the latter used as fuel. South Africa's extensive experience with gasification and re-forming for both syngas and hydrogen production have given it an excellent knowledge base from which to contribute to pre-combustion technologies generally.

Thirdly, CO_2 can be captured using post-combustion technologies. In post-combustion technology, CO_2 is separated from flue gas after the fuel has been burned (IEA GHG, 2000). The best proven technique to separate the CO_2 from flue gas is to scrub it with mono-ethanol amine (MEA) solution (Engelbrecht et al., 2004). The disadvantages of post-combustion capture are that the equipment sizes are large due to the large flue gas volumes and the low CO_2 concentration in the flue gas (10–15 percent) (Engelbrecht et al., 2004). The energy requirements of CCS reduce the efficiency of power plants, imposing an "energy penalty" (Bolland & Undrum, 1999). International reviews suggest that the efficiency of pulverized coal declines from 46 percent to 33 percent for pulverized coal and from 56 percent to 47 percent for natural gas combined cycle power plants (Lloyd, 2004). In the South African case, therefore, the large Eskom (South Africa power utility) power stations, with units on the order of 600 MWe, would not be able to retrofit proven systems for post-combustion CO_2 capture (Lloyd, 2004).

2.2 Carbon storage

Once captured, CO_2 can be kept in storage areas such as geological formations. The CO_2 can be trapped physically below impermeable rock, dissolved or ionized in groundwater, retained in pore spaces, or adsorbed onto organic matter in coal and oil shale (Hitchon, 1996). All these forms of storage have long residence times (thousands to millions of years). Possible types of storage sites include depleted oil and gas fields and deep underground formations filled with saline water.

Existing technology required to inject carbon in deep geologic formations has been developed by the oil and gas exploration industry (Bajura, 2001). Projects specifically designed to store CO_2 have started to develop experience with storage for CCS specifically, although the scale is still small relative to the future requirements. Costs are variable and are location-specific (Knauss et al., 2001). Environmental concerns relate to the permanence of the storage and the health and safety implications of possible concentrated releases in the future. Criteria for site selection include the storage capacity (related to its porosity), permeability, any physical or hydrological barriers to CO_2 storage, and the stability of the geological formation.

Oceans can also be used for carbon dioxide storage by releasing CO_2 to the deeper ocean water layers, at least 1,000 meters below sea level. Ocean storage of CO_2 is made possible by the fact that the cold deep sea waters of the oceans are unsaturated with CO_2 and therefore have a significant potential to dissolve it. Ocean storage relies on the fact that below a certain depth, CO_2 becomes "supercritical," with liquid-like densities, and being less buoyant than water, will not rise (Gunter, 2001). However, slow turnover in the ocean's layers, even at great depths, means eventual release on the timescale of centuries.

3. THE POTENTIAL FOR CCS IN SOUTH AFRICA

A report (Engelbrecht et al., 2004) by the Council for Scientific and Industrial Research, CSIR, commissioned by the Department of Minerals and Energy, made a preliminary assessment regarding the potential for CO_2 sequestration in South Africa (Surridge, 2004). Unsurprisingly, the major potential for capture lies in the major point sources of CO_2 emissions—electricity generation, synfuels (Sasol), oil refineries, and energy-intensive industries such as iron and steel, nonferrous metals, pulp and paper, and cement (Engelbrecht et al., 2004).

3.1 The potential for carbon capture in South Africa's energy sector

This first scoping report identified the Sasol coal-to-liquids process as well-suited for CO_2 sequestration. In their coal gasification process, there are reportedly CO_2 streams of 90 to 98 percent purity, meaning that minimal capture is needed (only pressurizing). Since capture costs dominate the overall costs of CCS, this is a substantial advantage (see section 4.1). Slightly lower concentrations (80 to 90 percent) are reported at Mossel Bay (Engelbrecht et al., 2004), where PetroSA generates synthetic fuel from gas.

The other potentially large source is coal-fired electricity generation, which provides 93 percent of electricity supply (NER, 2002) through the publicly owned company Eskom. However, the flue gases contain much lower concentrations of CO_2 at 10-15 percent,[5] implying that the costs of capture will be significant. Coal provides some three-quarters of total primary energy supply (DME, 2002), and industry uses large amounts of coal as the other major energy carrier next to electricity.

The electricity sector contributes almost half (47.4 percent)[6] of CO_2 emissions in South Africa (Van der Merwe & Scholes, 1998; RSA, 2004). CO_2 emissions in South Africa are concentrated in the central industrial area.

3.2 Review of potential for geological and ocean storage

3.2.1 Geological storage

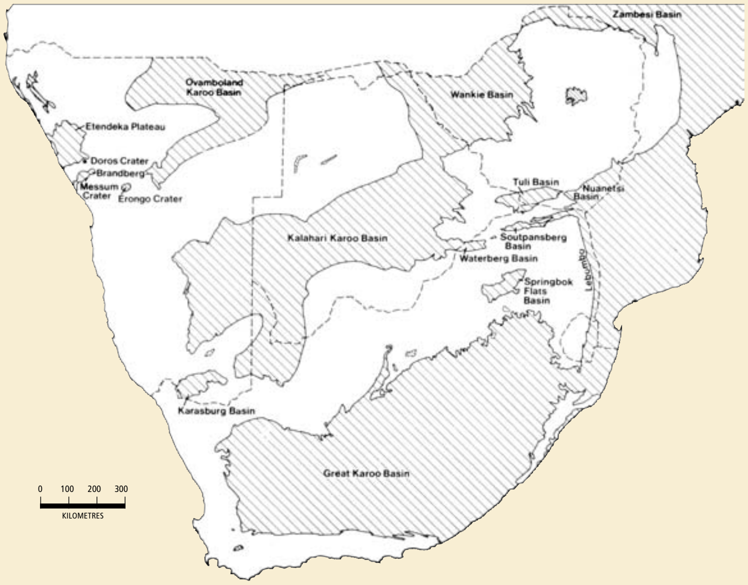
Geological sequestration of CO_2 involves the use of geological formations like depleted oil and gas reservoirs, abandoned gold mines, deep saline aquifers, or unminable coal seams. Such storage of CO_2 would involve injection into the formations after capturing it at source points. Geological gas and oil reservoirs can be ideal for CO_2 storage because the injected CO_2 can be used to restore the reservoir to its original pressure, thereby reducing the risk of possible collapse. Further, the natural sealing mechanism that retained the hydrocarbon in the first place offers a significant advantage in ensuring that the CO_2 does not escape to the surface. However, oil or gas development activities might be a potential source of risks due to reservoir fractures.

For South Africa, the potential for using depleted oil and gas fields for CO_2 storage is not significant because of the low prevalence of oil and gas activities in the country (Lloyd, 2004). In the CSIR study (Engelbrecht et al., 2004), the storage capacity of oil and gas fields in South Africa has been based on their current production rate of about 1.4 billion m^3/y. Discounting this figure by 50 percent after some allowances produces a CO_2 storage capacity of about 0.7 billion m^3/y (approximated at one million ton of CO_2 per year) at 80 bar pressure (Lloyd, 2004).

