ANALYZING DEFORESTATION AND EXPLORING POLICIES FOR ITS AMELIORATION: A CASE STUDY OF INDIA

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ABSTRACT

Causes of deforestation have been debated by foresters, demographers, geographers, and economists alike (Palo 1994). Yet no consensus has been reached on the roles of various factors such as population, external indebtedness, income, and agricultural productivity. The paper demonstrates that when deforestation is analyzed in a forestry context alone (that is, in isolation of socio-economic context) in contrast to a systems level (that is, when the focus is on the interaction between the forestry and other socio-economic sectors), the results can be conflicting and confusing. This is primarily because different socio-economic contexts are not accounted for in the analyses.

This paper argues that causes of deforestation are numerous and lie interlinked within a socio-economic system. To capture the complex and dynamic nature of the deforestation process, a system dynamics language is used to model the process. In the proposed model, a system was conceived of sectors which includes four other sectors besides forests — agriculture, livestock, energy, and socio-economic sectors — that compete for forest land use or for forest produce. The process of deforestation is seen in terms of a dynamic interaction between all five sectors of the model. Deforestation in India is used as a working example. To demonstrate the role of population and its socio-economic context on total forest area (TFA), and forest biomass (FBM), a sensitivity analysis has been conducted. The model shows that a focus on the factors in isolation rather than on combinations of inter-sectoral interactions among the elements of the systems will be an imprudent step towards sustaining forests. By employing a system dynamics approach, the results reveal the short comings of the current forest policies in India. The current policies have narrowly focused on the legally mapped area of forest land while overlooking the rapid erosion of biomass from the same lands. If this continues within the next 2–3 decades India will be completely deforested.

The socio-economic environment provides an essential insight into how, and why, people use forest resources. Policies aimed at the amelioration of deforestation need to focus on population control policies and socio-economic issues. In particular, Indian planners need to restructure the environmentally degrading energy sector to a environmentally benign sector, one which follows a soft energy path of biogasificaton, co-generation, and increasing the use of energy efficiency. They also need to plan investments for rural needs, ameliorate poverty, control livestock numbers and consequent forest grazing, and increase average productivity of agriculture, and forests through increased conservation in forests, and development around forests. Forest conservation policy implemented in isolation from policies of other sectors will be insufficient to conserve forests in the current socio-economic milieu of India.

Keywords: Deforestation, systems dynamics, socio-economic context.

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INTRODUCTION

Causes of deforestation have been debated by foresters, environmentalists, geographers, and economists alike (Palo, 1994). Yet no consensus has been reached on the role of various factors such as population, external indebtedness, income, and agricultural productivity in deforestation (WCED, 1987; UNCED, 1992; WB, 1992; Kummer & Sham, 1994; Palo, 1994). Some warn that population growth is accelerating defor-

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estation (Bowonder, 1982; Allen & Barnes, 1985; Palo, 1987; Repetto & Gillis, 1988; and Rudel, 1994), while others suggest that a focus on population obscures the socio-economic and political context of deforestation (Westoby, 1978; Kummer & Sham, 1994; and Palo, 1994). A third party to this debate, arguing from a neo-classical economic framework, maintains that technological ingenuity and market forces will solve any problem of resource shortage. These researchers believe in an abundance of resources in perpetuity, and bolster this assumption by further assuming perfect substitutability of resources (*cf.* Herfindhal & Kneese, 1974; Dasgupta & Heal, 1979; Baumol, 1986).

People may have faith in both technology and market forces, but their degree of faith is limited. Many are aware that average rate of tropical deforestation, which was 11.3 million hectares per year during 1981–1985 has increased to 15.4 million hectares per year during 1981–1990 (FAO, 1993). Evidently, technology and markets have failed to provide adequate price signals and innovative solutions to mitigate the worsening situation of the world's forests. Technological solutions alone do not seem able to retard the problem of deforestation, let alone arrest it. This paper demonstrates that deforestation is driven by the intersectoral interactions among forests and other sectors such as the agriculture, livestock, energy, and socio-economic sectors. Controlling deforestation therefore, requires understanding the processes of deforestation in this systems context.

In the past, deforestation has been examined at the level of individual causal factors. We suggest, instead, that deforestation can better be envisioned at a systems level. At this level deforestation is recognized as a part of complex phenomenon in which the focus is on the dynamics of systems; that is, on the interactions among the elements of the system over time and scale (Saxena & Nautiyal, 1996). Ultimately, this view of deforestation sets the stage for both more comprehensive and effective policies aimed at halting the loss of the world's forests.

In this paper we analyze the process of deforestation through a system dynamics model, and explore development policies that may ensure sustainable forestry development. The paper also demonstrates that when deforestation is analyzed at a factors level (that is, the factors in isolation of system context), the results can be conflicting and confusing. The primarily reason for this is that other important sectors are not incorporated in the conventional analyses. A secondary reason is that important feedback dynamics are also omitted in the conventional analyses. In order to place our work in context, we briefly review the recent trends on this topic.

RECENT DEFORESTATION STUDIES

There are several recent empirical studies that attempt to identify and explain the role of factors causing deforestation on a global, and on a national scale (*cf.* Allen & Barnes, 1985; Grainger, 1986; Palo *et al.*, 1987; Panayotou & Sungsuwan, 1989; Reis & Margulis, 1990; Bilsborrow & Geores, 1994; Kummer & Sham, 1994; Rudel, 1994; Reis & Guzman, 1994; Shafik, 1994; Southgate, 1994). However, their results are conflicting and, therefore, unsettling. For example, Allen & Barnes (1985), Grainger (1986), Panayotou & Sungsuwan (1989), found that the population increment has a significant positive relationship with the annual change in forested areas, while Westoby (1978) emphasized, that taken in isolation, there was no correlation between population variables and deforestation. Burgess (1991, 1992) found a negative relationship between population growth and level of deforestation, and Palo (1994) found zero correlation between population growth and forest cover. Kahn & McDonald (1994) found that both the population and population growth were statistically insignificant in explaining deforestation. Kummer & Sham (1994), in their case study of the Philippines, illustrated that factors other than population, such as the change in agriculture area and annual allowable cut (a proxy for commercial logging), were more important in explaining deforestation during 1970–1980. They also found that when population change is regressed by itself against deforestation, the r-square is only 0.05 and when population density is regressed against the deforestation the r-square is only 0.02. In short, the role of population in deforestation is characterized by conflicting empirical results.

Similarly, there are many other studies that arrive at different conclusions with regard to roles of external debt, income and agricultural productivity in deforestation. For example, Shafik (1994), through a panel regression analysis of 66 countries for the period 1962–1985, concluded that debt per capita is not a significant factor in explaining deforestation on a global level, while Burgess(1991) found that debt service ratio (expressed as percentage of exports) was a significant positive factor in explaining the level of deforestation. Kahn & McDonald (1994) supported the Burgess's finding that the external indebtedness is contributing to the deforestation problem. They found a significant and positive association of deforested areas with annual changes in public external debt. Capistrano's (1991) results in contrast, contradicted these studies. She found debt service ratio to be negatively related to forests depletion in her sample of 45 countries for the four periods (covering 1969–1985).

Constantino & Ingram (1990), Panayotou & Sungsuwan (1994), and Rudel (1994) found income (expressed as GDP per capita) to have a positive and a significant effect on the deforestation rate, while Shafik (1994) illustrated that per capita GDP was not a significant factor in explaining the deforestation rate. While Constantino & Ingram (1990), and Katila (1992) observed a negative correlationship between agricultural productivity and relative forest cover, Shafik (1992) and Chakraborty (1994) found agricultural productivity to be an insignificant factor in explaining deforestation. Southgate (1994) observed that increasing agricultural productivity has a negative impact on the growth of area used to produce crops and livestock. Thus, he suggested that an increase in agricultural productivity will retard the land use competition between forest and agriculture, and thereby will retard the process of deforestation. But to make the matters worse and more confusing, in contrast to earlier studies, Reis and Guzman (1994) found that agricultural productivity has a significant and positive effect on deforestation density. In short, when deforestation is analyzed at the factor level, the roles of various factors are found to yield conflicting results. Table 1 summarizes the findings of recent deforestation studies. It lists the causal factors identified, the methodology adopted and the nature of recent deforestation analyses.

Table 1. Summary of the Recent Deforestation Studies.

Study	Unit of Analysis	Dependent Variables	Independent Variables	Methodology & Sample Size	Nature of Analysis
1. *Lugo, Schmidt & Brown (1981)*	Nation (regional)	%Forest Cover (%FC)	-0.001population (pop), +0.001energy use	C.S. , Linear Regression, 30	Static
2. *Allen & Barnes (1985)*	Nation global	Deforestation rate(D.R.)	+pop increase, + increase in farmland, +wood-use, -0.05wood export in 1968	C.S, Linear Regression 39 Units from Africa, Asia, and LA.	Static
3.*Grainger (1986)*	Nation (global)	D.R.	+pop increase, +area logged	C.S. , Linear Regression, 43	Static
4. *Palo, Salami and Gerado (1987)*	Nation (global)	%FC	-pop density	C.S. , Linear Regression, 60	Static
5. *Rudel (1989)*	Nation (global)	D.R.	+pop increase, availability of capital	C.S. , Linear Regression, 36	Static
6.*Panayotou and Sungsuwan (1989)*	Province (Nation)	%FC	-pop density, -wood price	C.S. , Linear Regression, 64	Static
7. *Scotti (1990)*	Nation (global)	%FC	-pop density	C.S. , Linear Regression, 47	Static
8. *Reis and Margulis (1990)*	Municipality (Brazil)	%Deforestation	+pop density, +road density, +crop area	C.S. , Linear Regression, 474	Static
9. *Burgess (1991)*	Nation (global)	Level of deforestation	+population growth, + GDP per capita, +debt service ratio as % of exports, +total roundwood production, food production per capita	C.S. , Linear Regression, 44	Static
10. *Burgess (1992)*	Nation (global)	Change in closed forest area	- pop density, + real GNP per capita in 1980, -roundwood production per capita	C.S. , Linear Regression, 44	Static
11. *Kahn and McDonald (1994)*	Nation (global)	Deforested area	-pop, +forested land area, + annual change in public external debt	C.S, 2 Stage linear regression model, 54	Static
12. *Capistrano (1994)*	Nation (global)	Depletion of broadleaf forests	+pop, +GNP per capita, -debt service ratio	C.S. , Linear Regression, 45	Static
13. *Kummer and Sham (1994)*	Province (Philippines)	Area in forest cover	-pop,-road density	C.S. , Linear Regression, 68	Static
14. *Chakraborty (1994)*	Nation (India)	Reserved forest area	-livestock unit,-per capita income,-net rate return, -fuelwood, charcoal production	T. S., Linear Regression	

Notes: C.S. = Cross section, T.S. = Time series; Nation (global) means unit of analysis is a nation while the sample is on global scale.

