ENERGY AND ENVIRONMENT SCENARIOS FOR SENEGAL

May 1993

Michael Lazarus
Stockholm Environment Institute-Boston (SEI-B)
11 Arlington Street, Boston, MA, USA, 02116-3411
Fax: (1) 617-266-8303

Souleymane Diallo

and

Youba Sokona
Environment and Development in the Third World (ENDA-TM), Dakar
54, rue Carnot, Dakar, Senegal
Fax: (221) 22-26-95

Acknowledgements: The authors wish to thank the United Nations Environment Programme and the International Development Research Center for their financial support, and Libasse Ba, Dominique Revet, and David von Hippel for their assistance.

In Africa, continued development depends upon resolving energy-environmental questions. Rapid changes occurring in both rural and urban areas will affect generations to come. Land clearing for agriculture and energy has both local environmental impacts as well as potential global climate impacts. The rapid expansion of urban areas is changing energy use patterns as more people come into the cash economy and modern, commercial fuels begin to displace traditional fuels. When they occur, these so-called *energy transitions* will have significant effects on air, water, and soils. Currently, great opportunities exist for directing energy use and production patterns to minimize long-term economic and social costs. To this end, the Stockholm Environment Institute (SEI) and Environment and Development in the Third World (ENDA-TM) have initiated a project to build institutional capacity for integrated energy-environment planning in Africa.[1]
This paper presents the results of preliminary energy and environment scenarios for Senegal that comprise the initial phase of this project.

Senegal faces two energy issues common to many African countries: heavy dependence upon imported petroleum and high levels of biomass energy use amid a declining wood resource base. Senegal also faces issues that are unique to the Sahel region of West Africa: highly vulnerable semi-arid ecosystems, relatively poor endowments of energy resources, and resulting high electricity prices.

Together, oil (0.80 million tonnes oil equivalent), wood (0.83 MTOE), and other biomass (0.15 MTOE) accounted for 98% of Senegal's 1988 primary energy supply. Between 1980 and 1988, oil imports accounted for 17% to 28% of total imports, and from 26% to 59% of total non-energy export receipts.[2] On a per capita basis, Senegal's annual agricultural expansion and the charcoal trade, are Senegal's most widespread and immediately apparent energy-related environmental problems. Indeed, environmental discussions in Senegal are dominated by concern for the declining forest cover, soil erosion, local climate changes, and interactions with agricultural and pastoral activities of rural people. Other environmental issues have only begun to enter into energy planning discussions. Some observers note "with regard to the questions of energy efficiency and of environmental impact, they are 1) raised only by energy users, and 2) for the time being, relatively, to not say totally, absent from the debate."[4] At the same time, the Senegal government's report to UNCED notes that uncontrolled industrialization and various pollutants (e.g. auto emissions) are rendering living conditions increasingly precarious, particularly around Dakar.[5] Indoor air pollution, largely attributable to household use of biomass fuels for cooking, may also pose serious health risks. Proposed hydroelectric development presents potential health risks and threats to traditional agricultural production systems in flooded and downstream areas, as well as disruption to areas that might be affected by long distance, high voltage transmission lines.

Furthermore, with considerable land area near sea level and a dry Sahelian climate, Senegal is highly vulnerable to the potential effects of global climate change. Saltwater intrusion into aquifers is already a problem in many areas. A significant rise in sea level could result in severe damages to many key areas, including the biologically rich island ecosystems of the Saloum region, important coastal tourist areas, and low-lying rice fields in Senegal's richest farming area, the Casamance. On a per capita basis, Senegal emits approximately one-quarter the world average greenhouse gas emissions from all sources: its scenarios for the Senegal study described here.

Given the complexities involved in full assessment of environmental impacts across a wide range of energy activities, we limited our focus to a few scenarios, representing a handful of energy policies and a limited set of emission and impact categories. Data availability and uncertainty dictated the design of a simple model of Senegal's energy system. Recent surveys by ENDA and the World Bank (1989) enabled a more disaggregated model for the household sector (i.e., by end-use) than for other energy consuming sectors.[10] We also used LEAP to model the operation of each of Senegal's major energy extraction and transformation (electricity, charcoal, and refinery) industries.[11]

Using this model, we prepared a reference case, which provides the background for the analysis of policy scenarios over a time horizon of 1988 to 2005. Assumptions regarding demographic and economic growth were drawn from indicative estimates developed by a team of researchers and managers contributing to the government's "Plan d'Orientation 1989-1995". These figures reflect continued rapid urbanization and growth rates for individual economic subsectors that range from over 3% per year for fishing, services, and other industries, to 2% per year for extractive industries (phosphates and salt), to no growth in the troubled vegetable oil industry. The saturation of household electrical appliances was assumed to nearly double during the 17-year time period considered here. Older oil-fired electric capacity is gradually replaced by new higher efficiency fuel oil and diesel base load and peaking stations, according to the reference plan of the state electric utility (SENELEC).[12]. The reference case also assumes continued operation of the national refinery (with its questionable cost-effectiveness) and no additional penetration of uses such as cooking has been a common strategy among many developing countries, most commonly implemented in the form of fuel and/or equipment subsidies. These subsidies have been justified as both an environmental benefit (avoiding deforestation) and a basic needs support for lower income groups. However, poorly designed subsidies achieve neither objective.[13]

In Senegal, the government has encouraged the transition from charcoal to LPG through subsidies and promotion campaigns since the mid 1970's. In 1974, the government began a program of equipment subsidies, followed by a switch to fuel subsidies in 1977. These early efforts appear to have benefited middle class, rather than poor households, with little impact on overall charcoal demand.[14] One survey conducted in the mid-1980s even suggested that demand for charcoal is inelastic with respect to the relative prices of charcoal and LPG. It thereby questioned the efficacy of either an LPG subsidy or a charcoal tax.[15]