Abandoned coal and gold mines in South Africa offer another potential for CO_2 storage. Storage capacity of CO_2 in abandoned mines was based on production rates. Abandoned coal mines have previously been used as storage facilities for oil (Engelbrecht et al., 2004), but appeared to offer little CO_2 storage capacity. No figures were available when the CSIR study was conducted. For abandoned gold mines, assuming production of 390 tons of gold annually, 20 million m^3 of ore removed annually, and the number of exhausted gold mines available in South Africa, a yearly CO_2 storage figure of more than 10 million m^3 would be possible at 80 bars of pressure (Lloyd, 2004).

Another potential area of geological CO_2 storage in South Africa is deep saline reservoirs (Figure 2). The Karoo Supergroup Sediments offer the highest potential compared to other sediment zones in the country, which lack a trapping or sealing mechanism. Two major areas in the Karoo sediments are the Vryheid Formation and Katberg Formation. These two formations are relatively old and highly consolidated. The Vryheid formation has an estimated CO_2 storage capacity of 183,750 million m^3 (approximately 183,750 million tons at 80 bar pressure) (Engelbrecht et al., 2004). The CSIR study found,

Figure 2. Southern Africa's Geological Zones for CO_2 Storage



Source: Engelbrecht et al. (2004). Shaded areas are those suitable for CO_2 storage.

however, that “these sandstones are characterized by low porosity (3 to 5 percent) and poor permeability” (Engelbrecht et al., 2004). Making allowances for poor permeability of the sediments and other factors, a storage capacity figure of 18,375 million tons was estimated.

The Katberg Formation was estimated with a CO_2 potential storage capacity of 8 billion m^3. This figure was discounted to approximately 1.6 billion m^3 (1,600 million tons of CO_2 at 80 bar pressure) to allow for poor storage capacity as well as geological and other constraints.

The combined CO_2 storage capacity for the two formations, given the low porosity and permeability, comes to about 20Gt CO_2, sufficient to store virtually all the capturable CO_2 produced in the next 100 years (Lloyd, 2004).

For South Africa, it would probably be reasonable to assume a distance of about 250km between source and sink, although this would clearly depend on improved source-sink matching.

Ocean storage

Deep ocean storage is “nearly unlimited,” but South African storage potential has not been quantified, nor has that that from ocean fertilization to increase the uptake of CO_2 (Engelbrecht et al., 2004). The CSIR study concluded that “deep ocean sequestration of CO_2 is potentially possible; however, environmental and legal consequences are poorly understood.” In order to understand the potential of ocean storage of CO_2 in South Africa, one would need to study the seabed profile of submarine contours adjacent to major sources of CO_2.

Total theoretical CO_2 storage potential

Table 2 summarizes the theoretical potential geological and ocean storage for carbon dioxide sequestration in South Africa.

Table 2. Potential for Geological and Ocean CO_2 Storage in South Africa

Potential sink	Tonnage ($MtCO_2/y$)	Potential Storage Duration (years)	Comments
Oil and Gas reservoirs	1	Very long (millions of years)	There may be enhanced gas recovery
Gold mines	10 or more	Site specific	More study required
Vryheid Formation	18,373 million total	Very long (millions of years)	Relatively poor porosity and permeability, more study required
Katberg Formation	1,600 million total	Very long (millions of years)	Relatively poor porosity and permeability, more study required
Deep ocean (Atlantic and Indian)	Nearly unlimited	Several hundred years	Deep ocean ecosystems poorly understood; impacts of CO_2 a potential cause for concern

Source: Engelbrecht et al. (2004)

Table 2 shows that South Africa has potentially large geological storage, particularly in saline reservoirs. The potential for CO_2 sequestration in exhausted gas fields at Mossel Bay needs more study, also because it may enhance gas recovery. There is also a potential to use exhausted gold mines for CO_2 sequestration, but this area needs more study as mining activities might have reduced the sealing effect for carbon storage. On geological formation storage, it appears that the porosity and permeability is rather low, but the potential for CO_2 sequestration is large and therefore further study is required.

Ocean storage in the country is potentially large, but quantified estimates are unknown. Ocean storage also raises environmental and legal issues that have led to widespread opposition internationally, and to the suspension of some high-profile research activities.

4. CCS AND SUSTAINABLE DEVELOPMENT

CCS needs to be assessed against the various dimensions of sustainable development. The indicators used by the Designated National Authority for the CDM in South Africa are shown in Table 3. Sustainable development is defined in three dimensions—ecological, economic, and social. The ecological dimension considers impacts on local environmental quality, natural resource use, and impacts on ecosystems. Economics considers not only cost, foreign exchange, and local economic development, but also includes appropriate technology transfer. The detail of the social indicators reveals an emphasis on delivery of services at a local community level and the alleviation of poverty.

While no set of indicators is perfect, the indicators reflect the broad priorities of the RDP outlined in section 1.1. Not only are these particular indicators used operationally in mitigation projects in South Africa, but they were informed by some stakeholder consultation. In our analysis the implications of CCS for sustainable development are evaluated very simply, as positive, negative, or neutral. Key impacts have been highlighted in bold.

The key positive implications for CCS are the reduction of GHG emissions, making production cleaner, and introducing new technology. The need to import significant components of new technology (and the negative impact on foreign exchange requirements) offsets the latter benefit. Negative implications that stand out are the increased cost of energy and other services. The economic, social, and environmental implications of CCS are described in more detail in the following sections.

Table 3. Review of CCS and Sustainable Development in South Africa

Criterion	Indicator	Reference to CCS	Positive or negative contribution to local sustainable development
Ecological			
Impact on local environmental quality	• Will the project increase air pollution in the area?	No	**Positive**
	• Will the project increase water pollution in the area?	Possible	Negative
	• Will the project increase solid waste in the area?	No	Positive
	• Will the project have any other negative environmental impacts (such as noise, safety, property, value, visual impacts, traffic)?	Possible, in case of pipeline construction, abrupt leakage	Negative
Change in usage of natural resources	• Will the project reduce community access to resources?	No	Positive
	• Will the project increase the sustainability of usage of water, minerals, or other nonrenewable natural resources?	No	Negative
	• Will the project achieve more efficient resource utilization?	Not applicable	Neutral
Impacts on biodiversity and ecosystems	• Will the project result in a loss of local or regional biodiversity?	Possible	Negative
Economic			
Economic impacts	• Will the project substantially increase foreign exchange requirements?	Yes	**Negative**
	• Will the project have a negative impact on existing economic activity in the area?	Unlikely	Neutral
	• Will the project increase the cost of energy?	Yes	**Negative**
Appropriate technology transfer	• Will the project result in the introduction of appropriate technology into South Africa?	Yes	**Positive**
	• Will the project result in local skills development?	Yes	Positive
	• Will the project provide demonstration & replication potential?	Limited	Positive
	• Will the project incorporate cleaner production technology?	Yes	**Positive**
Social			
Alignment with national, provincial, and local development priorities	• Will the project undermine other government objectives?	No	Positive
	• Will the project increase the cost of other services?	Yes	**Negative**
	• Will the project result in relocation of communities?	Possible, in case of pipelines	Negative
	• Will the project provide infrastructure or essential services to the area (such as increased access to energy)?	No	Negative
	• Will the project complement other development objectives in the area?	No	Negative
	• Will the project contribute to a specific sectoral objective? Example: to increase access to renewable energy.	No	Negative
Social equity and poverty alleviation	• Will the project result in the creation of jobs? (provide details as above)	Possible, high skills	Positive
	• Will the project provide any social amenities to the community in which it is situated?	Unlikely	Neutral
	• Will the project contribute to the development of a previously underdeveloped area?	No	Negative

Source: Adapted from those published by the Designated National Authority, DME (2004). Key positive or negative impacts are highlighted in bold.