Kummer & Sham (1994), disagree with the results of many of these studies on the ground that most (for example, Lugo *et al*., 1981; Palo et *al*., 1987; Panayotou & Sungsuwan, 1989; Reis & Margulis, 1990) have failed to distinguish between the determinants of forest cover and the determinants of deforestation, and have not investigated the determinants of deforestation. Further, these cross sectional studies have failed to incorporate the implications of different *initial amounts* of forest cover, and different *historical timings* of the process of deforestation in their unit of analysis. Since the initial forest cover of the geographical units and the time the process of deforestation began were different, the results of the above studies do not provide any meaningful direction. Furthermore, the term population pressure has been used very casually, and several variables such as population growth, population growth in forest area, population density per unit of geographical area, population density per unit of forest area, and population change measured by increment in absolute population have been used to signify population pressure. There can be areas where population growth is high but population density can be low (for example in forested area) or high (in urban area). Therefore, results using these variables may indicate conflicting implication for the relationship between population pressure and deforestation.

Saxena & Nautiyal (1996) have pointed out many other limitations of recent studies (for example Allen & Barnes, 1985; Grainger, 1986; Palo, 1987; and Rudel, 1994) in which both the static and the linear analysis has been applied to a dynamic deforestation problem. These analyses are based on simple linear multivariate regression methodology, and generally neglect possible non-linear interactions between the factors, and the dynamic feedback between the factors. In fact, the focus of recent studies is on causal factors of deforestation rather than on the interactions of factors, and totally neglects the complex and dynamic nature of the deforestation process. A systems approach is required to overcome these limitations and to gain a meaningful insight into the role of population or any other factor in deforestation.

In general, the approach adopted by the previous authors has been linear, static, and partial. In contrast this paper develops a dynamic systems model founded on a complex, dynamic and a comprehensive approach. The approach is complex in that it incorporates a web of relationships (or interactions) among various factors (or variables) that influence the process of deforestation. The approach is dynamic in that it focuses on the patterns of behavior (of the forest stocks and flows) over time rather than on individual events (a snapshots of their values in time), and is comprehensive in that it does not take partial view (looking at only the forestry sector); rather it shows that interplay between the web of relationships among sectors of the system that causes dynamic deforestation behavior. Further, while the constructed model is based on the operational values for a single country (India), it is general enough for any geographical unit.

A SYSTEMS MODEL OF DEFORESTATION

To capture the complex and dynamic nature of the deforestation process, a systems dynamics approach is used to model the process of deforestation. Systems are comprised of interrelated relationships and the combination of these interrelationships is called the structure of the system. The relationships may be linear or non linear. Because the relationships are interrelated, the structure produces dynamic behavior in the system. A system approach is designed to uncover the performance of the system over time. The conceptual application of the building blocks have largely been drawn from Saxena & Nautiyal (1996).

Generic Building Blocks

In a systems model stocks area signified by rectangles. They are accumulators and can be used as barometers of the system. Stocks reflect conditions within the system at a point in time. When one takes a snapshot of the system, all flows cease and accumulations remain. Therefore, the accumulations reflect the state of system at any given point in time. These stocks also act as a buffer and as a resource in the system. They build or decline whenever their associated rates of inflow and outflow are out of balance with one another. For example, Total Forest Area (TFA) and Forest Biomass (FBM) are the primary forestry barometers of system. A decline in TFA or FBM indicates that deforestation is occurring. Halting deforestation means stabilizing both of these stocks.

Flows are signified by a pipe (or conduit), with a spigot or flow regulator and an arrow showing the direction of flow. Flows can be unidirectional or bi-directional, indicated by a single arrow or double arrow, respectively. The specific volume of the flow is calculated by the algebraic expression in the flow regulator. Flows generally are measured in the same units as the stocks. However, some flows involve transformations (such as logs being processed into lumber), and can be unit converted flows. The unit calculations ensure the dimensional consistency of the model. Production, removal, and change in forest area are examples of flows in the system.

Converters are "catchalls" and are represented by circles. They convert inputs into outputs, and can represent either material quantities or information. They are used to elaborate the details of the stocks and flows of the model and are sometimes used to substitute for a stock concept. For example, the population converter in the model is replacing the population stock variable because population stock is considered exogenous. If the specific processes that fill and drain a stock are unimportant, converters can be used as substitutes. Converters are also used to combine several flows. Converters do not accumulate (that is, can not act as a buffer) and, as a consequence, there are no delays between successive converters. An example of a converter is productivity per hectare.

The final building block is the Connector. Connectors link stocks to the converters, stocks to flow regulators, flow regulators to flow regulators, and converters to flow regulators. It is useful to think of connectors in terms of wire carrying electricity and flows in terms of pipe carrying water. Connectors do not take any numeric values. Connectors reflect assumptions about "what depends on what." For example, the model illustrates that the production of forest biomass depends on the productivity per hectare and the total area of forest. Therefore, connectors are used to connect production to productivity and total forest area.

MODEL STRUCTURE

In the past, the focus of deforestation models has been on the geophysical unit, that is, on forest area (Allen & Barnes, 1985; Grainger, 1986; Palo, 1987; Palo *et al.*, 1987; Khator, 1989; Rudel, 1989; Scotti, 1990; Rudel, 1994; Shafik, 1994). The independent variable in these studies has been "forest area" or some derivative of "forest area" such as "average forest area lost per year", or "the ratio of forest area lost to the initial forest area". While these definitions account for changes in the geophysical unit, they neglect the changes occurring in biophysical unit, that is, forest biomass. The FAO (1993) definition implicitly incorporates the biophysical aspect of deforestation by incorporating the crown density limit of 10%. However, this definition also will not be able to capture complete behavior of forest biomass. For example, if crown density decreases from 15% to 9%, the process will be termed as deforestation, but if the crown density decreases from say, 90% to 15% the change will not be captioned as deforestation under the FAO definition. Indeed, the impact of change in crown density from 90% to 15% will be serious enough to attract attention of the forestry policy planners. The limit of 10% seems to be arbitrary. Therefore, to be more realistic and to incorporate the dynamic nature of the deforestation process, it is useful to focus on both forest area and forest biomass in measuring deforestation. In this model, deforestation will explicitly include changes in the behavior of the geophysical unit, that is, total forest area, and the behavior of biophysical unit, that is, total forest biomass. The declining behaviors of either of these two stocks will be used to characterize the process of deforestation.

For the purpose of illustrating a *Systems Dynamic Model* of deforestation in general, and the above-mentioned concepts in particular, we enlarged the model of Saxena & Nautiyal (1996). In this model, a system is conceived of four sectors in addition to forests. These are called the agriculture, socio-economic, energy and livestock sectors. These sectors compete for forest land use or for forest produce. The process of deforestation is seen in terms of the dynamic interactions between these five sectors.

The forest sector interacts with the agriculture sector primarily through forest land area. A part of forest land is frequently under encroachment by the people at the margin. These people grow food for their sustenance. Another link between the agriculture and forest sectors is through the use of cultivable land which can be either used for agriculture or for forestry plantations. The connection is established through the dynamic flow mechanisms, called the land development rate and the plantation rate. The land development rate links the stocks of cultivable land and the area in food, while the plantation rate connects stocks of cultivable land and the stock of forest plantation. In addition to the above relationships, the trade in agriculture products also affects the land development rate for agriculture, and thereby diminishes available land for forest plantations. In short, the competition for land use between forest and agriculture depends upon the interplay of relationships within and between the forestry and the agriculture sectors. Besides these interactions, there are various other relationships between forest and agriculture which act through a web of relationships incorporating environmental factors such as soil structure, rainfall pattern, shelter belt, and the microclimate. All of these factors are affected by forests and in turn affect the agricultural crops. Their effects are incorporated in the agriculture and forest sectors by using time functions for agriculture and forest productivity.

Besides agriculture, the forest sector affects, and in turn is affected by the socio-economic, energy and livestock sectors. For example, the behavior patterns of both the forest land and forest biomass are determined to a great extent by their use in the social and economic life of the people. Forest lands are encroached upon or diverted for economic needs such as for industries, mining, dams, roads, and any other infrastructure development. Sometimes, diversions of forest land may be to hold value (speculative asset value) and not for its productive functions (for example, in Brazil, in times of inflation forest land was used as an asset to hold value).