More recent LPG subsidies and promotions appear to have been more successful. Over 60% of all households in five major cities now have LPG stoves.[16] In a 1989 survey, LPG was the primary household fuel in 47% of Dakar households[17], compared with 24% in a survey from 1987.[18] The 1989 survey also suggests a significant increase in Dakar households with smaller rather than larger gas stoves. Over 75% of Dakar households now own stoves designed for the subsidized, smaller 2.7 and 6 kg LPG bottles. Only 14% own the unsubsidized but more convenient 4-burner stoves that use the 12 kg and larger containers. The relatively high availability of the subsidized small (2.7 kg) containers and associated stoves helps to overcome the obstacle of "lumpy" payments that is often cited as a major obstacle to the purchase of gas and electricity by poorer urban areas that already use substantial levels of LPG (Dakar, Thies, St. Louis), by the year 2000, we project cooking fuel use to approach the characteristics of households currently using approximately equal (final energy) amounts of gas and charcoal, with LPG dominating afterwards.[24] In other urban areas, we assume that the transition occurs more slowly. Although such a transition may appear optimistic, at the rate of substitution suggested by preliminary analysis of the 1989 surveys, this transition could occur even more rapidly.[25]

Whether continued subsidies would need to continue at the current rate for this transition to occur is not clear. Increasing the charcoal price could achieve the same goal, but perhaps at greater hardship to poorer urban dwellers and with significant political obstacles hindering implementation.[26] Efforts to improve the reliability of LPG supply have been suggested and might increase LPG penetration at a lower marginal cost to the government than subsidies alone. In addition, further lowering of LPG equipment costs should be investigated. Rapid household switching to LPG has taken place in a number of developing country contexts during the 1980's.[27] While declining LPG prices relative to charcoal and rising household incomes may have been important factors, according to consumer surveys, the most important factor was the decrease in LPG equipment prices.

<u>Scenario B: Improved Biomass Efficiency</u>

The many efforts thus far to develop and disseminate improved wood and charcoal stoves and kilns have met with limited success.[28] Therefore, we have developed very conservative estimates of achievable potential.[29] The low level of these savings is further reduced by the shift away from charcoal to LPG; there are simply fewer old charcoal stoves

For other sectors, because there have been no similarly extensive efficiency studies to draw upon, we were forced to use evidence from studies in other countries. For instance, in the services sector, where GDP is projected to grow at over 3% per year in Senegal, commercial building studies in other tropical countries have shown substantial potential for savings, particularly with improved lighting and cooling technologies. Equipment standards, building codes, shared savings programs, and other implementation measures increasingly commonplace in industrialized countries, have yet to be attempted in most African countries. With aggressive programs aimed at all major service sector end-uses, we estimate that energy efficiency improve at an annual rate of 2.5%.

For transportation, the major oil-consuming sector of the economy, there are many opportunities for improving efficiency, from "feebates" (using taxes on gas guzzlers to subsidize efficient vehicles) to mandatory maintenance of older vehicles. Given the lack of local data on transport energy use patterns, we rely on rough estimates based on assumptions for efficiency improvement potential for all developing countries.[33] Equipment standards and reduced import fee for high efficiency household appliances could also help to mitigate the 6% growth in household electricity use -- increasing the sectoral share from 20% to 29% of total electricity use by 2005 -- projected under the reference case.

Scenario D: Hydroelectric additions

This scenario assumes the successful completion of projects to import hydropower from the first projects of the Senegal River Development Organization: the Manantali and Felou dams in Mali. Although Senegal, Mauritania, and Mali, have already succeeded in increase by less than 5% (from 1.25 to 1.31 million TOE) relative to the reference case in 2005. Significant reductions in total primary energy requirements are achieved (from 2.83 to 2.34 million TOE) as the substantial losses due to inefficient charcoal production and use are greatly reduced.

Scenario B, with more efficient charcoal kilns and stoves could also reduce these losses. However, due to two factors - - the conservative assumed penetration rates and the decreased losses already achieved by switching to LPG - - the energy impact of the policies included in Scenario B is relatively small.

With the achievement of improved efficiency potentials in most demand sectors, combined with butanization, by 2005, Scenario C demonstrates significant decreases in final consumption of nearly every fuel compared with the reference case: electricity (19%), all petroleum products including LPG (8%), charcoal (80%) and firewood (4%). When translated into primary energy, the reduction in fuel requirements for power generation leads to a total reduction in oil requirements of 12% relative to the reference case in 2005. This more than offsets the increased petroleum product consumption of increased butanization. Oil consumption for 2005 decreases by 31% in Scenario D, with the displacement of oil-fired generation by 130 MW of new hydroelectric capacity.[34] Although still preliminary, these results indicate potential savings in both oil and charcoal consumption that might accrue from a combined strategy of butanization, improved efficiency, and hydro development.

Environmental Analysis

At the same time, increasing quantification, even monetization, of environmental externalities is proceeding at a rapid pace. In the U.S., 29 states have acted to incorporate environmental externality costs in electric sector planning.[37] Internalizing environmental costs has been termed "the wave of the future", with 85 pollution taxes already in place by 1989 in OECD countries.[38] So-called market-based initiatives, are rapidly spreading worldwide, though they remain relatively rare among African countries. Forestry levies targeted toward reducing negative environmental impacts of woodfuel harvesting are a possible exception, although one of questionable efficacy because of enforcement difficulties. Other means to internalize environmental externalities may deserve attention.

While simplifying the complex web of human and environmental interactions, we have sought an approach that can be implemented within the institutional and data constraints faced by African planners. As an initial step, we developed a limited set of emission factor and land clearing estimates, largely deriving the former from the existing Environmental Data Base (EDB). It must be emphasized that none of the emission factors were derived from tests or measurements conducted in Africa. Instead, they were derived from the relatively limited number of studies based on measurements from OECD countries. As described below, for transport and household sectors, emission factors were also drawn from Asia, which shares with Africa an older less maintained vehicle stock and the use of small household stoves fired by traditional biomass fuels. Emission source categories were created for most aspects of energy production and use in Senegal.