4.1 Economic

4.1.1 Comparing CCS to alternative mitigation options

Compared to alternative mitigation options, the initial costs for CCS storage technologies are likely to be high, with expectations of a decrease when they become more widespread and popular. This is the general trend for all new technologies. It has been argued that CCS, compared to most other mitigation or sequestration projects, does not offer other sustainable development benefits, apart from the reduction of GHGs in the atmosphere. The sustainable development aspect will be discussed in a later section.

CCS technology transfer elements become relevant to South Africa when considering the envisaged development of the natural gas industry. South Africa has small reserves of natural gas and coalbed methane—not enough to justify an extensive pipeline infrastructure. The existing pipeline system links Gauteng, Durban, and Secunda, where Sasol plants are located. An extensive pipeline infrastructure will be necessary to access gas fields in neighboring countries, including Angola, Namibia, and Mozambique. Angola has large gas fields; in the future, gas could be piped to South Africa from there. Since CO_2 transport by pipeline has similarities to that of natural gas, this is where the relevance of CCS technology transfer comes into play. Similarities include the need for pipeline construction that is not intrusive to communities, as well as issues like safety, efficiency of pipeline operations, and improving telecommunications and computer systems for monitoring and remote control of pipelines. Other areas include developing tools and technologies that detect areas of potential deterioration from dents, corrosion, metal loss, and pipeline cracks.

4.1.2 International cost estimates and first South African estimates

CCS would clearly impose additional costs for Eskom's generation of electricity or producing synfuel at Sasol. The other cost components relate to transport and storage costs. There have been few attempts to quantify monitoring costs in existing studies.

International cost estimates

With no local CCS experience, most of the studies are based on international experience. Table 4 shows increased costs of electricity in the United States. With post-combustion capture, the increase in electricity cost to capture CO_2 is 87 percent. For integrated gasification-combined-cycle (IGCC) plants with pre-combustion capture, the increase in electricity cost is 52 percent. For in-combustion capture, the cost increase is estimated at 34 percent. For South Africa, some initial indications of the cost *patterns* in South Africa emerge (Lloyd, 2004).

Costs of CCS in coal-to-liquids plant and industry

The lowest costs for capture are those where there are already high concentrations of carbon dioxide present. In the case of pure CO_2 streams, such as those available at Sasol's Secunda plant and PetroSA, there are only compression costs. Since capture costs typically dominate total costs of CCS, these options are being investigated for their potential (Surridge, 2004). Furthermore, a number of industrial processes such as iron and steel and cement probably lend themselves to low-cost capture (Lloyd, 2004).

Costs for CCS from electricity generation

For post-combustion systems on new 300–500 MW units of electric generating capacity, the capital cost is likely to increase by 65 to 90 percent. The cost of electricity sent out increases by 60 to 85 percent, and the cost of CO_2 emissions avoided is \$40 to \$55 per ton (\$/t). Retrofitting increases these further by about 10 percent; that is, the cost of CO_2 emissions avoided is about \$45 to \$60/t. These costs are similar for both coal-fired and natural-gas-fired stations, although the natural-gas-fired stations report somewhat lower costs, particularly in the combined-cycle mode (Lloyd, 2004).

In the case of new IGCC power stations, CO_2 recovery adds about 20 to 60 percent to the sent-out power cost and gives a CO_2 emissions-avoided cost of between \$15 and \$40/t. Retrofitting an existing power station with an IGCC is about 20 percent cheaper than retrofitting the same station with post-combustion capture.

It is unlikely that the lowest cost option, pre-combustion, can be available for at least 10 to 15 years, as most new generating capacity will probably be conventional powdered fuel combustion, for which, even on new stations, a cost penalty of at least \$40/t CO_2 avoided is likely.

For post-combustion carbon capture on operating plants, current generation produces about 190 $MtCO_2$ annually in producing about 190 TWh (Lloyd & Trikam, 2004). Present electricity prices are about R150,000/GWh. The cost penalty for capturing one ton CO_2 would

Table 4. Cost of CO_2 Capture in the United States

Capture technology	Technology status	Electricity cost		Capture cost US\$/ton CO_2	Total cost US\$/ton CO_2	Increase in electricity cost (%)
		USc/kWh	US\$/ton$^+CO_2$			
Post-combustion	Current	3.1	30.3	26.4	56.8	87
Pre-combustion	Demo plants	4.2	41.2	21.5	62.7	52
In-combustion	Pilot plants*	3.5	34.3	11.7	46.0	34

* Estimated cost.

$^+$ Electricity cost based on CO_2 emitted.

Source: Engelbrecht (2004) (Citing Canmet Energy Technology Centre.)

be about \$40, or R265—a 175 percent increase in present prices. Thus post-combustion capture of CO_2 from the generation industry does not seem likely for many years (Lloyd, 2004).

Transport costs

Transport of CO_2 is the second major step in the process, as shown in Figure 1. After initial capture of the gas, the CO_2 needs to be transported to a suitable storage site for injection.

The technology to transport CO_2 is well-developed and fully proven. Typically it involves drying the gas and ensuring it meets the required composition (typically >95 percent CO_2 and <5ppm water); compressing the gas to above 6 Mpa (a pressure similar to that used to transport natural gas); and passing it down a pipeline (Lloyd, 2004).

Costs of transport of the CO_2 from the point of capture to the point of storage are difficult to estimate, as they are determined by the tonnage being transported and the distance between source and sink. Assuming a distance of about 250km between source and sink in South Africa, from Figure 4, this would suggest a transport cost of around \$1.50/t CO_2 transported (Lloyd, 2004).

Storage costs

Storage costs are difficult to determine in the absence of site-specific information, but it seems reasonable to suppose that, given the rather impermeable nature of much of South Africa's sedimentary rocks, the costs would be at the upper end of those found elsewhere, that is, about \$10/t CO_2.