Another barometer of the forest, the stock of forest biomass, is also affected by the fractions of forest biomass removals for fuelwood, industrial wood and fodder. These removals have been identified as one of the causal factors of deforestation (Allen & Barnes, 1985; Repetto & Gills, 1988; Chakraborty, 1994). However, these factors are not only the causes but the consequences of the social and economic structure of society. For example, fuelwood removal is an outcome of the interplay between various factors, such as between population, economic poverty, settlement structure (for example, the rural or urban distribution of population, the energy composition and the consumption pattern in a country. Similarly, industrial wood removal also depends upon the structure of the economy (particularly on the number of wood or wood product consuming industries and their capacities, and the requirement of industrial wood or wood products for trade). These removals in turn affect the state of forest regeneration and thereby the forest productivity.

Similarly, livestock sector grazing affects both the forest biomass removal and the forest regeneration. Forest biomass removal is affected by the size of the livestock sector, the fraction of livestock grazing in the forests, and the fodder requirements of livestock, while the forest regeneration is affected by the intensity of grazing (number of livestock grazers per unit of forest area). High intensity of grazing leaves the forest area degraded, and eventually completely unproductive which, in turn, supports a reduced number of livestock units. The reduction in grazing potential negatively impacts the livestock size (that could be sustained by forest grazing). Thus, the livestock sector has a significant impact on the forest sector which in turn affects the livestock sector.

The complete model structure is presented in Figure 1. The model emphasizes that the interactions of factors and sectors within the system produces the dynamic and complex behavior of the deforestation process. Each sector is seen to be in a state of dynamic interaction within and between the other sectors. The details of each sector are attached in appendices under respective sector headings (see Appendix, Table A1 to A6). The interaction of each sector's operational elements are specified through mathematical equations, also attached in the appendices.

The model comprehensively incorporates the linkages between population growth and deforestation (for example, emphasized by Hardin, 1968; Mathur, 1976; Bowonder, 1982; Tiwari, 1983; Allen & Barnes, 1985; Grainger, 1986; and Palo, 1994); between poverty and deforestation (suggested by WB, 1978; WCED, 1987; Bojo *et al.,* 1991); between trade and deforestation (Tucker & Richard, 1983; Guppy, 1984; WRI; 1985; Richard & Tucker, 1988); between agriculture productivity and deforestation (suggested by Reis & Guzman, 1994; Southgate, 1994), and the linkage between distorted developmental choices and deforestation (emphasized by Haeuber, 1993). The model in a nutshell, suggests that emphasis on individual factors such as population or trade or individual productive activities (shifting cultivation, logging or diversions) in explaining the complex and dynamic process of deforestation will be an incomplete and potentially misleading approach. Rather, it is the interplay of interrelationships within the interacting sectors of a complete

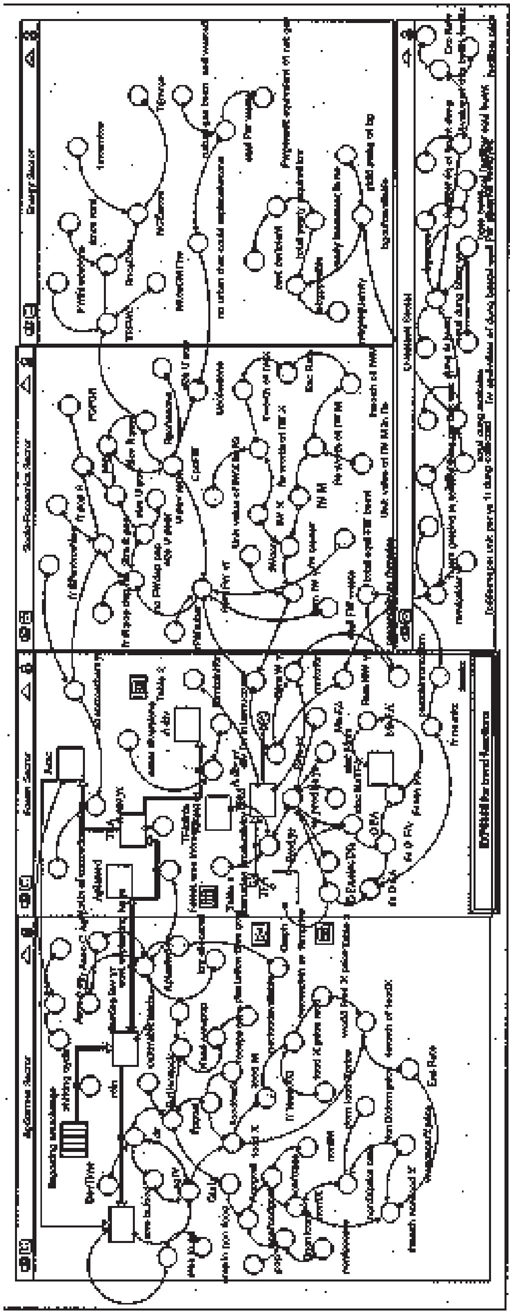

Figure 1. A Five Sector System Dynamics Deforestation Model.

system that explains and drives the process of the deforestation. The interplay varies from country to country and over time. Therefore, there can not be a single set of policies for ameliorating deforestation. Rather, the policy packages will vary in different countries and at different times. However, the suitability of a policy package for a given country can be explored by using a systems model that highlights the intersectoral interactions on a systems level. The key issue in understanding deforestation is to understand the interactions between the factors and sectors of the system.

Operationalizing the Model

Deforestation in India is used as an operational example. Currently available data are used to establish the numeric values in the model (see Appendix). The initialization values and sources of some of the important elements are given below in the Table 2; other values can be seen from equations in appendices.

Indian forests as well as foresters are facing a great challenge. The challenge is to avert the looming environmental disaster in a land scarce and in-

TABLE 2. INITIALIZATION VALUES AND SOURCES.

NAME OF ELEMENT	INITIALIZATION VALUE	SOURCE
1. Total Forest Area (TFA) of India (1993), Dwivedi (1994)	64.01 million hectare.	Forest survey
2. Forest biomass	4090,000,000,000 kg	FAO (1993)
3. Area in Food	127.8 million hectare	GOI (1994)
4. Population	828 million	Bose (1994)
5. Cultivable land (culturable waste + fallow other than current fallow land)	24.5 million hectare	GOI (1994)
6. Standard Livestock units	321 million	Rao (1994)
7. Total energy consumed in 1990	199 (mtoe) in million tons of oil equivalent	Estimated value Mehetre (1990)
8. Fraction of non-commercial energy in mtoe	0.53	Mehetre (1990), World Energy Council (1992)
9. Fraction of non-commercial energy consumed in rural areas	0.79	Mehetre (1990), Khoshoo, (1994)
10. Fraction of rural population dependent on fuelwood	0.8	Khoshoo (1994)
11. Fraction of dense forest area	0.60	FSI (1993)
12. Fraction of open forest area	0.39	FSI (1993)
13. Industrial wood consumption	16*10^6 million ton	FAO (1993)
14. Urban Poverty ratio	0.4012	Planning Commission (1993)
15. Agriculture food productivity per hectare in 1990	1382 kg	GOI (1994)
16. Natural gas burnt	19..27 cubic meter	GOI (1992)
17. Plantation productivity in kg per hectare	4000 kg	Chaturvedi (1994)
18. Area in plantation	18900000 hectares	FAO (1993)
19. Area planted on average per year	1.2 million hectare	Mukerji (1994)
20. Fodder required per unit per day for a standard livestock unit	5 kg	Rao (1994)

dustrializing country, and to meet the forest product needs of its growing human and livestock populations. The main task for the foresters, therefore, is to resolve the conflict between the conservation and development policies, and to sustain the forests. India, therefore, provides an important illustrative example of this approach to the analysis of deforestation.

Currently India has 64.01 million hectares of forests, but only about 0.08 hectares of forest percapita. Indian forests are under immense pressure. Many poor people both living in and around forests depend heavily on forests. They either directly meet their subsistence needs from the forests or through the income generated from the sale of the forest produce (including fuelwood, timber and non-timber products).

Fuelwood is still the dominant form of household energy for both the rural and the urban poor population. Although the percentage of both rural and urban poverty is decreasing over time, the total number of the poor people who are dependent upon forests for fuelwood have not diminished because the absolute number of population has increased faster than the decline in poverty ratio over time (1951–1991).

A large part of livestock grazes in natural forests which causes serious damage to regeneration and young plantations. Currently, India has 0.6 hectare of forest area per grazing livestock unit, while ecologically the minimum required area of threshold is estimated at 2 to 3 hec-

TABLE 3. TFA: ACTUAL AND SIMULATED VALUES.

YEAR	TOTAL FOREST AREA (TFA) RECORDED BY GOVERNMENT OF INDIA (1994) IN MILLION HECTARE (MHA)	SIMULATED VALUES OF TOTAL FOREST AREA (TFA) BY THE MODEL IN MILLION MECTARE (MHA)	DEVIATION PERCENTAGE
1951	40.4	40.4	0
1961	54.0	51.1	+5.3
1971	63.9	62.9	+1.5
1981	67.4	68.4	–1.4
1991	67.9	70.2	–3.3

tares per livestock unit on average forest areas in India (Mathur, 1976). This disparity between the threshold and the current area of forest per livestock unit clearly indicate that the livestock pressure in India is much beyond the capacity of its forests to sustain livestock and in turn itself. Besides pressures on forest biomass, the forest areas are the only remaining source for agriculture land. Shifting cultivation and diversions are prevalent (WB, 1993). Also mining, dams, road constructions, transmission lines, hydel and other infrastructural projects continue to reduce the forest area. However, forest plantations if carried on other lands can contribute to an increase in forest areas. But, plantations are subjected to intense grazing pressures, fire and insect damage. Consequently, the productivity per hectare is low (0.8 cmt /ha/year) in comparison to the world average of 2.1 cmt /ha/year. Therefore, there is urgency to develop policies to manage forests sustainably and augment the forests production flow. In order to do so, the first step is to understand the dynamic process of deforestation as impacted by the interactions between the factors and the sectors over time.