Given the paucity of available data, coefficients for items such as soil erosion, direct health and safety, solid waste and water effluent emissions from energy processes were not conditions, we estimated average emissions based on an average of available test data for Asian stoves closest in fuel and design. We incorporate the results of recent tests of Asian stoves that indicate emissions of previously measured greenhouse gases (CH4, N_2O, etc.) could be very high.[41]

Transport sector emissions are the major source of increasing levels of urban air pollution in Senegal, and Africa generally.[42] In Asian, Latin American, and OECD cities, motor vehicles typically account for about 90% of CO emissions, and often a majority of HC and NO_x emissions.[43] Sub-Saharan Africa, with 10% of global population, accounts for only 2% of the global stock of 470 million vehicles. While not yet approaching the severity found in major Asian and Latin America cities, urban air quality problems related to transport emissions are of increasing concern in many African cities. High levels of CO and SO_2 have been measured in Ibadan City, Nigeria, and haze and eye irritation are indicative of high levels of photochemical smog on major transportation routes in Lagos.[44] Continued use of leaded gasoline poses health risks, particularly to small children who breathe the higher lead concentrations found near tailpipe height.

Transport sector emissions depend on a variety of factors: vehicle type, emission controls, fuel characteristics, maintenance level, fleet age, and driving conditions. We developed current 'best guess' estimates for Senegal by averaging the emission characteristics of 1985 European vehicles and those of average Indian vehicles to reflect maintenance and age characteristics more typical of a developing country.[45] For rail, water, and air transport, we use data derived directly from U.S. studies. Similarly, the emission characteristics of representative generic, U.S. technologies (without emission populations. Does continuing reliance on traditional biomass resources lead to land degradation? Where would cooking and heating fuels come from if such land clearing were not to occur? And how do these dynamics change with expanding population densities?

Globally, it has been estimated that the use of biomass energy causes one-eighth of observed global deforestation, with the rest attributable to logging, agricultural land clearing, and road building.[47] For Brazil, Poole and Moreira suggest that firewood production for residential and agricultural uses do not contribute significantly to deforestation.[48] In addition, they assume that 50% of total charcoal production leads to deforestation and thus to net CO_2 emissions.[49] The term deforestation is often used with unclear definition; the meaning used here, and implied in the numbers above, is a non-regenerative reduction in biomass stocks.

Land clearing alone does not necessarily imply permanent deforestation. Under certain conditions -- adequate soil moisture, limited soil erosion, presence of seeds or coppices, and limited land pressures -- forests can regenerate within one to two human generations. A review of studies of forests previously cleared for woodfuel production in Senegal and Nigeria suggests a range of impacts under actual conditions, but are inconclusive for either precise or generalized determination.[50] Hosier found that among recently harvested charcoal production sites in Tanzania, biomass cover showed signs of recovery.[51] However, the question of whether harvested lands will return to earlier levels of biomass stocks remains open. Harvesting methods, soil and nutrient loss, and most importantly, post-harvest land use and management determine whether full regeneration will occur.

stopping charcoal production in Senegal would certainly not halt land clearing, and the precise nature of damage to rural environments of this industry is not fully understood, a pervasive impression is that "charcoal demand is a key cause of the decline of Senegal's ecology."[55]

Although rural consumption of charcoal is relatively minor compared with rural use of firewood, the latter generally tends to be gathered as twigs and dead wood rather than from live trees.[56] Therefore, at present, the contribution of rural firewood consumption to permanent land degradation and to net carbon emissions is relatively small. For the scenario analysis, we assume that 10% of firewood harvested does not regenerate, an estimate that lies between the assumptions for Brazil (20%) and an assumption of no impact (0%), which would seem unlikely. With increasing population densities, the impact of rural firewood demands could increase. It is possible that during the time horizon of this study (to 2005), this 10% assumption could prove too conservative with respect to environmental damage. As with the charcoal assumption above, uncertainty will be reflected in future sensitivity analyses.[57]

For agricultural residues, energy uses might reduce total soil carbon, since the residues are not left to rot in the fields. However, if the residues are burned, as is often the case in Senegal, total greenhouse gas emissions would likely be even greater.[58] We thus assume no net CO_2 emissions from agricultural residue energy uses.

<u>Environmental Results</u>

generalized, indicator of health-related indoor air quality issues. The transport sector accounts for the largest share of current nitrogen oxide emissions, a share that is likely to increase with urbanization and increased traffic congestion. Fuel oil use in electric and industrial steam boilers is responsible for most sulfur oxide emissions.

As illustrated in Figure 7, under the reference case, emissions increase for all categories except sulfur oxides. This decrease in sulfur oxides reflects assumptions regarding the use of lower sulfur fuels with newer electric generating units. Total annual carbon dioxide emissions in 2005 increase by 1.9 million tonnes, an increase of 59% over 1988 levels. The share of net biogenic emissions remains relatively constant at about 30% of the total throughout the period.

The policy scenarios result in significant decreases in all emission categories by 2005, as shown in Figure 8. The butanization scenario (A) reduces total carbon dioxide emissions by 0.9 million tonnes relative to the reference case in 2005, cutting in half the projected increase in reference case CO_2 emissions. The decrease in net biogenic CO_2 of almost 70% shown above, far more than offsets the increased CO_2 emissions from fossil fuels by about 4%. At the same time, total emissions of CO, HC, CH_4, and TSP decrease from 28% to 56%, relative to the reference case, as two major sources of these emissions, charcoal production and use, are greatly curtailed.

Scenario C results in an additional decrease of 0.6 million tonnes in fossil fuel CO_2 relative to the reference case, leading to only a 14% increase in total CO_2 emissions over the 17 year study period. In addition, all other categories of emissions further decrease relative to the reference case. By avoiding oil-fired power plant emissions, hydro additions

Because of the inefficiency of charcoal production and use, CO_2 emissions are about three times higher than in the case of either LPG or kerosene production and use.[59] In terms of GWP, the contrast is even more dramatic: emissions from charcoal are up to six times higher. Even if all wood destined for charcoal production were harvested on a renewable, fully regenerative basis, overall greenhouse gas emissions would still likely be higher than in the case of LPG refining and use.

Assuming that a 60 CFA/kg LPG subsidy is required to overcome barriers to switching from charcoal to LPG,[60] this policy results in a cost of about $30 U.S. per tonne of CO_2 reduced, and around U.S. $15 per tonne of CO_2 equivalent GWP.[61] This cost compares favorably with a recently proposed European Community carbon/energy tax of U.S. $22 per tonne by the year 2000. We do not suggest here that such an LPG subsidy is necessarily the best approach to encouraging substitution (indeed it may be a relatively high cost option), but it is one that has proven politically acceptable in practice.