Overall costs of CCS

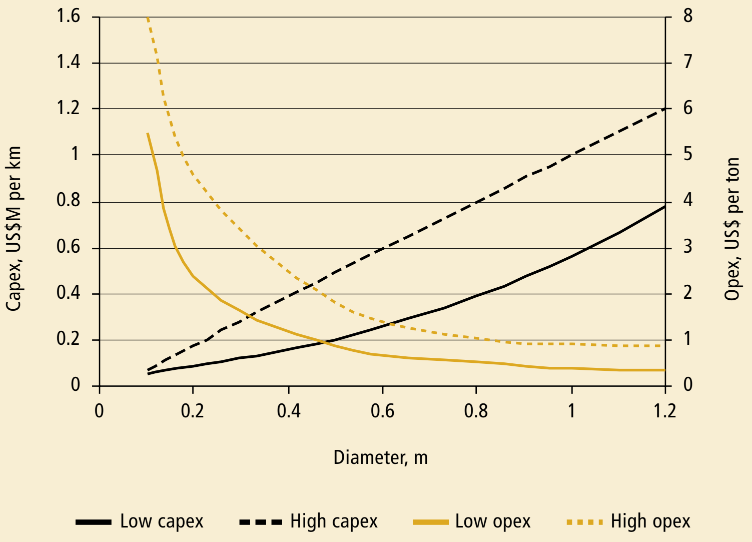
The *patterns* of likely costs of CCS in South Africa are broadly apparent. Even without knowing exact costs, it is apparent that the Sasol plant would be the most cost-effective, since it avoids the largest portion of costs, namely capture. Important gaps remain in understanding the costs of monitoring CO_2 to ensure it remains stored in geological formations or under the ocean.

The costs of capture, transport, and storage have to be added together to provide the overall costs of CCS, even before monitoring costs are quantified. Given the range of costs for different aspects, there is no single cost for CCS as a mitigation option.

As shown in Table 4, capture costs are the largest component of total costs. Pre-combustion options in the iron and steel and cement sectors may provide further options, at total costs around \$20/t CO_2. Costs of carbon capture in electricity generation, the largest source of CO_2 in South Africa, are still much higher than current market prices of carbon (around \$5 to \$10/t CO_2). New plants would add \$50 to \$65/t CO_2 (capture plus storage costs), which is high. This would more than double electricity prices, and therefore does not seem likely for quite some time.

In sum, therefore, it seems entirely possible that as much as 20 percent of South Africa's capturable CO_2 emissions, or 12 percent of its total emissions, could be captured, transported and stored for about \$70/t, based on maximum cost estimates. These are important figures, because a 12 percent reduction in emissions is large in comparison with the reductions accepted by the countries in Annex I to the Kyoto Protocol, and because \$70/t CO_2 is between fourteen and seven times the price offered for CDM and JI credits at present. The carbon emissions credits being traded at present are the low-hanging fruit, where simple benefits are being bought cheaply, but it is still unlikely that in the long run the price of carbon will rise closer to the level at which significant quantities can be captured and stored. However, the coal-to-liquid, iron & steel, and cement industries offer a better chance for carbon credits, since in this area capture costs are signifi-

Figure 4. **Ranges of Capital and Operating Costs for High-pressure CO_2 Pipelines (based on distance of 250 km)**



Source: Engelbrecht et al. (2004)

Table 5. **Summary of Cost Estimates for Carbon Capture and Storage**

	Cost estimates	Considerations
Capture		
Coal-to-liquid plants	Very low	Very pure CO_2 stream, only compression costs
Iron & steel, cement	< \$10/t CO_2	
Electricity – new plant	\$40-55/t CO_2	Similar for pulverised coal and simple gas; less for natural gas combined cycle
Retro-fit	\$45-60/t CO_2	Adds about 10%
IGCC	\$15-40/t CO_2	Not likely in SA for the next couple of decades
Transport	\$1.50 per 250 km	Cost rises with distance of storage site from sources; best storage options may be outside of SA or in ocean
Storage	\$10/t CO_2	
Monitoring		Not quantified yet

cantly lower, at a maximum of \$10/t CO_2 (Table 5). This implies a total of \$20/t for capturing, transportation, and storage. This is low compared to the \$70/t given above, but still out of range of the current carbon price of \$5 to \$10/t CO_2.

4.2 Social

The social benefits of CCS in South Africa can be viewed in terms of the government priorities in the area of social development and standard of living. Generically, CCS is an option in addressing climate change issues, an initiative with global dimensions. The social benefits that will accrue to South Africa as a result of following this sequestration option are principally the same as those that would result in any other initiative to reduce CO_2 in the atmosphere. At ground level, however, CCS has the disadvantage that it does not have direct social benefits to communities, which may be the case in other climate change mitigation or sequestration projects that would have some or all the ingredients of CDM projects.

For South Africa, where government policy has sought to keep increases in retail electricity prices below inflation, increased prices due to CCS would add significant pressure on social delivery. In the next few years, as new power stations will be needed, the price of electricity is expected to rise anyway. Adding CCS would add to the cost burden. If implemented, special measures to protect poor households from such increases would be needed. Currently, the government has a policy on providing free electricity to the poor, an initiative called "poverty tariff" in which a range of 20 to 50 Kwh per month of free electricity is provided to poor households.

Co-benefits for local sustainable development

The aspirational goals of the RDP (see section 1.1) serve to illustrate the importance of socioeconomic development, conceived around delivery of basic services, in the broader context of South African policy. While the status of RDP has become uncertain and lives in tension with macroeconomic policy, these overall development objectives continue to provide an important context for energy policy as well.

CCS poses a conflict in terms of energy policy. On the one hand, it offers a potential to reduce the environmental impacts of coal, particularly in the synfuel industry. On the other hand, at current costs (see section 4.1), implementing CCS would raise prices of electricity and liquid fuels. *Affordable* access to modern energy services is an important energy policy objective (DME, 2004, 1998). The success in raising rates of electrification of households from about one-third in the early 1990s to 67.9 percent by 2002 (NER, 2002) was made possible in part by cheap coal-fired generating capacity. Given that alternative supply options are not yet cost-competitive with coal-fired power, there is a tension between the goals of universal access to electricity and moving toward a cleaner fuel mix.

As shown in Table 3, the key area where CCS, in accordance with sustainable development criteria for South Africa, plays a significant role is in the area of technology transfer. Direct social benefits to communities are quite low. As a mitigation option focused exclusively on climate change, CCS would need to be motivated only on the basis of the global benefits accrued from the reduction of CO_2 in the atmosphere. Impacts on environmental quality, equity, and poverty alleviation are mixed, some positive and negative.

The key negative impact appears likely to be socio-economic. At current prices in the carbon market, the revenues from selling carbon credits would not be sufficient to offset the costs of CCS. If a CCS program were to be reviewed under the dual advantages typical of CDM projects, then it would be quite unlikely to get government approval, since it offers little in terms of direct local or even regional benefits. In fact, CCS is likely to be seen as a disadvantage to communities since, as shown above, they can result in increased costs of energy services. Presumably, the cost of CCS will eventually be relayed to the energy service customers. It is possible, however, that customers could be cushioned from such added operation costs if CCS projects were to be eligible for CDM. This might require making some allowances in the sustainable development criteria for CCS CDM projects to be approved.