Model Validation

The model is validated by reproducing historical behavior of total forest area from 1951–1991. The model uses 1951 values as initial values instead of 1990 values, and uses dynamic functions to incorporate changes that might have occurred over time in the element values of the model (see Saxena, 1997).

During the last 40 years (see Table 3) TFA behavior, as simulated by the model, finds close resemblance with the recorded behavior of TFA, as reported by the Ministry of Agriculture (GOI, 1994). This resemblance to the past behavior instills confidence in the predicted behavior of TFA. Unfortunately similar historical data do not exists for the forestry stock, FBM.

RESULTS AND DISCUSSION

In order to fully appreciate the role of interactions in the process of deforestation and to explore the alternative policies for halting deforestation, the results of the model are discussed in four steps. First, the base case scenario results are presented. These show the dynamic outcome of current policies assuming no policy interventions. Second, the results of "forest only" interventions are discussed. These results show the impacts of forest conservation and development policies in isolation from other policy initiatives. Third, the results of more broader policy initiatives, such as changes in population, poverty, the rural-urban population distribution, fuelwood and energy structure, and livestock policies are discussed. These results provide essential insights into how other sector impinge on the health of forestry resources. Finally, results for a combination of the forest and other development polices are presented and analyzed. These results demonstrate that if Indian forests are to be sustained, forest policies will have to be designed in combination with polices in other sectors. Foresters will have no choice but to look beyond the forest sector to sustain forests.

The Base Case Scenario

In the base case scenario, or the "business as usual approach", the model uses the values of the system's elements set at the 1990 levels (Table 2). Therefore, the base case output reveals the outcome of no new policy interventions and thus provides a reference for comparing the impacts of the various alternative policy interventions. As a comparison it also provides an opportunity to understand the implications of future changes in population and other important variables on deforestation. In the base case scenario, the population value is set at a 1990 level of 828 million. It is known that the population will rise in the future. Therefore, expected impacts of an increase in population on deforestation can be obtained by comparing the two sets outputs, one for the base case scenario, and another for the rising population scenario. Similarly, an insight into the impacts of other policies can be appreciated by using the base case scenario as a comparison. The results of the base case scenario for the variables of immediate importance to forestry sector are presented in Figure 2. The numbers on vertical axis show the display range scales for the five chosen elements (area in food, cultivable land, forest biomass, total forest area, and area planted per year) in their respective units, and the horizontal axis shows simulation time displayed in years. For example, vertical axis displayed "area in food" in the range 128 million hectares to 142 million hectares. Other elements are interpreted similarly.

In this Figure 2, the stock of forest biomass (curve 3) declines from the outset and reaches zero in the year 2015. This deforestation is due to the fact that forest biomass removal exceeds the growth rate. When

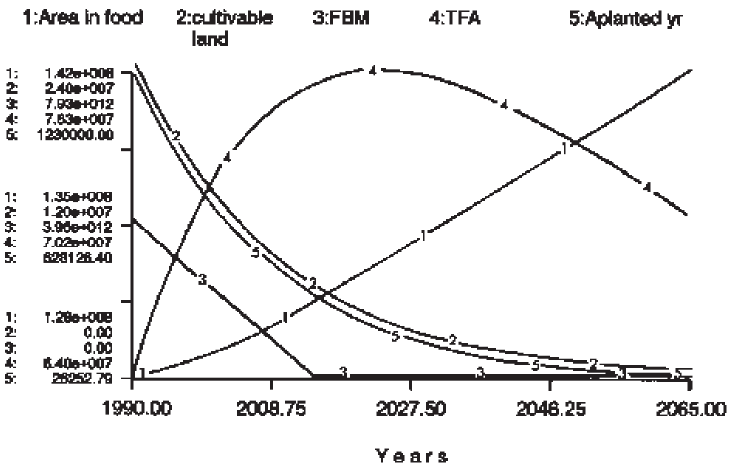

FIGURE 2. BASE CASE SCENARIO OF FIVE SECTOR MODEL.

the stock is completely depleted in the year 2015 the removals are limited to annual production. The potential consequences of the FBM completely depleting within three decades are not pursued in this study, but clearly they may be catastrophic.

The *total forest area* (curve 4) exhibits a non-linear behavior over time, increasing continuously from the 1990 level of 64 million hectares to a level of about 76.3 million hectares in 2025, and thereafter, TFA declines once again emphasizing the deforestation process. The increase to 2025 occurs because plantations exceeds diversions and encroachments. In the base case scenario, the plantation rate is assumed to be positive but continuously falling. After 2025 the posited increases in plantations are insufficient to offset the reductions due to diversions and encroachments. The FSI (1991, 1993) attributed increases in TFA to forest plantations that have outstripped diversions and encroachments, but with the current polices it seems that the optimistic picture seen in the mid 1990s will be relatively short lived.

To better understand these forestry results, it is necessary to evaluate other elements in the system. The *area under food production* (curve 1) increases continuously from its 1990 level of 127.8 million hectares to 141 million hectares in the year 2065 in response to sustain food production. Every year large forest areas are encroached for subsistence agriculture farming by the shifting cultivators. However, in spite of increase in area under food production, per capita net availability of food has been declining over the years (GOI, 1994). This exacerbates the need to bring more area under agriculture and indeed more and more areas are worked upon by shifting cultivators every year. The need to convert more forest areas is compounded by the low agriculture productivity resulting from the serious problem of soil erosion particularly in the areas where shifting agriculture is practiced. The observations by FSI (1987, 1989, 1991, 1993) especially in the tribal areas of Orissa, Madhya Pradesh, Andhra Pradesh and North-Eastern States supports the above observations.

The stock of *cultivable lands* (curve 2) that includes fallow lands and cultivable lands shrinks over the period 1990–2065 covered by the model. There is little need to look for the reasons. With fixed total land area and increasing pressures for food production little else can be expected.

The *area planted per year* (curve 5) outside the conventional forest area is expected to decline during 1990 to 2065. The reason is the decrease in cultivable lands available for forest plantation due to the increasing pressures for food production.

In short, these results are driven by cumulative effects of the current (in the model 1990) levels of population, low agricultural productivity in areas under shifting cultivation, the high level of livestock grazing and the present socio-economic structure of the population. In particular, the levels of rural-urban poverty, the land inequality, and the control of elite in development planning. The distortion in energy level planning is one example of elite and urban oriented policy results in impingement on forest resources. Almost all of the energy sector investments are directed for increasing the supply of the commercial energy (mostly consumed by the rich and the urban population) while 80% of the people depend on non-commercial energy. The distortion in energy planning forces a high level of fuelwood consumption by the poor and the rural people. The distortion in development planning is further accentuated by the existing financial fragmentation and suppression. The result of all these interactions is that the annual outflow of forest biomass far exceeds the annual production capacity of the forest.

It is important to note that these results are obtained under the assumption that the values of all the elements in the system continue to remain at their 1990 level over the time horizon of the model. In reality, the elements are dynamic in nature, therefore, the values will change. For example, the population will not remain at the 1990 level, it will increase. The agriculture productivity of food production may possibly increase. And similarly many other elements of the system will change. In order to understand the important dynamics of the model and to investigate the impacts of changes in some of the elements of the system on deforestation, the model was used to simulate these impacts one at a time. In all cases, the effects on deforestation are evaluated.

Impacts of Forest Conservation Policies

In the process of ameliorating deforestation, foresters generally focus their attentions on forest conservation policies: such as increasing plantations, increasing protection of the existing forests and consequently increasing the density of forests, and increasing the productivity of plantations through genetic or other technological measures.

To examine the policies in the forestry sector in isolation from the development policies of other interacting sectors (such as policies for population control, poverty alleviation, rural energy planning and the livestock control), the model was simulated by holding development policy parameters at current 1990 levels so as to reflect the business as usual approach, and introducing forest conservation policies. By focusing only on policies of forest plantation and forest conservation could the forest biomass and forest area be sustained?

The efforts of forest conservation were incorporated by incrementally changing the fraction of dense forest area from the current 60% to 100% (theoretically the upper limit of forest conservation). The density of forest can be increased by the increasing forest plantations on forests areas, increasing forest protection of the existing forests by increasing the protection staff, increasing penalties for forest removals, and devising effective forest institutions to manage the forests. The increases in productivity of forest from its present level of 1000 kg per hectare to 1500 kg per hectare can be brought about by planting genetically productive materials, improving other input levels such as fertilizers, and water at early stages of plantation establishments, reducing incidence of forest fires, diseases, and insects. All of these activities demand increased investment on forest research and on enhanced protection of plantations.