Conclusions

The results of the preliminary scenarios indicate that LPG substitution policies could substantially reduce greenhouse gas emissions, while contributing to the improvement of more important near-term environmental problems in an African country such as Senegal. Given their potential as low-cost contributors to reducing greenhouse gas emissions, these policies may deserve additional attention and support from aid and funding sources.[62] The effects on oil imports and resulting foreign exchange requirements of increasing LPG use in estimates for employment, ecological, and human health and welfare, balancing these impacts is inherently the domain of social values, typically resolved in a political process. As shown in Table 4, a matrix of impacts across scenarios and issues of concern provides a first step toward a comprehensive overview to assist decision making. The next step, whether explicit or not, involves placing relative weights on different issues and on the relative differences in emissions or impact for a given issue.

Efforts to make these values and weights explicit in the policy making process will help to ensure that energy choices do not ignore important environmental considerations, and to provide a more transparent and publicly-accessible basis for decisions. To this end, several methods have been explored for valuing externalities and implementing decision frameworks. Practical experience with these comparative approaches is relatively limited. Perhaps the most extensive experience is the recent efforts to internalize air emission impacts in the U.S. electric sector planning process. These efforts have generally resulted in the use of monetary cost values (eg., planning adders) for individual pollutants, rather than scoring systems, which require an additional method to balance environmental with standard market costs.[63] Can such efforts can be extended across the full set of energy resources, and can these methods can be usefully applied in smaller developing countries such as Senegal? Or will the "wave of the future" affect larger electric systems alone?

Scientists, Cambridge, MA, 1991.

[9] Together, LEAP/EDB comprise a computerized modeling system designed to explore alternative energy futures, along with their principal environmental impacts. As a flexible, model-building tool, model relationships and detail can be tailored to the local dynamics and data constraints of individual applications. The emphasis of the combined LEAP/Environmental Database (EDB) framework is to provide a means for rapid initial assessment of the comparative impacts of energy policies. As such, EDB provides a comprehensive database of environmental impacts associated with energy use. It contains a large existing database of coefficients describing air, water, solid waste, and occupational health and safety effects. This core data of EDB are derived from 70 literature sources of international origin. LEAP has been developed by the Stockholm Environment Institute, while EDB is a joint project of UNEP and SEI. An early description of a previous version of the LEAP system can be found in P. Raskin, "Integrated Energy Planning in Developing Countries: The Role of Computer Systems", *AMBIO, Vol. 4, No.4-5.*

[10] See World Bank, *Urban Household Energy Strategy*, ESMAP, 1989 and D. Cavard, Y. Sokona, L.Ba, "La Consommation d'Energie des Menages a Dakar: Changements de Structures, Evolution des Equiprements, et des Comportements des Consommateurs", COPED/EPE/ENDA-TM, 1991.

[11] For a more complete description of the modeling and scenario analysis energy, see Lazarus, Diallo, and Sokona, "Integrated Energy-Environment Planning: Initial Results from Senegal", Working Paper, Economic Development Institute of the World Bank, 1993.

[12] "Programme D'Equipement de Production sur le Reseau Interconnecte a Moyen et Long Terme", Direction des Etudes Generales, SENELEC, August, 1989.

[13] For example, Pitt (1983) found that kerosene subsidies in Indonesia in the 1970s disproportionately benefited wealthier urban households and through econometric analysis, he "conclusively rejects the deforestation argument", by showing that the cross-price elasticity of firewood demand with respect to kerosene price is very

[22] Diour cites an estimate that 40% of charcoal consumption is supplied by production that circumvents government controls and regulation, while Ribot suggests similar figures. See D. R. Diour, "Senegal: Strategie de l'Energie Domestique", SENELEC, paper submitted for the Seminar on Energy Planning and Policy, World Bank/EDI, June 1991, and J. C. Ribot, "Forestry Policy and Charcoal in Senegal", *Energy Policy*, forthcoming, 1993.

[23] The low figure is from World Bank, op cit, ref 10, the high estimate from Cavard et al, op cit, ref 9. The World Bank estimates that 55 kg. of charcoal use per person per year is displaced when LPG is used as the primary fuel. Since household behavior is far more complex than simple substitution of one energy form for another, precise estimation of substitution impacts is difficult. In fact, some survey results suggest that charcoal use is only displaced if significant levels of LPG are used. Where LPG accounts for 10-20% of total household fuel use, charcoal use may be unaffected. (see Cavard et al, op. cit., ref. 10)

[24] This "gas + charcoal" category of 1989 households, which used, on average, 100g of charcoal and 70g of LPG per day, was the largest survey group, accounted for almost half (46.1%) of survey respondents. (Cavard et al, op. cit., ref. 10)

[25] Although this approach has certain advantages, it potentially obscures the implicit differences in income and lifestyle among groups in different fuel categories. It could be that households currently using gas with charcoal have different cooking and eating patterns than households using charcoal alone, as a function of disposable income and status for which changes are obviously much harder to implement than a butanization policy.

[26] Not surprisingly, given the current disfavor of subsidies, the World Bank has called for a gradual end to the LPG subsidies, and the imposition of increased stumpage fees.

[27] Leach, op cit, ref. 19.

and Industry Department, May 1991; World Health Organization, *Management and Control of the Environment,* Report WHO/PEP/89, Geneva, 1989; and Ehrlich, Ehrlich, and Holdren, *Ecoscience*, Freeman, 1977.

[36] For a discussion of the models and approaches for looking at some of the other aspects of the system, such as transport-impact and dose-response models, see ibid and World Bank, *Environmental Assessment Sourcebook, Volumes I-3*, Environment Department, World Bank Technical Paper 139, Washington DC, 1991. The approach described here is not intended to substitute for these methods, but rather to stimulate more thorough project-specific environmental analysis, such as that typically undertaken in an environment impact assessment.