CCS might play a role in slowing the transition of South Africa's energy economy to a more diverse fuel mix. Coal accounts for about three-quarters of total primary energy supply in South Africa (DME, 2002), and 93 percent of electricity generation (NER, 2002). In the context of the climate change debate, a key energy development objective has to be borne in mind—increasing access to affordable energy services. This policy goal has assumed the status of a "non-negotiable" issue in South Africa energy policy. However, if extending access to electricity continues to rely on coal-fired generation capacity, the environmental implications are considerable. Concerns about job losses in both the electricity and coal mining sectors are additional arguments in favor of a gradual transition to a lower-carbon energy economy, although these should be weighed against the employment potential of other options (AGAMA, 2003). CCS might mitigate the GHG effects on continued use of coal, and hence dilute motivation for diversion to other energy sources in addition to coal.

This argument raises a number of other issues concerning the implications of a global CCS. Would it mean a continuation or a business-as-usual scenario for CO_2-emitting technologies simply because there is a huge potential for capturing and storing the emitted CO_2? Would it be at the cost of other carbon-saving technologies like renewable energy? South Africa's sustainable development criteria put significant weight on social issues like job availability. A CCS initiative that maintains the status quo of the coal industry in terms of exports and job availability might find considerable favor among decision makers in South Africa.

Institutional capacity

A solid institutional framework in South Africa would be necessary for effective implementation of CCS mitigation options. The environmental implications of CCS and infrastructure requirements will necessitate key players becoming involved. For example, organizations dealing with environmental monitoring and regulation of pipelines may need to be strengthened.

Where pipeline transportation infrastructure is in place, then issues of access by different players to the pipeline network would have to be considered, just as in natural gas pipeline transportation. The same issues would be relevant to CO_2 storage area access. A decision would have to be made to either use existing regulatory organs, such as the Gas Regulator, and redefine its mandate. Further functions would need to be integrated into a National Energy Regulatory Authority, which is expected to combine electricity, gas, and petroleum regulators in South Africa within five years.

South Africa would probably have the institutional capacity to implement a CCS project. However, CCS would still present new areas in which capacity development would be required. An important concern is whether

there would be sufficient capacity to monitor and/or independently verify the long-term storage of CCS. These institutional issues are likely to have implications for the overall cost of implementing CCS initiatives in SA.

It will also be necessary to enact legislation that will not only explicitly consider transportation and storage of CO_2, but also consider liability and environmental requirements. The Department of Environmental Affairs and Tourism (DEAT) and the Department of Minerals and Energy (DME) would naturally be important players.

4.3 Environmental and safety concerns

Safety issues

Carbon dioxide occurs naturally in the air; at atmospheric concentrations, it is nontoxic. Being a nonflammable gas, the most probable concern for humans, plants and animals would be exposure to high concentrations of carbon dioxide. With CCS, risks from CO_2 would occur where there is the possibility of high concentrations due to leakage, either acute or long-term, or due to the forms in which it would be transported or stored. In the atmosphere, the concentration of CO_2 is around 0.3 percent. At high concentration, above 10 percent, CO_2 is quite lethal, causing death due to asphyxiation. It is 1.5 times as dense as air, and if atmospheric oxygen is displaced such that oxygen concentration is 15 to 16 percent, signs of asphyxia will be noted. If CO_2 leaks into surface soils, displacement of oxygen can be lethal for plant life.

In most cases, CO_2 would be handled under high pressure, whether in transportation or storage. The safety risks here would mainly be those associated with process, structural engineering, or transport infrastructure failure. Some intermediate storage of CO_2 will be needed to cope with variability in supply, transport, and storage, particularly if CO_2 is transported by rail, road, or ship. The highest exposure is likely to result from failure of transport pipelines, causing a large release of CO_2 in gaseous form. It is possible that such releases could endanger human life and other biodiversity. The risk of problems from pipe leakage is very small; to minimize risks, CO_2 pipelines could be routed away from large population centers. Generally speaking, handling of CO_2 should be relatively safe, especially when we consider that other potentially hazardous gases such as natural gas, ethylene, and LPG are already being transported and stored with relatively few problems.

An extreme example of the hazards of CO_2 is that of Lake Nyos, a volcanic crater lake in Cameroon, which emitted large quantities (estimated at 80 million cubic meters) of CO_2, causing 1,700 deaths and loss of livestock up to 25km from the crater (Johnston and Santillo, 2002).

This natural phenomenon, while illustrative of the dangers of high concentrations of CO_2 in low-lying areas, is unlikely to be reflective of the risks posed by CCS.

While aboveground equipment for handling CO_2 would be subject to the same processes and standards for handling gaseous products under high pressure, monitoring of CO_2 levels would still be important. This can be done by placing sensors at selected locations that would measure the amount of CO_2 in the atmosphere. The monitoring systems should be able to sound an alarm siren if CO_2 gas concentrations in the air around large volume storage points reach dangerous levels. For people living near CCS infrastructure, it would be critically important to provide awareness-raising programs regarding possible hazards and how to respond to hazardous situations.

Geological storage concerns

With geological reservoirs, the assumption is generally made that such formations have held hydrocarbons or liquids for considerable durations of time, and thus injection of CO_2 into the reservoirs and properly sealing them is likely to maintain the original conditions. However, the pressure at which CO_2 would be stored in the reservoirs would be an important factor to consider, albeit in maintaining similar conditions as the case might have been before depletion of gas or oil. Injection of natural gas into depleted oil or gas fields is a common practice in the petroleum industry, and a number of oil and gas reservoirs have been successfully used to store natural gas. CO_2 storage would therefore present a similar practice, and experience on natural gas storage can provide a useful example for development of CO_2 storage in oil and gas reservoirs.

With abandoned gold or coal mines, however, more attention would be needed, since mining processes in this case usually involved use of explosive and other equipment that causes considerable vibrations. Mines in South Africa have created areas of seismic activity associated with mining processes. There is thus a strong likelihood that subsidence will have induced fractures in the rocks, which would create a poor sealing of the rock and a possible route for CO_2 to escape to the atmosphere by slow leakage or abrupt eruption.

Research, development, and demonstration projects examining environmental concerns of CO_2 storage are under way in Canada, Europe, and Japan. There are still a lot of uncertainties and informational gaps related to ocean and geological storage of CO_2. The environmental concerns of CCS would thus need to include an understanding of both exposure and effects of carbon dioxide in various situations associated with carbon dioxide transportation, injection into storage points, or leakage from storage points.

5. CONCLUSION

It is clear that South Africa has a potential for CCS. The major potential for capture lies in the major point sources of CO_2 emissions—electricity generation, synfuels, oil refineries, and energy-intensive industries such as iron and steel, nonferrous metals, pulp and paper, and cement. The highest quantified storage potential is in geological formations. There is limited storage potential in abandoned mines, ocean storage, and in oil and gas fields. Major issues of concern include porosity and permeability of the geological formations, as well as environmental, safety, and legal issues.

In pursuing the CCS initiative in South Africa, major obstacles include the high cost of capture and storage, which would increase the cost of energy services. The benefits from international carbon trade are highly unlikely to offset the costs of CCS, even in the long run. In terms of South Africa's sustainable development criteria, CCS could have a number of positive elements, the most outstanding being technology transfer. Social benefits appear to be quite low.