The increased plantation efforts were introduced by relaxing the financial constraints; that is by increasing the value of investment for plantation from 8,000 million rupees to 10,000 million rupees, and reducing the cost of plantation from 6,000 rupees per hectare per year to 4,000 rupees per hectare per year. The efforts of agro-forestry plantations were also incorporated. Operationally agro-forestry is equivalent

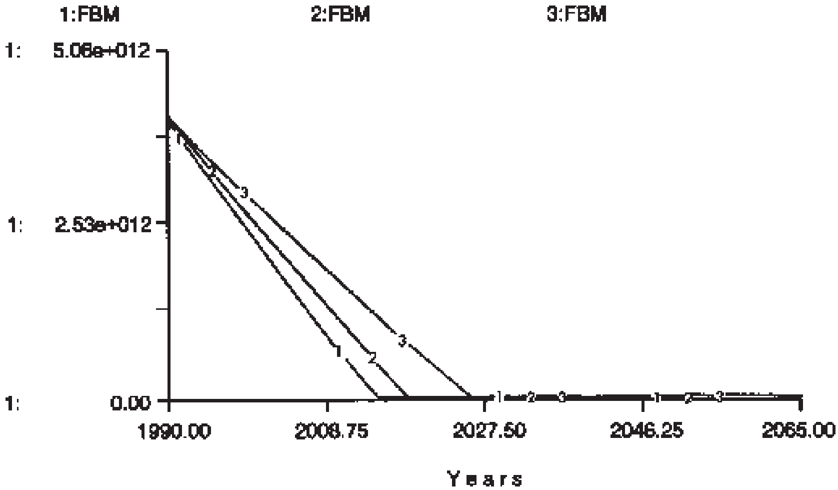

FIGURE 3. IMPACTS OF FOREST CONSERVATION POLICIES.

to the increased availability of area for forest plantations. This effect was incorporated by increasing the value of available cultivable lands. The results of these changes are summarized in Figure 3.

These forest conservation policy measures indicate that improving forest protection, increasing the financial flow for forests plantation and improving the productivity of dense forest have a significant positive effect on the stock of FBM. But despite these measures, the dynamic behavior of the FBM does not change. FBM remains a declining stock. The forest biomass is not sustainable. The results clearly indicate that by *simply focusing on forest conservation policies, the desired goal of sustaining forest biomass in India will not be met*. Conservation policies that focus solely on forest are not sufficient for forest biomass sustainability.

Moreover, the behavior of TFA does not change (see Table 4) by simply focusing on forest conservation policies of increased plantations, increased protection reflected in increased density of dense forests, and technological improvement, bringing improvement in productivity per hectare. The explanation of this behavior lies in understanding the dynamics of area change; the forest area change is governed mainly by policies of the agriculture and socio-economic sectors that drive the competition between forest and other uses for land. Therefore, if the policies that affect land competition are not addressed, the behavior of TFA will not change.

TABLE 4. IMPACT OF "FOREST-ONLY" INTERVENTIONS.

POLICY SCENARIO SIMULATION MILLION	YEAR AT WHICH FBM VANISHES	TFA AT THE END OF PERIOD (2065) IN HECTARES
1. Base case scenario	2015	70.4
2. "Forest-only" interventions	2026	70.4
3. "Forest-only" interventions with emphasis on Forest Conservation Act (1980)	2028	81.2

The Forest Conservation Act (1980) in India was a concrete step in this direction and addresses the issue of forest area dynamics. Its impact goes beyond the conventional boundary of forestry sector, and regulates and monitor the forest diversions and encroachments triggered by the other economic and demographic policies. When "forest only" interventions include the effect of Forest Conservation Act (1980); that is, by assuming a reduction in average encroachment from 12,500 hectares to 6,000 hectare per annum, reduction in average diversion of 12,000 hectare to 6,000 hectares per annum, and reduction in percentage of rural population engaged in encroaching the forest from its present level of 0.17 percent to 0.008 percent, the model suggests a significant impact on TFA (see Table 4). Further, the behavior of FBM does not change, FBM remains a declining stock, but the sustainability of FBM is marginally improved, now FBM will last two more years, that is, till 2028.

However, the act is not sufficient. Because it cannot isolate the forest sector from the effects of other sector policies. Policies related to agriculture yield, and population growth in rural areas affect TFA because these policies effect the land competition between forest and other sectors, while the policies addressing the issues of population control, rural energy consumption and the livestock grazing may affect FBM because these policies impact on the dynamics of forest biomass; that is, forest production and forest biomass removals.

Two important results emerge from the forest conservation policy simulations:

(1) FBM and TFA are subject to different policy influences, since forest sustainability requires the stability of both elements, different sets of policies are required to sustain them. In this simulation forest conservation policies impacted FBM but not TFA (until Forest Conservation Act (1980) is enforced) because these polices effect primarily the production flows and were not addressing the dynamics of forest area.

(2) Forest Conservation policies in isolation are ineffective in sustaining the stock of the forest biomass (FBM). The "Forest only" interventions can significantly effect the biophysical production flow per hectare per year, but these interventions are primarily based on technological aspects in isolation from the other sector's use of the forest resources, and thereby fail to direct and control the removal outflow per hectare per year. By increased forest productivity and conservation efforts, the forest sector managers can delay the FBM depletion, but *the forest sector policies in isolation to the other development policies are ineffective in sustaining the forest biomass in India.*

Impacts of Development Policies

Given the apparent lack of success in forest conservation policies in maintaining forest sustainability, alternative socio-economic policy interventions to sustain forests in India were investigated. Various policy alternatives such as the (negative) influence of population growth on forest biomass, the positive relationship between poverty alleviation and the loss of forest biomass, the positive relationship between the distortion in energy planning and the rural fuelwood consumption and the positive relationship between control on livestock grazing and the rate of forest biomass loss were examined.

To examine the role of factors (for example, population or trade) and sectors (agriculture, energy, socio-economic or livestock) on total forest area (TFA) and forest biomass (FBM), our analysis has been conducted in two steps. First, the population value, is increased, keeping the values of all the other elements set at their 1990 levels (see Table 2). The effect of increasing the number of human bodies on TFA and FBM is examined. This establishes the impacts of increased population alone on deforestation. Second, the population value is changed along with changes in values of various important policy variables such as the poverty ratio, the percentage of rural population, the energy consumption structure and the fraction of livestock grazing. This enables us to measure the impacts of these variables on deforestation in conjunction with population increases. The graphed output of these sensitivity analyses explicitly demonstrates the effect of the change in the population on the total forest area and on forest biomass, first in isolation from socio-economic changes, and then combined with changes in other socio-economic elements. The results of these sensitivity analyses (see Table 5) provide insights into the effectiveness of alternative development policies for controlling deforestation.

Population Policies

As noted in the review of recent deforestation studies, population is often mentioned as an important causal factor in deforestation. Hypothetical population increases were examined in two separate simulations over the period 1990–2065. The population totals considered increases from the current 828 million to one and 1.2 billion persons. All the other elements were as in the base case scenario. With every increase in population the FBM curve shifts downward (see Figure 4). Increases in population result in forest biomass depletion at a higher rate. This finding supports the population increases accelerates the process of forest biomass depletion. The population increases negatively effect the production rate by reducing the forest area (through diversions and encroachments) while simultaneously increasing the forest removal rate by the increasing the fuelwood removals.

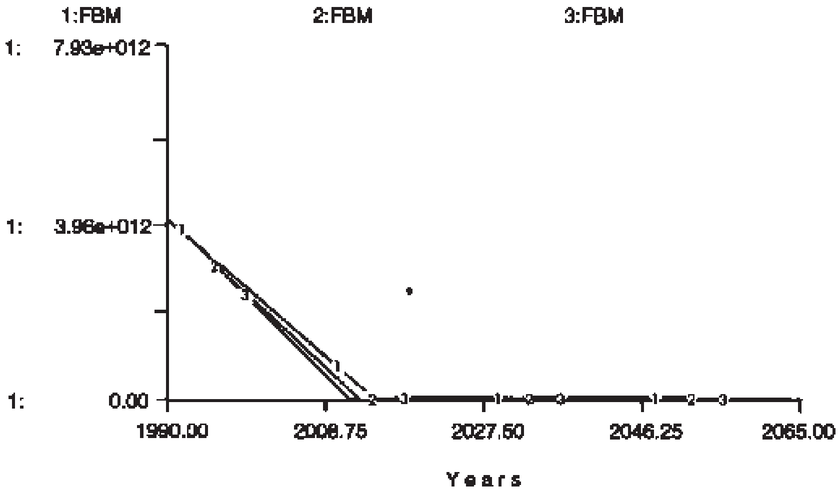

FIGURE 4. IMPACT OF POPULATION INCREASE ON FOREST BIOMASS.

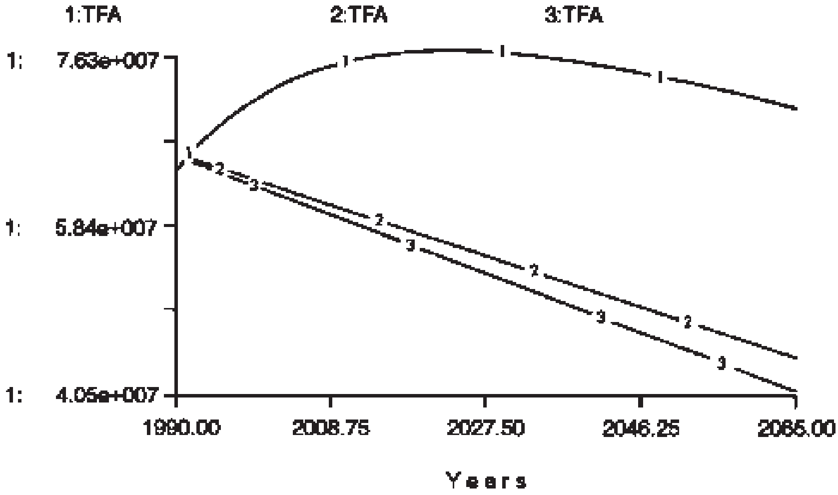

FIGURE 5. IMPACT OF POPULATION INCREASE ON TOTAL FOREST AREA.

The effect of an increase in population is also visible on the stock of total forest area (see Figure 5). The stock of total forest area shrinks at a faster rate than in a "no population" increase situation. The TFA curve no longer experiences a rising section over the next 20 years and instead slopes downwards throughout, indicating a negative effect from an increase in population. This confirms that increases in population in India on their own reduce both the stock of forest biomass and the stock of forest area. Therefore, policies aimed at reducing population growth will positively affect the levels of both stocks of forest biomass and total forest area.