[37] Of these, 19 states have issued orders or passed legislation requiring utilities to include these costs in planning or new capacity bidding processes. R. Ottinger, "Consideration of Environmental Externality Costs in Electric Utility Resource Selections and Regulation", in *Energy Efficiency and the Environment: Forging the Link,* Vine, E. et al., eds. American Council for an Energy-Efficient Economy, Washington, DC, 1991.

[38] Ibid , p. 190.

[39] Op cit, ref. 11.

[40] Smith et al, 1983, as reported in A.O. Adegbulugbe, "Energy-Environmental Issues in Nigeria", paper presented at the International Energy Workshop, Harvard University, Cambridge, MA, June 1993.

[41] K. R. Smith. M. A. K. Khalil, R. A. Rasmussen, et al., "Greenhouse Gases from Biomass and Fossil Fuel Stoves in Developing Countries: A Manila Pilot Study", forthcoming in *Chemosphere,* 1992

[42] The transport sector in Senegal is unique because of its dominance by air transport, which accounts for over 40% of transport energy use. Since Dakar acts as a hub for a major regional airline (Air Afrique), the transport data may seem misleading. Airplanes are fueled in Senegal in part to meet the transport needs of other countries. Furthermore, the emissions from planes leaving Dakar may occur thousands of kilometers away. The responsibility for international transport emissions could be considered no different from emissions associated with

[52] These estimates are generally extrapolations between land use assessments conducted many years apart, that have used somewhat different land type categories and other methods, introducing added uncertainty.

[53] Amous (op cit, ref. 7) implicitly assumes 100% permanent loss of harvested woody biomass, as do many other analysts in their discussion of woodfuel production impacts.

[54] Other problems related to the charcoal trade include selective cutting of commercially valuable lumber species and road damage from heavy vehicle use. (Ribot, op cit, ref. 22)

[55] p. 32, World Bank, op cit, ref. 10.

[56] Ribot, op cit, ref. 22, World Bank, op cit, ref. 10.

[57] The impacts of urban firewood consumption are assumed to be the average of rural firewood and urban charcoal demand, while the impacts of rural charcoal (which we assumed to be purchased from the same markets that supply urban dwellers) are assumed identical to urban charcoal consumption. Loss of soil carbon, which could be significant, particularly at charcoal kiln sites, was not considered here.

[58] The emissions of CO, NOx, and HCs are generally higher in open rather than controlled combustion conditions.

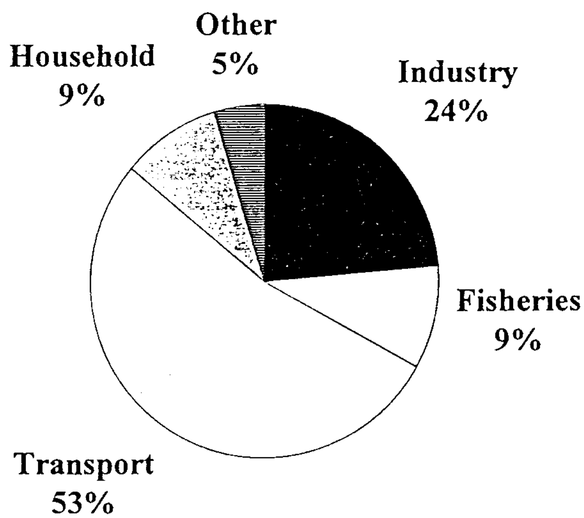
[59] This calculation uses the previous assumption that 50 percent of charcoal production involves non-regenerative harvesting. The "break-even" level at which LPG and charcoal CO2 emissions would be equal is about 16%.

[60] In 1988, the subsidy amounted to between 60 and 65 CFA/kg.

[61] This calculation assumes the following: (a) no free riders, that is, fuel switching would not occur in the absence of the subsidy; (b) switching occurs between the most commonly available charcoal and small LPG