CCS, in the context of South Africa's climate change strategy, could be part of an agenda to facilitate the transition from a coal-dependent energy system to a more diversified one, making the coal "cleaner," but there is a need to conduct further studies on how CCS compares to other mitigation and sequestration options in terms of costs and long-term sustainable development benefits.

ENDNOTES

[1] SA ratified the UNFCCC in August 1997 and the Kyoto Protocol in 2003.

[2] The Department of Minerals & Energy and Eskom participate in the CSLF's policy group. The participants in the technical group are from Sasol and AngloCoal (Surridge, 2004). Together with other researchers, Eskom and Sasol are also involved in the preparation of the IPCC special report on CCS.

[3] Sasol is, however, switching feedstock from coal to gas over a period of time; a gas pipeline from Mozambique started to deliver gas in February 2004.

[4] React the fuel with oxygen or steam, create syngas (CO and H_2); shift reaction to CO_2 and H_2; CO_2 separated by chemical absorption.

[5] The range depends inter alia on load factors, excess air supply and similar factors; some measurements have been conducted by Lloyd & Trikam (2004).

[6] CO_2 emissions dominate South Africa's total GHG emissions. Electricity CO_2 emissions constituted 37 percent of total GHG emissions in the 1994 inventory. However, since this report considers capture of CO_2 rather than other GHGs, the comparison to total CO_2 is the relevant one.

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CHAPTER VII

Conclusion

Rob Bradley ■ Jonathan Pershing

Sustainable development policies and measures (SD-PAMs) are at once both an old and a new idea. While the Climate Change Convention lays out the basic contours of the concept, it is only recently that concrete proposals have emerged that explain how to integrate basic development needs with climate protection. This report reviews the SD-PAMs concepts, evaluates how they fit into a formal greenhouse gas (GHG) mitigation framework, and reviews specific cases of how the concepts apply in the real world. It makes clear that we can move from concept to reality, and that SD-PAMs can indeed be a stepping stone to a better climate future

Climate policy in the real world

The SD-PAMs approach has a number of potential shortcomings, which will be summarized below, but it has one overriding virtue: it roots climate policy in practical reality. A fuller engagement of key developing countries in emerging climate policy is by no means a sufficient condition for stronger climate protection—the leadership of industrialized countries remains essential—but it is a necessary one.

The fact remains that most developing countries are unlikely to accept commitments formulated as emissions limits for the foreseeable future. Their reasons for doing so are not arbitrary or unreasonable, but are again rooted in their own realities—large populations in need of economic development. It is only by keeping the focus on development that we can start to leverage the major climate gains that are achievable by steering that development down a more sustainable path. The task in front of those that believe that GHG emission reductions are important for the future well-being of humanity is to make these cuts a political priority. This means looking outside the narrow confines of the traditional climate policy arena, which lacks political prominence relative to energy services, transportation infrastructure, and other issues more directly connected to economic development and poverty alleviation.

This report argues that in some important cases policy and technology options exist to help limit emissions while furthering these development goals. Brazil's experience has shown that determined government policy can make major difference to the energy mix, and thus to GHG emissions. Brazil has benefited enormously in non-climate terms from its ethanol use: its external debt would be $100 billion higher if it had relied exclusively on gasoline for transport, as almost all other countries have done.

Not all climate policies have a counterpart in development needs. As the case studies in this report show, some initiatives—carbon capture and storage (CCS) is a good example—are unlikely to work under this model. In essence, the sustainable development benefits of a policy or measure, seen from the point of view of the host country, need to provide a significant (though not necessarily complete) part of the reason to implement it. The climate benefits may be reason for the international community to assist to an appropriate degree. Where these sustainable development benefits are small or zero, more traditional measures aimed exclusively at paying the incremental cost of carbon abatement are more appropriate. This reinforces the point that SD-PAMs will complement, rather than replace, existing mechanisms. SD-PAMs are not a panacea, but an additional tool of climate policy.

The potential climate gains are real

The country studies presented in this volume illustrate the potential for major reductions in GHG emissions, depending on the development choices made. These are generally made without climate considerations playing a role. However, where climate and domestic goals are mutually reinforcing there is real potential for international cooperation to enhance both sets of goals.

Brazil's biofuels program has saved the equivalent of 10 percent of Brazil's CO_2 emissions over the period 1975-2004 due to displaced oil consumption. This saving, equivalent to taking *all* of Sweden's cars off the road during that time, was achieved without climate protection being an overt aim, but is nevertheless one of the world's most effective policy regimes for reducing GHG emissions. The studies in this volume suggest that considerable scope exists for similar "incidental" climate wins. The China study (Chapter 4), calculates that a suite of policies and measures aimed at managing oil demand can reduce China's forecasted oil demand for transport in 2020 by 50 percent below a business-as-usual scenario. When policies to reduce the stress on overcrowded urban infrastructure are added, this saving rises to 79%. And while the effective reduction in CO_2 emissions in 2020 would be of 187 and 295 $MtCO_2$ per year respectively under these scenarios, this benefit would be entirely independent of climate policy per se. For China the policy goals are to reduce oil import demand and stress on overburdened urban infrastructure, while improving mobility for the masses.

The examples in this volume are illustrative, chosen because they addressed important sectors and development issues. The power and transport sectors are among the fastest growing in each of the countries included in this report, and among the most critical for development. More needs to be done to identify opportunities for applying these lessons more widely, and for a more systematic method of identifying SD-PAM opportunities. But a crucial requirement will remain the leadership of the host country itself in identifying its policy priorities and providing the political will to implement them.

SD-PAMs build on, rather than replace, existing policy

The UNFCCC, the Kyoto Protocol, and the plethora of implementing measures by Parties represent a substantial investment in climate policy. For many Parties this will remain the core of future policy: for countries that have accepted the need to reduce their emissions as an explicit policy goal, emission caps combined with trading and project mechanisms represent an efficient and effective means of implementing this goal. SD-PAMs, by helping to engage countries that are not yet ready to undertake explicit emissions commitments, complements these mechanisms.

Particularly important in this context will be the relationship between SD-PAMs and the Clean Development Mechanism (CDM). Both developing countries (hoping for more investment) and industrialized countries (looking for lower emission abatement costs) have placed great hopes on the CDM. The CDM has demonstrated some effectiveness in finding low-cost abatement options, but there are limits to the potential for such a project mechanism to make the policy-based, systemic changes considered in this volume. SD-PAMs thus fill a void, rather than competing directly with the CDM.

A strength of SD-PAMs is that they also build on existing development policy in each country. In developing countries, climate change as such has little standing as a political priority, while development objectives suitable for SD-PAMs have much greater prominence for policymakers. In the case of India, discussed in Chapter 5, the authors derive their electrification scenarios from the Indian government's own priorities. Their study demonstrates that even when discussing alternative ways of meeting a predefined policy goal, the choices made can have profound impacts on both national development and emission levels.