Can these negative impacts of increased population on forest sustainability be overcome? This question is examined in the model by changing values for a variety of other policies variables such as the urban poverty ratio, the percentage of rural population, and the energy-consumption structure. What is to be observed is whether the negative ef ect of population on FBM and TFA gets mollified or accentuated. The two population simulations now become the base case for evaluating the effects of above mentioned changes.

Poverty Policies

In order to examine the effect of poverty on forests, the urban poverty ratios were assumed to decline from 40.1 percent to 30.1 to 20.1 percent along with the two increases in population. The reduction in poverty gives a small positive boost to the forest biomass as indicated by the upward shift of FBM curve, but it still results in a declining curve. Forest sustainability while improved does not result from this policy

It is interesting to observe that a reduction in the urban poverty fraction from 30.1 to 20 percent nullifies the effect of an increase in population from 1 billion to 1.2 billion. The FBM curve shifts upward (positive) when the urban poverty ratio is decreased which compensates for the downward (negative) impact of an increase in population inputs on FBM. This observation confirmed another hypothesis that a *ceteris* *paribus* decrease in urban poverty positively affects the stock of forest biomass. This is primarily because the number of urban poor people dependent on fuelwood for their energy needs reduces with the decrease in urban poverty ratio. Indirectly, the decrease in urban poverty provides an incentive for the rural migration and the percentage distribution of rural and urban population will change. Therefore, in the long run, the rural poverty amelioration programs must be targeted as a priority

The issue of rural poverty was not separately discussed because most of the rural-population is dependent on the forest biomass for their energy needs unlike the urban population where only poor urban people are the primary biofuel consumers. However, the impact of rural poverty is accounted by varying the fraction of rural people dependent on fuelwood.

The results of the impact of urban poverty on the total forest area (TFA) are shown in Table 5. These results suggest that a reduction in urban poverty does not have any noticeable impact on TFA. Urban poor people affect only the forest biomass consumption while rural people who are primarily engaged in land based economic activities (for example agriculture, forestry or mining) affect both the forest biomass consumption and production. This is because the number of rural people affect forest biomass consumption and the nature of their economic activities affects biomass production by affecting one of the production inputs — the forest area. Hence, a change in the consumption of the urban poor simply affects the forest biomass depletion rate and the forest area, which is a physical input of forest biomass production, and is not affected by decreasing the urban poverty ratio. This suggests that forest area is independent of urban poverty variations. However, programs directed towards the amelioration of rural poverty (which affect

Table 5. Impacts of Non-Forest Policy Interventions.

Policy Scenario	Year at which FBM Vanishes	Value of TFA at the End of Simulation (2065) in Million Hectares
1. Base case scenario	2015	70.4
2. Population increase to 1.2 billion	2012	42
3. Urban Poverty amelioration with scenario 2 measures	2013	42
4. Reduction in fraction of rural population along with poverty but population increase	2012	48
5. Reduction in fuelwood dependence along with scenario 4 measures	2018	48.3
6. Change in energy consumption structure expressed by a reduction in fraction of non-commercial energy consumption along with scenario 5 measures	2024	48.3
7. Change in energy structure with focus on rural areas along with scenario 6 measures	2028	48.3
8. Increased investment on alternate energy, and reduction in their cost along with scenario 7 measures	2037	48.3
9. Agriculture productivity increase impact along with policy measures of scenario 8	2106	
10. Decrease in fraction of forest grazingfrom 30% to 20% along with scenario 9 measures	2115	48.3

both area and forest biomass) may be of greater policy significance than those directed at the urban poverty amelioration.

Rural-Urban Distribution Policies

In addition to the impact of a reduction in the urban poverty ratio, reducing the percentage of rural population from 70 percent to 60 and 50 percent improved the TFA stock but does not change the behavior of the FBM stock (see Table 5) because the rural migration swells the urban population and the number of urban poor. Consequently, the number of forest encroachers reduces and forest encroachments are reduced leading to a small positive boost is observed in forest area. However, the impact of reduction in urban poverty on FBM is nullified by swelling number of slum dwellers. This finding supports the suggestion that rural poverty must be a priority in poverty alleviation programs that will have a positive effect on both the forest biomass and the forest area. Further, these results demonstrate that the sum of the positive effect of the reduction in urban poverty and the reduction in the fraction of rural population do compensate to a large extent for the effect of increased population. However the negative effect of increased population is not fully compensated for by the positive effects of the reductions in both the urban poverty ratio and the percentage of rural population.

RURAL ENERGY POLICIES

Another policy initiative that can impact on forest sustainability is the rural energy policy. A reduction in the dependency of rural people on fuelwood can more than compensate for the negative effect of a population increase on FBM stock. Currently 80 percent of the rural population is dependent on fuelwood for their cooking energy needs. If that fraction is reduced to 50 percent by the enhancement of biogas and other energy sources the FBM sustainability will further improve and FBM will last longer (see Table 5). This suggests that impact of policies directed towards ameliorating the dependence of people on fuelwood will be somewhat effective in delaying depletion of the stock of forest biomass. Nonetheless, there is still a decline in FBM throughout the projection period (Table 5). FBM now disappears in 2018. The policy changes of a reduction in fuelwood dependence does not have any perceivable impact on TFA since the reduction in fuelwood dependence impacts the biological stock of FBM, and not the dynamics of the physical stock-area. This result once again confirms that different policy measures will have different impacts on the two stocks of FBM and TFA.

General Energy Policies

Improvements to the forests are possible when changes in population and population structure, such as rural and urban distribution (expressed through the percentage of rural population), and the energy sector are considered simultaneously. Currently in India, about 53 percent of energy use (in million tons of oil equivalent (Mtoe)) is non commercial. Non-commercial energy is obtained from fuelwood, agricultural wastes, and animal dung (Mehetre, 1991). If the fraction of non commercial energy can be brought down to 30 percent from its current level of 53 percent, it is possible to increase the positive effect on the level and the rate of depletion of the FBM stock.

In a business as usual approach the FBM stock will be depleted by 2015 (indicated by base case scenario). If the alternative set of policy measures (as indicated above) are implemented, the rate of depletion of FBM stock will fall and the stock of FBM will last longer. The altered socio-economic policies compensate more than the negative effect of a population increase. The altered policy interventions can sustain the FBM stock for a further three years. However, this is a negligible increase. Moreover, the change in energy consumption structure will not effect the forest area; instead it positively impacts (reduces) the outflow from the forest biomass only.

The positive impact of changes in energy policy on forest biomass can be further strengthened if the rural areas in particular are targeted and the current fraction of non commercial energy consumed in rural areas is reduced from its present level of 79 to 60 percent. With the changed policy measures the stock of FBM will not be depleted till 2028.

The positive effect of energy changes on FBM will be enhanced (see Table 5) by reducing the cost of supplying alternate energy, say hypothetically from 26,700 to 20,000 rupees millions/Mtoe, and increasing the investment from the hypothetical value of 800,000 to 1200,000 millions of rupees. Unlike FBM, there is no visible impact on TFA by directing energy policy changes to rural areas. The behavior of TFA remains unchanged even by implementing this policy variation, that is, by reducing the fraction of non commercial energy in rural production.

TFA was negatively affected by an increase in population, and positively affected by a reduction in the size of the rural population. Besides these two, other policy measures that have affected FBM have not affected TFA. This strengthens the policy suggestion that different policy measures are required to change the behavior of the two forestry stocks of TFA and FBM.

Livestock and Agriculture Policies

If the combination of socio-economic interventions are enlarged to include the livestock and agriculture sector policies, a noticeable change in the rate of FBM decline is possible (see Table 5). If the grazing fraction is reduced from its present level of 30 to 20 percent, and agriculture sector productivity is assumed to increase from its present level of 1382 kg/ha to 2500 kg/ha, the declining rate of FBM changes. Instead of earlier depletion, the FBM lasts until the 21st century. The reduction in grazing impacts both removal and production of forest biomass. Reduced grazing decreases the forest biomass outflow while improving the forest regeneration rates. As a result, the FBM is sustained for a longer period of time (see Table 5). The increase in agriculture productivity increases the agriculture production and reduces the demand for land.[1] As a result, the land competition between agriculture and forest decreases and subsequently the land potentially available for agriculture production or for forestry production increases; this in turn, increases the availability of area for forest biomass production.

[1] In case of India, agriculture intensification will save forests because most of forests conversion is for substance farming. However, if the agriculture technology makes converting forests to farmland more economically attractive than before such agriculture intensification may accelerate deforestation and reduce TFA. Nevertheless, Forest Conservation Act 1980 (India), prohibits conversion especially for commercial purposes.

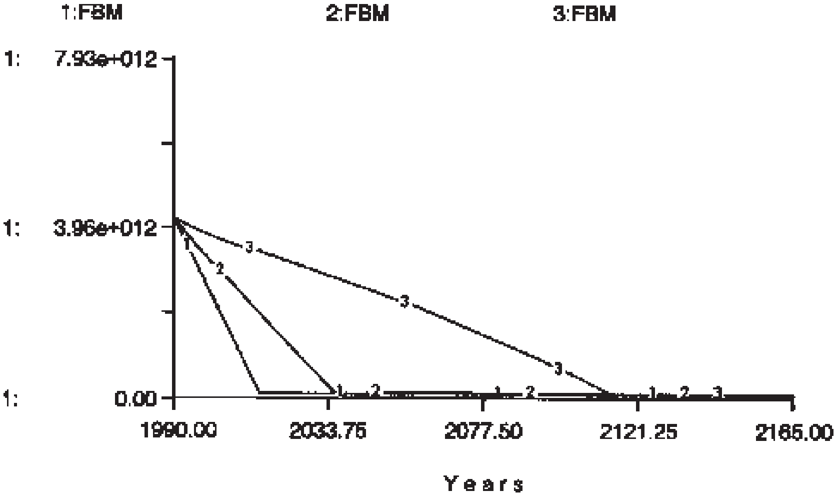

FIGURE 6. IMPACT OF ALTERNATIVE DEVELOPMENT POLICY INTERVENTIONS ON FORESTS.