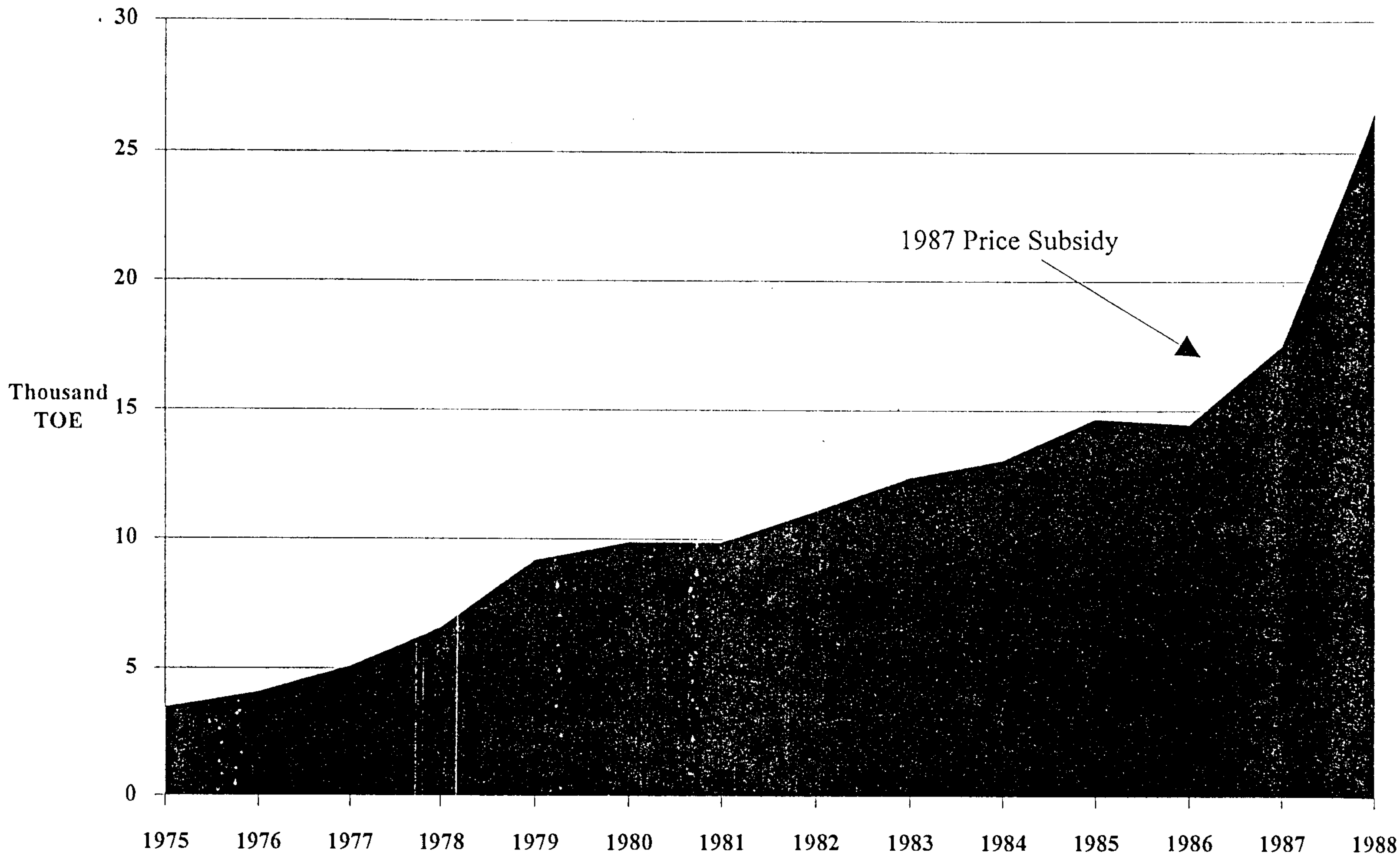
gure 1

Final Energy Consumption by Sector, 1988



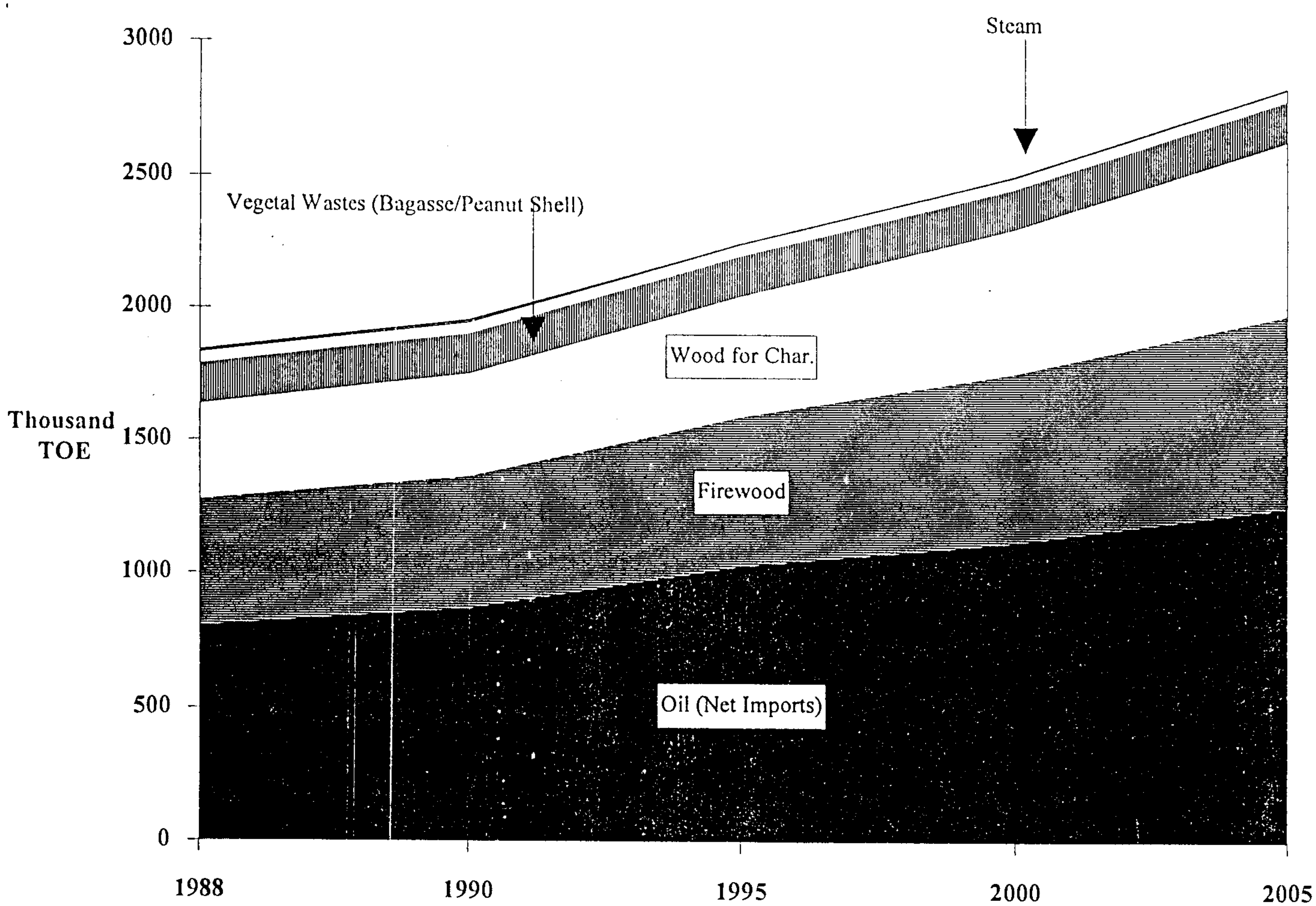
Excluding Traditional Biomass Energy

Household LPG Consumption Trends



Sources: ENDA, 1990; World Bank, 1989. See Ref. 10.