While they start from existing policy objectives, the purpose of SD-PAMs is of course to achieve more, in both climate and development terms, than might have been done otherwise. "Achieving more" can take a number of forms. Building on the case of Brazil's ethanol program, which has been a considerable success, future SD-PAMs could lead to more countries adopting similar approaches. In the Chinese case the government is already taking initial steps towards improving the efficiency of its transport systems. Here "achieving more" with SD-PAMs might focus on pushing that process faster and further. In some cases, such as the Indian example, international institutions or other donors may have a role in improving access to capital for renewable energy programs. In others, such as the markets for biofuels and efficient cars, it is rather a question of pooling developed and developing country efforts. The key in each case is to start with the existing development priority, and seek to add to it elements that both more effectively address that issue and that also reduce emissions.

Financing remains a problem, but SD-PAMs offer the potential to move beyond a battle over "climate change money"

If money for SD-PAMs is not to come (primarily) from generating emission reduction credits, then where will it come from? This question is bound to be near the top of any negotiator's list. The crucial, unresolved issue is that, to date, the funds that Parties are willing to commit to fighting climate change are out of all proportion to the scale of the challenge. Resources put to emissions reductions amount at best to a few billions dollars; too little to transform the $16 *trillion* of (largely private) capital needed in the energy sector over the next 25 years (IEA, 2004). To date, no proposal with significant traction in negotiations comes close to generating the resources needed. The important question therefore is how to influence existing financial flows. The Global Environment Facility, established under the UNFCCC as the mechanism to provide for the incremental costs of climate mitigation, provided less than $2 billion from 1991–2004 (UNFCCC, 2004). Overseas Development Assistance, while considerably larger, is not likely to be enough: total resources in 2003 were only $69 billion, and little of this goes to climate protection efforts (World Bank, 2005). Private sector financial flows are considerably higher: net flows of equity and foreign direct investment were $192 billion in 2004 (World Bank, 2005), heavily concentrated in large countries such as those considered here. Export credit agencies leverage substantial parts of these private financial flows—some $81 billion of investment flows in 2003 were supported with investment insurance or export credit insurance—and these are subject to the policy constraints of the lending countries (Harmon et al., 2005).

A vital point to remember is that the role of international support and investment can only be to help leverage the far greater domestic investment flows. In all the four countries we consider in this volume, domestic capital is overwhelmingly dominant in energy and transport sector investment. Thus the commitment of the host country government and the implementation of domestic policies and measures are the key factors for the success of an SD-PAM.

SD-PAMs by no means provide a full answer to the problem of providing finance for cleaner energy on the scale needed, but then nothing does. The question is whether an SD-PAMs approach makes it more or less likely that these resources can be leveraged. In this volume we argue that SD-PAMs improve the outlook for resources for two reasons.

First, by integrating climate considerations into what are generally (for the host country) larger development concerns, it aims more to improve the climate performance of existing investment flows than to generate new funds. This is a major advantage: experience under the UNFCCC gives little cause for optimism that funds aimed at climate mitigation will be large enough. By aiming at broader development efforts, SD-PAMs offer at least the potential to leverage both domestic and international investment flows. The case of carbon capture and storage is one for which little such leveraging will be possible, and thus major new resources would have to be provided for an exclusively climate-related benefit. In the Indian example however, rural electrification is inevitably going to be financed from domestic sources. The role of SD-PAMs can be to make a renewable energy approach—already attractive for domestic policy reasons—the first choice for Indian policymakers.

Second, and perhaps more importantly, countries are more likely to provide funds for a known policy or technology objective. Numerous proposals posit an emission trading regime in which developing countries take growth targets, such that developed countries make large-scale financial transfers of purchase emission rights. The notion that rich-world governments (and voters) will provide such a blank check is one that, in the words of Thomas Schelling (2002), "requires a sense of humor to appreciate." Experience with development assistance suggests rather that countries will be more willing to put resources into activities that can be mutually agreed with the recipient.

It is important to stress that supporting SD-PAMs need not be exclusively about financial flows. To take one example, developed and developing countries might collaborate in promoting biofuels through a combination of trade agreements, sharing intellectual property, collaborating on research and development and other such measures, as well as straightforward financial support where appropriate. One "free" encouragement for SD-PAMs is recognition. Though this might seem trivial, the acknowledgement of the efforts being made in developing countries will do much to debunk the myth that industrialized countries are shouldering the burden of mitigation alone.

How might SD-PAMs be established?

Chapter 2 discusses ways in which SD-PAMs might be pledged or agreed. An important question is whether SD-PAMs will be negotiated, with an effort by Parties to ensure that they are each taking a mutually acceptable level of effort; or simply pledged, with each Party presenting its own SD-PAM proposals as it sees fit. In practice the distinction between these approaches may not be so clear-cut. First, the possibility of sectoral agreements, particularly in industries exposed to significant international trade, means that some types of SD-PAMs may require more negotiation than others. Second, some groups of countries with similar national circumstances might choose to negotiate similar SD-PAMs to more efficiently meet their goals—for instance, establishing a renewable energy market, or developing and deploying new technology. Third, an SD-PAM may entail a mutual commitment, for instance engaging a donor to provide assistance to a developing country, on condition that certain policy conditions are met.

The eclectic nature of SD-PAMs, and the fact that they are shaped by the sustainable development priorities of the host country, means that they are difficult to compare, and no attempt is made here to describe a standard of comparison. An important distinction between SD-PAMs and most other forms of climate commitment is that the country undertakes to implement certain policies and measures, not to meet a specific target or result. The commitment is not expressed in terms of emission reductions.

Unlike emissions targets, which at least in principle can be set so as to entail a "comparable effort" between countries (or, just as important, to create that impression), comparing effort in the case of SD-PAMs is highly subjective. There can be no simple formula, and the SD-PAMs approach will likely entail some level of mutual scrutiny and negotiation among Parties. However, various fora exist for reviewing and evaluating the efficacy of such policies. Analogs exist in the realm of trade negotiations, in the context regional organizations (such as the OECD), and within the World Bank. Additional opportunities exist to expand discussions within the international climate change framework.

While an agreement on an SD-PAMs framework is likely to be challenging, it may be substantially more plausible than alternative negotiations involving emissions or intensity targets, which are problematic for developing countries and which present tricky framing problems. Rather than foment perennial North-South acrimony, SD-PAMs have the potential to open up new space for international cooperation on climate change and sustainable development, including cooperative funding arrangements, harmonized actions at the sector level, and unique country-specific approaches that are reflective of different national circumstances.

The way forward

This report seeks to further develop the SD-PAMs concept, but it is by no means definitive. Several issues need further investigation including:

- The application of SD-PAMs in sectors other than power and transport. Agriculture, water management, forestry and building efficiency are all areas central to development priorities that also offer large potentials for emission reductions.
- Elaboration on the link between SD-PAMs and energy security. It is noteworthy that energy security has emerged as an important issue in every case evaluated in this volume, and offers obvious scope for international cooperation.
- Further examination of financing of SD-PAMs, and how mutual commitments might work in practice.
- Interaction between SD-PAMs and other instruments, particularly the project mechanisms such as the CDM.

The world is in sore need of some way to jointly engage developed and developing countries more constructively to tackle the twin (and intertwined) challenges of promoting human development and preventing dangerous climate change. The evolving concept of SD-PAMs may just provide that opportunity.