The set of alternative development interventions are unable to change the declining behavior of FBM. *In short, like the "forest-only" interventions, the set of alternative development policy interventions in isolation of other interacting sector policies cannot sustain the forest biomass.* This is shown in Figure 6.

While these policies together result in a significant upward shift in the FBM curve. And FBM will last much longer (until 2115) than base case or the only forest policy intervention cases, the declining behavior of FBM stock is not altered even by the impacts of the combination of only these alternative development policy interventions. For forest sustainability — it is still necessary to find a package of policy measures that could possibly change the behavior of FBM from a declining to at least stable behavior.

The observed upward shift in the FBM curve is caused by the alternative policies that positively decrease the removal flow per hectare per year. However, these policies do not significantly affect the biomass production rate. Therefore, *the behavior of the FBM stock does not change even when these well intentioned developmental policies are implemented in isolation of forest conservation policies.*

In general, the two results obtained in the "alternative development only" interventions strengthens the results of "forest only" interventions. In particular:

(1) by altering the alternative development policy context the process of deforestation can be delayed to a large extent. However, alternative interventions in isolation of forest sector interventions fail to change the declining behavior of forest biomass. The alternative policies in isolation do not sustain the stock of forest biomass and the forest area;

(2) TFA and FBM are subject to different policy influences. Therefore, different policy measures are called for to sustain the two stocks.

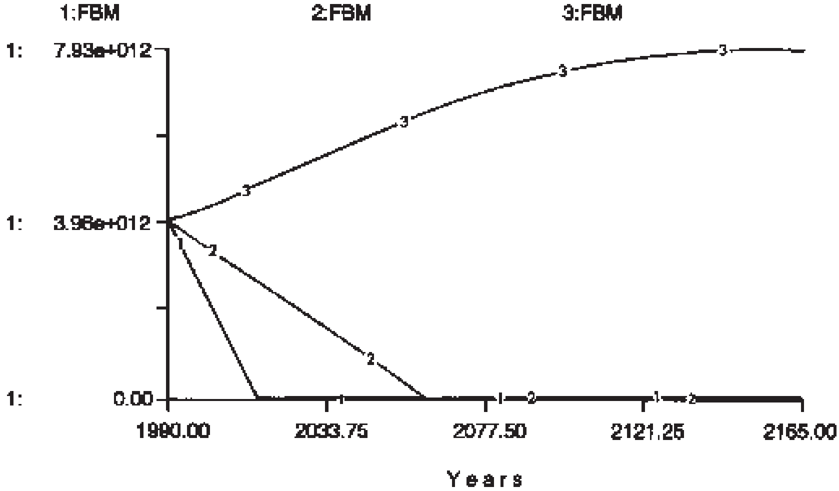

FIGURE 7. IMPACT OF COMBINATION OF FOREST CONSERVATION AND DEVELOPMENT POLICIES ON FORESTS.

The results of increasing population is to deplete forest biomass and to reduce the total forest area, while the changes in other socio-economic policies such as the development of the hinterland (small town or villages) as growth centers to reduce the fraction of rural populations and their dependence on fuelwood, the reduction in poverty, planning energy supplies dominantly for the end use of rural peoples needs, and the reduction in livestock grazing retard FBM depletion to a great extent.

Combination of Forest Conservation and Development Policies

A combination of forest conservation policy interventions and development policy interventions together provides a ray of hope to forest planners. A radical change in behavior of FBM is possible. Instead of a declining trend FBM starts moving upwards and stabilizes at a higher level of forest biomass than the initial level in the base case scenario (see Figure 7).

Thus, a combination of forest conservation and development policies, if implemented together could avert the downward trend in the behavior of FBM stock, and will result in sustainable FBM. The policy package also indicates that focusing on population policies alone will not yield the desired result of stabilizing FBM. It is essential to understand how and why the people use the forest (and other environmental) resources. Simulations with a systems model that integrates all impacts on forests demonstrates that the result of a population increase on FBM can be mollified if adequate attention is given to forest conservation policies and to ameliorating poverty, to undertaking structural changes in energy consumption (so as to reduce the fraction of non commercial energy particularly in rural belts of India), and significantly reducing the fraction of livestock grazing in forest areas.

Thus far, we have demonstrated the sustainability of FBM. it is worth observing, and considering that the above set of policy measures are not effective in changing the behavior of TFA. A different combination of policy that includes the above forest conservation and development policies along with the emphasizes on enforcement of Forest Conservation Act is required. forest conservation policy emphasizing forest conservation Act and development policy interventions, will simultaneously act both on the dynamics of forest area and the dynamics of forest biomass stocks. Either policy interventions in isolation will only significantly effect the dynamics of a single stock, that is, forest biomass or the forest area. For forest sustainability, what is required is to effect the dynamics of both the stocks: for maintaining or for improving their behavior. Therefore, the combination, that includes both the forest conservation and development policies and emphasizes the enforcement of forest conservation act (FCA) will not only alter the behavior of FBM but will also improve the stock of TFA. Forest conservation policies that include emphasizes on FCA impact significantly the dynamics of TFA and marginally the FBM dynamics by affecting only the production inflow, while the development polices impact significantly both the dynamics of FBM outflow and the dynamics of TFA by effecting the land use competition between forests and other land using sectors. In short, the development policies play a dominant role in determining the dynamics of forestry sector. However, it is the combination of forest and development polices that ensures the forest sustainability. Following the combination of the forest conservation and development policies only, India can move on the path of forest sustainability (see Table 6).

These results should be understood by the current policy planners who are trying to develop a set of policies that could stabilize FBM by focusing on the stock of TFA alone. For example, the "Forest Conservation Act 1980 India" simply focuses on the stock of forest area. It prescribes stringent rules for forest encroachments and diversion, but does not spell out any inter-sectoral policy links for the conservation of forest biomass. Similarly, "Forest Policy 1988 India" is not clear about distinct policy measures for distinct stocks of FBM and TFA. This is not surprising. In past policy studies (for example, Allen & Barnes, 1985; Grainger, 1986; Palo *et al.*, 1987; Repetto & Gills, 1989; Reis & Guzman, 1989; Scotti, 1990; Kummer, 1992; Chakraborty, 1994; Kummer & Sham, 1994), the distinct behavior of the two stocks, FBM and TFA was not appreciated, and uniform policy measures were called for to control deforestation.

TABLE 6. IMPACT OF VARIOUS POLICY INTERVENTIONS.

POLICY SCENARIO	YEAR AT WHICH FBM VANISHES	TFA VALUE AT THE END OF SIMULATION PERIOD (2065)
1. Base case scenario	2015	70.4 million hectare
2. Forest-alone interventions	2026	70.4 million hectare
3. Forest interventions with emphasis on Forest Conservation Act (1980)	2028	81.2
4. Alternative Development policy alone interventions	2115	48.3 million hectares
5.A Combination of Forest Conservation and Development Policies with emphasis on Forest Conservation Act (1980)	FBM level improves and sustained at a improved level	81.4 million hectares

Therefore, reliance on the results of the past analyses of deforestation (for example Khator, 1989; Haeuber, 1993; Chakraborty, 1994) that focused on the stock of forest area, and neglected the stock of FBM, and have not clearly demonstrated how and why the people use forestry resources, are of very limited use for designing the policy package to ameliorate the process of deforestation, and bring about sustainable forest management.

Only a combination of the forestry and development policies will be able to sustain the forest biomass in India. It is only the combinations of polices that addresses the core issue of forest interactions with other sectors, including both its biophysical nature (productivity flow of forests) and its socio-economic uses. forest or development policies in isolation cannot sustain the forest biomass in the current socio- economic milieu of India. Table 6 illustrates the general impacts of various policies. At the risk of repetition, it is worth reminding that sustainable policies require gaining insight into the behavior patterns of FBM and TFA over time and not from the snapshot policy impacts on FBM or TFA in isolation.

Conclusions

Deforestation is a complex and a dynamic process. Therefore, linear and static analyses based on one sector fail to provide the needed insights into the deforestation process, and the required policy directions for sustaining forestry development. A systems approach is needed to understand the process of deforestation. Through sensitivity analysis, the model presented in this paper shows that a focus on factors in isolation rather than on a combination of inter-sectoral interactions will be an imprudent step towards developing policies that sustain forests. The model also demonstrates that TFA and FBM are subject to different policy influences and the role of the interactions among the elements of the system is crucial in driving the deforestation process.

The socio-economic sectors provide an essential insight into how, and why, people use their forests. Policies aimed at the amelioration of deforestation need to focus on combination of forest conservation policies and the policies that address socio-economic issues. India can effectively control deforestation only if the Indian planners understand the process of deforestation on a systems level. In particular, they need to restructure the environmentally degrading energy sector to a environmentally benign sector, one which follows a soft energy path of biogasification, co-generation, and increasing the end use efficiency of energy. They also need to plan energy investments for rural needs, and implement economic development programs to ameliorate poverty of the people in rural areas, control livestock numbers and consequent forest grazing, and increase the average productivity of agriculture and forests through increased conservation in forests and development around forests. Only through measures such as these can India hope to sustain its forest biomass. The model shows clearly that a forest conservation policy implemented in isolation from policies of other sectors will be insufficient to conserve forests in the current socio-economic milieu of India.