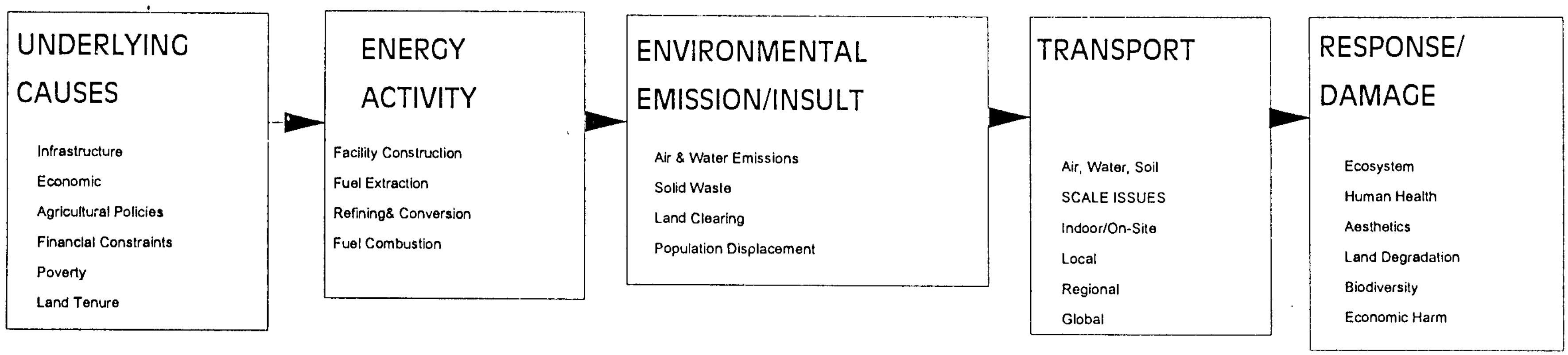
Primary Energy, 1988-2005
Reference Case



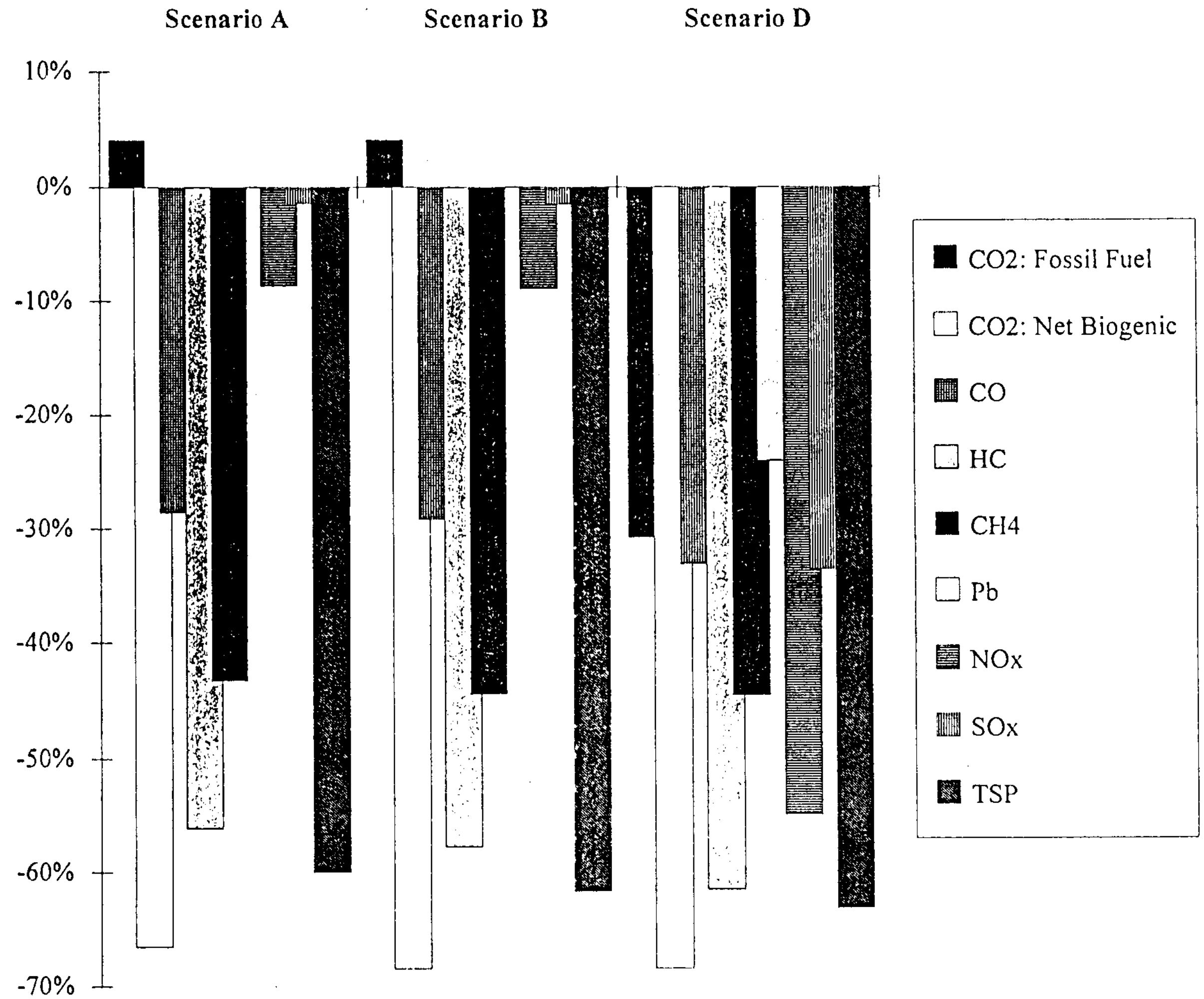
Note: 1988-1990 time period not to scale