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Glossary and Abbreviations

Note: All tons are metric tons. Unless otherwise noted, all dollars are U.S. dollars.

Annex I Countries
The industrialized and transition countries listed in this Annex to the Climate Convention. These countries include Australia, Austria, Belarus, Belgium, Bulgaria, Canada, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, Netherlands, New Zealand, Norway, Poland, Portugal, Romania, Russia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom, United States of America.

Bagasse
The refuse of sugar cane; the crushed outer stalk material that remains after the juice is extracted.

Biofuel
A renewable energy source that includes any fuel derived from recently living organisms or their byproducts.

CCS
Carbon Capture and Storage. The capture, separation and compression of carbon dioxide from fuel combustion, industrial processes or natural gas, and its permanent removal from the atmosphere by injection into a geological formation.

CDM
Clean Development Mechanism. A project-based emissions trading system under the Kyoto Protocol that allows industrialized countries to use emission reduction credits from projects in developing countries that both reduce greenhouse gas emissions and promote sustainable development.

Climate Change Convention.
See UNFCCC.

CO_2
Carbon dioxide. A naturally occurring gas that is also a byproduct of burning fossil fuels and biomass, other industrial processes, and land-use changes. CO_2 is the principal anthropogenic greenhouse gas affecting the Earth's temperature.

CO_2 equivalent
The amount of CO_2 by weight emitted into the atmosphere that would produce the same estimated radiative forcing as a given weight of another GHG. Carbon dioxide equivalents are computed by multiplying the weight of the gas being measured (for example, methane) by its estimated global warming potential (see GWP). One unit of carbon is equivalent to 3.664 units of carbon dioxide.

Coal
Includes primary coal products (for example, hard coal and lignite) and derived fuels such as patent fuel, coke oven coke, gas coke, BKB, coke oven gas, and blast furnace gas. Peat is also included in this category.

Developed Countries
See Annex I Countries. Where noted, the term "developing countries" instead denotes the collective member states of the OECD.

Developing Countries
Those countries not designated in Annex I of the Convention. See Annex I. This group, as used in this report, includes some countries that may be considered industrialized or transitional.

EIA
Energy Information Administration. An independent statistical agency of the U.S. Department of Energy. See: http://www.eia.doe.gov.

Energy Use (Consumption)
Energy use refers to apparent consumption, which is equal to indigenous production plus imports and stock changes, minus exports and fuels supplied to ships and aircraft engaged in international transport. Energy use may also be referred to as energy supply.

Energy Production
Production of primary energy; that is, petroleum (crude oil, natural gas liquids, and oil from nonconventional sources), natural gas, solid fuels (coal, lignite, and other derived fuels), and combustible renewables and waste as well as primary electricity production (nuclear, hydro, renewables). Production is usually converted into units of oil equivalents.

EPA
U.S. Environmental Protection Agency. See: http://www.epa.gov.

Ethanol
A clean-burning, high-octane fuel that is produced from renewable sources such as corn, sugar cane, wheat, barley, or potatoes and can be mixed with unleaded gasoline for motor fuel. Ethanol is grain alcohol, produced by the fermentation and distillation of the feedstock.

EU
European Union. Includes either 15 member states (EU-15) or 25 member states (EU-25). For a listing of member countries, see http://cait.wri.org/cait.php?page=notes&chapt=4.

FAO
Food and Agricultural Organization of the United Nations.
See: http://www.fao.org.

Fossil Fuels
Natural resources, such as coal, oil and natural gas, containing hydrocarbons. The burning of these resources feeds industrial development and fuels motor vehicles but also contributes to the emission of carbon dioxide into the atmosphere.

GDP
Gross Domestic Product. The total value of goods and services produced by labor and property located in a given country.

GHG
Greenhouse Gas. Any gas that absorbs and re-emits infrared radiation into the atmosphere. The main greenhouse gases include water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

IEA
International Energy Agency. See: http://www.iea.org.

Industrialized Countries
Those countries designated in Annex II of the Convention; namely, members of the OECD, but excluding Mexico and South Korea. See OECD.

IPCC
Intergovernmental Panel on Climate Change. An organization established in 1988 by the World Meteorological Organization and the United Nations Environment Programme. It conducts rigorous surveys of the worldwide technical and scientific literature and publishes assessment reports widely recognized as the most credible existing sources on climate change.

Kyoto Protocol
An international agreement adopted by Parties to the Climate Convention in Kyoto, Japan, in December 1997. The Protocol entered into force in 2005. See: http://unfccc.int.

$MtCO_2$
Million metric tons of carbon dioxide equivalent. This measure can aggregate different GHGs into a single measure, using global warming potentials (see GWP). One unit of carbon is equivalent to 3.664 units of carbon dioxide. MtC denotes one million tons of carbon, or 3.664 $MtCO_2$.

Non-Annex I Countries
Those countries that are not listed in Annex I of the Climate Change Convention (see Annex I Parties). This group consists primarily of developing countries. For a listing of members, see: http://cait.wri.org/cait.php?page=notes&chapt=4.

Natural Gas
A gaseous mixture of hydrocarbon compounds, consisting mainly of methane.

OECD
Organisation for Economic Co-operation and Development. An international organization consisting of the major industrialized countries. Member states include: Australia, Austria, Belgium, Canada, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, South Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. See: http://www.oecd.org.

OPEC
Organization of Petroleum Exporting Countries. An international organization made up of oil-producing countries that aim to influence world oil prices. Member states include: Algeria, Indonesia, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, the United Arab Emirates, and Venezuela. See: http://www.opec.org.

Oil
A mixture of hydrocarbons usually existing in the liquid state in natural underground pools or reservoirs.

PPP. Purchasing Power Parity. An international dollar “currency” for GDP that has the same purchasing power over local GDP as a U.S. dollar has in the United States.

Reserves (or proved reserves)
Estimated quantities of energy sources that analysis of geologic and engineering data demonstrates with reasonable certainty are recoverable under existing economic and operating conditions. The location, quantity, and grade of the energy source are usually considered to be well established in such reserves.

SD-PAMs
Sustainable Development Policies and Measures. An approach to climate protection that builds on sustainable development priorities.

UNFCCC
United Nations Framework Convention on Climate Change (Climate Convention, or Convention). A treaty signed at the 1992 Earth Summit in Rio de Janeiro to which nearly all countries of the world have joined. See: http://unfccc.int.

WRI
World Resources Institute. See: http://www.wri.org.

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About WRI

World Resources Institute is an environmental research and policy organization that creates solutions to protect the Earth and improve people's lives.

Our work is concentrated on achieving progress toward four key goals:

- Protect Earth's living systems
- Increase access to information
- Create sustainable enterprise and opportunity
- Reverse global warming

Our strength is our ability to catalyze permanent change through partnerships that implement innovative, incentive-based solutions that are founded upon hard, objective data. We know that harnessing the power of markets will ensure real, not cosmetic, change.

We are an independent, non-partisan organization. Yet, we work closely with governments, the private sector, and civil society groups around the world, because that guarantees ownership of solutions and yields far greater impact than any other way of operating.