Figure 6

PATHWAYS FROM ENERGY TO ENVIRONMENTAL IMPACTS



Emission Changes Relative to Reference Case in 2005



Units (T = Tonne)	CO2 Fossil (1000 T)	CO2: Net Biogenic (1) (1000 T)	CO (1) (1000 T)	HC (1000 T)	CH4 (1000 T)	Pb (2) (T)	NOx (1000 T)	N2O (3) (T)	SOx (3) (1000 T)	TSP (1000 T)
SUPPLY/TRANSFORMATION SECTORS										
Crude Oil Prod.	0									
Nat. Gas Prod.	1						0		0	
Charcoal Prod.		699	31	36	9		2			40
Nat. Gas T&D Loss				1	1					
Refinery	111		0	1	0		1		1	
Electricity (SENELEC + Self-Gen)										
Diesels	57		0	0			1		0	0
Gas Turbines (Distillate)	49		0	0			0		0	0
Gas Turbines (Nat. Gas)	15		0				0			
Steam Boilers (Fuel Oil)	740		0	0		0	2		10	1
Bagasse			0	0			0			3
TOTAL SUPPLY/TRANSFORMATION	**973**	**699**	**32**	**38**	**10**	**0**	**6**		**11**	**44**
DEMAND SECTORS										
Industry	313		0			0	1		3	0
Fisheries	164		8	3	0		1	3	0	0
Transport	878		20	3	0	16	5	10	1	1
Household	105	179	156	9	12		1	81	1	12
Other	2								0	
TOTAL DEMAND	**1462**	**179**	**185**	**16**	**12**	**16**	**8**	**94**	**5**	**13**
TOTAL SYSTEM	**2435**	**878**	**217**	**53**	**22**	**17**	**15**	**94**	**16**	**57**

Blank entries indicate that no values have been entered (inadequate data or not an applicable category); zero values indicate a value of less than 0.5.

(1) All charcoal-related CO2 emissions reported under charcoal production, while household line reflects all firewood-related emissions. The net biogenic emissions reflects the assumption 50%-90% of the carbon emitted, as described in the text, is either balanced by wood regrowth or is not attributable to other factors such as land clearing primarily for non-energy purposes. These factors were also applied to the carbon emitted as CO from biomass fuel consumption.

(2) N2O estimates were included only for recent household measurements (Smith et al., 1992), and are thus useful only for comparisons within this sector.

(3) Lead and Sulfur emissions will be proportional to their content in fuels used in Senegal. Senegal purchases and produces petroleum products with a wide variation in sulfur content (heavy fuel oil sulfur content ranged from .1% to 3.3% from 1986 to 1991), thus standard assumptions were made about sulfur content as shown in the annex tables (1% for heavy fuel oil etc.)

Issue	Indicators (*only items in italics analyzed here*)	Reference Case	Scenario A: Butanization	Scenario B: Improved Biomass Efficiency	Scenario C: Improved End-Use Efficiency	Scenario D: Hydro Development
			Impacts relative to Reference Case (numbers show differences in 2005)			
Land Degradation	*Cumulative Land Cleared (1988-2005) for Charcoal Production* Soil Erosion	420,000 to 1,200,000 hectares cleared for charcoal production, 1988-2005	34% reduction in cumulative land clearing	37% reduction in cumulative land clearing		Same as B. In addition, Felou dam will flood areas in neighboring Mali. Downstream areas in Senegal subject to altered flow and siltation patterns from hydro operations.
Natural Ecosystems	Biodiversity/Habitat loss	Continued habitat loss and reduction in biodiversity likely as charcoal demand grows and land clearing continues.	Likely biodiversity and habitat benefits due to reduced land clearing.			Likely benefits due to reduced land clearing. Potential harm to fish populations from hydro operations.
Indoor Air Pollution	*Household Emissions of CO, NOx, HC, SOx, TSP* Interior Architecture/Ventilation	No major changes	Household Sector emissions down 4-24% (depending on pollutant)			Approx. same as A
Local Air Pollution	*Emissions of Nitrogen Oxides, Ozone, HC,,Sulfur Dioxide, Air Toxics*	Most emissions up 60-70%, 1988-2005., except SOx, NOx.	Emissions down 10% (NOx), 30% (CO), 60% (TSP, HC)	Approx. same as A	Emissions down 20% (Pb, SOx, NOx) , 30% (CO), 60% (TSP, HC)	Emissions down 20% (Pb,) , 30% (SOx, CO), 60% (TSP, NOx, HC)
Acid Precipitation	*Sulfur Dioxide* *Nitrogen Oxides*	SOx, down 20%, NOx up 140%, 1988-2005., due to changes in electric fuels.	See above			
Global Warming	*Greenhouse Gas Emissions:* *Carbon Dioxide (CO2)* *Volatile Hydrocarbons (CH4, HC)* *Other GHGs (N2O, CO, etc.)*	Total GHG emissions up 60% by 2005 (GWP, 1992 IPCC 100 year integration values)	GHG emissions down 20%	Approx. same as A	GHG emissions down 30%	GHG emissions down 40% (6% lower than 1988)
Water Use and Pollution	BOD, COD, Suspended Solids, Chemicals , Toxics, Thermal Discharges, Silt, Water Availability	Emissions and impacts highly site-specific, not estimated.				Senegal River affected by operation of hydro facilities.
Other Environmnental Issues not considered	Solid andToxic Wastes, Ozone Depletion, etc.					Studies indicate potential increase in water-borne diseases.
Employment	Jobs Created/Lost		Short-term: More jobs could be lost in charcoal industry than gained through increased LPG supply and equipment. Positive impacts on other rural activities could offset other losses. Impacts of other policies (e.g. improved efficiency), difficult to judge.			
Economic Development	GDP Natural Resource Accounts		Macroeconomic effects of subsidy likely to be negative, but may be offset in part by environmental benefits.	Approximately same as A.	Same as B, with macroeconomic benefits of 20% reduction in oil imports.	Increased debt from expensive hydro project & transmission line must be compared with additional 20% reduction in total oil imports.
Rural welfare	Effects on local farming systems and substitence activities Local Firewood Availability	Continued degradation with on-going charcoal making activities.	Likely benefits, since charcoal industry can be disruptive to rural activities and well-being (benefits mostly to urban areas.).	Some additional improvements, relative to A	Same as B.	Same as B, except potential disruption to local communities in Senegal River Basin, due to upstream hydro projects.
Agricultural Productivity	Soil and Nutrient Loss Microclimate changes	If suggestions that reduced biomass cover leads to detrimental microclimate changes (wind erosion, moisture loss) are correct, then continued land clearing could degrade farming conditions.	Reduced charcoal harvesting could thus lead to improved agricultural productivity.	Some additional improvements, relative to A	Same as B.	Same benefits as B, but potential harm to agriculture in Senegal River Basin . (Avoided nutrient deposition)