The model explicitly includes the complex inter-linkages between agricultural, socio–economic, livestock and forests sectors. The process of deforestation is affected by the web of relationships between and within sectors. The strength of relationships can vary over time, depending upon the values of converters which affect the relationships. Because of this variation in strength between various relationships, there is a strong possibility of change in the dominance of one relationship over the other. Consequently, the cause of deforestation that could be explained by a complete set of relationships shifts with the shift in dominance of the relationship of elements within and among sectors. Hence, it is too simplistic to point out the causation of deforestation at an isolated factor level such as growth of population (for example, at Rio by the advocates from Northern countries) or growth of trade (for example, by the advocates of South in Rio). This paper shows that the deforestation can be the result of a combination of relationships. The need is to understand why one relationship dominates over the other, and why the dominance varies over time.

The question of analyzing the process of deforestation does not end with determining who is describing the truth, or which is the correct argument for explaining deforestation, but by understanding the need to link these varied truths to get a holistic picture about the complex web of factors affecting deforestation. Any partial attempts to analyze the process of deforestation will be analogous to the fabled attempt of searching for a truthful description of an elephant by seven blind persons. Each one of the single accounts may be correct but it will not be complete.

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APPENDIX A

Table A1

Land Use Trend in India (Million Hectares)

Heading	1951	1961	1971	1981	1991
I. Geographical Area	328.73				
II. Reporting Area	284.32	298.46	303.76	304.15	305.02
1. Forests	40.48	54.05	63.91	67.47	67.99
2. Not Available for cultivation	47.52	50.75	44.54	39.62	40.88
2a. Area under non agricultural use	9.36	14.84	16.48	19.66	21.22
2b. Barren and Unculturable land	38.16	35.91	28.16	19.96	19.66
3. Other uncultivated land excluding fallow land	49.45	37.64	35.06	32.31	30.51
3a. Permanent pastures and other grazing lands	6.68	13.97	13.26	11.97	11.80
3b. Miscellaneous tree crops and groves	19.83	4.46	4.30	3.60	3.70
3c. Culturable waste	*22.94*	*19.21*	*17.50*	*16.74*	*15.01*
4. Fallow lands	28.12	22.82	19.88	24.75	23.40
4a. Fallow lands other than current fallow lands	*17.44*	*11.18*	*8.76*	*9.92*	*9.59*
4b. Current Fallows	10.68	11.64	11.12	14.83	13.81
5. Net area sown	118.75	133.20	140.27	140.90	142.24

Source: (GOI 1994. Agricultural statistics at a glance. Ministry of Agriculture, Government of India. New Delhi. pp. 140).

Table A 2

Elements of Forest Sector

Stocks

1. Total Forest Area (TFA)
2. Area encroached (Aenc)
3. Area diverted (A div.)
4. Area planted (Aplanted)
5. Forest Biomass (FBM)

Flows

1. Change in Forest Area (CH FA)
2. Area encroached per year (A enc yr.)
3. Area diverted per year (A div. yr.)
5. Area planted per year (A planted yr.)
6. Production per year (Prod yr.)
7. Removal per year (Rem yr.)

Converters

1. Average size of encroachment (av. size of encroachment)
2. No.of encroachers per year (no encroacher yr.)
3. Diversion for infrastructure (div. for infrastructure)
4. Other diversions (other diversions)
5. Dense Forest Area (DFA)
6. Open Forest Area (OFA)
7. Mangrove Forest Area (MnFA)
8. Mean annual increment of dense forest area (ainc Dfa)
9. Mean annual increment of open forest area (ainc Ofa)
10. Mean annual increment of open forest area (ainc Ofa)
11. Fraction of Dense Forest Area (FrDFA)
12. Fraction of Open Forest Area (Fr OFA)
13. Fraction of Mangrove Forest Area (Fr MnFA)
14. Weighted productivity per year (wt prod ha yr.)
15. Removal of Non wood per year (Rem NW YR.)
16. Removal of wood per year (Rem W YR.)

Table A 3
Elements of Agricultural Sector

Stocks
1. Area in food production (area in food)
2. Cultivable Lands (Cultivable lands)

Flows
1. Area encroached converted for agriculture (Aenc cag)
2. Land development rate (l dr)
3. Area planted per year (A planted yr.)

Converters
1. Shifting cycle
2. Fraction of encroached area converted for agricultural food production(Fr Aenc C Agfp)
3. Cost of planting /ha./year(cost of planting ha yr.)
4. Planting investment /year (planting inv yr.)
5. Plantation time goal (Plantation time goal)
6. Population (Pop)
7. Net food available
8. Food consumption per capita (food pc cons)
9. Quantity of food consumption (Qfood cons)
10. Buffer stock of food (Buffer stock)
11. Food Trade (food trade)
12. Food production goal (Fpgoal)
13. Food exports quantity (food X)
14. Food imports quantity (food M)
15. Fraction of food quantity exported (fr food XQ)
16. Food Exports price ratio(food X price ratio)
17. Domestic Food Exports price (dom food X price)
18. World Food Exports price (world food X price)
19. Dollar worth of food exports ($worth of food X)
20. Exchange rate of Indian RS in US $ (Exc. rate)
21. Dollar worth of nonfood exports ($worth nonfood X)
22. Non Food exports quantity (nonfood X)
23. nonfood imports quantity (non food M)
24. Non- Food Trade (nonfood trade)
25. Non-Food Exports price ratio(nonfood X price ratio)
26 Domestic Non-food Exports price (nonf X dom price)
27. World nonfood Exports price (world nonf X price)
28. Development time (Dev time)
29. Non food percapita consumption (nonfpcons)
30. Quantity of nonfood consumption (Qnonfcons)
31. Non food production goal (nonfood goal)
32. Agriculture production goal (Agpgoal)
33. Area in non food production (area in nonfood)
34. Area in agriculture production (area in ag)
35. Agricultural food production yield
36. Quantity of current food production (Qtcfp)
37. Investment allocated for forest plantation (inv allocated)

Table A 4
Elements of Socio-Economic Sector

Converters
1. Removal of Fuel wood per year (Rem FW yr.)
2. Number of Fuelwood dependent population (no FW dep pop)
3. Size of Urban Poor (size U poor)
4. Size of Urban Population (size of Upop)
5 Fraction of Rural Population dependent on fuelwood (fr Rpop dep fw) 6. Size of Rural Population (Size R pop)
7. Fraction of population residing in rural areas (fr pop R)
8. Urban poverty ratio (U pov ratio)
9. Rural population growth (Rp growth)
10. Rural Population increment (RPinc)
11. Fraction of Rural population increment encroachment forest areas
12. Consumption per capita of fuelwood (CpcFW)
13. Rural percapita fuelwood consumption (Rpcfwcons)
14. Urban percapita fuelwood consumption (Upcfwcons)
15. Removal of Industrial wood per year (Rem IW YR.)
16. Industrial wood Consumption per year (IWCons)
17. Industrial wood trade (IW trade)
18. Industrial wood Export Quantity (IW X)
19. Industrial wood Import Quantity (IWM)
20. Rupees worth of industrial wood exports (RS worth of IWX)
21. Dollar worth of industrial wood exports ($worth of IWX)
22. Rupees worth of industrial wood imports (RS worth of IWM)
23. Dollar worth of industrial wood imports ($worth of IWM)
24. Unit value of industrial wood exports in RS
25. Unit value of industrial wood imports in RS.
26. Converter for million tons of oil equivalent to million tons of fuel wood (Mtoe C MTfw)

Table A 5
Elements of Energy Sector

Converter
1. Total consumption of fuelwood in rural areas (TRFWC)
2. Fuelwood as fraction of non-commercial energy consumption (FWFr nce cons)
3. Rural consumption of non commercial energy (RnceConsumption)
4. Non commercial energy consumption in million tons of oil equivalent (NCEmtoe)
5. Fraction of non commercial energy consumed in rural areas (frnce rural) 6. Total energy consumption in million tons (TE mtoe)
7. Fraction of total energy consumed as non-commercial energy(frnce mtoe)
8. Fraction of alternate energy (Fr alt energy)
9. Supply of alternate energies in millions of tons of oil equivalent oil(supp alt energy mtoe)
10. Average Cost per million tons of alternate energies (cost per mtoe alt energy)
11. Investment on alternate energies for rural areas (inv on alt energy for rural area)
12. Natural gas burnt and wasted
13. Fuelwood perunit equivalent of natural gas (Fwperunit equivalent of nat gas)
14. No. Of urban that could replace fuelwood consumption
15. Equivalent fuel wood wasted (equi FW waste)

Table A 6
Elements of Livestock Sector

Converters
1. Removal of fodder per year (remfodder yr.)
2. Fraction of live stock grazing in forests (fr lstk grazing in forests)
3. Fodder required perunit of livestock per year (fodder reqper unit yr.)
4. Livestock number (lstk no)
5. Dung per unit of live stock per year (dung per lstk per yr.)
6. Total dung available
7. Fraction of dung collected (fr dung collected)
8. Dung fraction burnt (dung fr burnt)
9. Total dung burnt per year (total dung burnt yr.)
10. Fuel wood equivalent of dung burnt (fw equivalent of dung burnt)
11. Total equivalent fuelwood burnt (total equi FW burnt)
12. Biogas conversion of dung (bgascon)
13. Biogas burnt (bgas burnt)
14. Thermal energy equivalent of biogas (thermal energy eq)
15. Total fertilizer equivalent burnt (total fertilizer equi burnt)
16. Fertilizer equivalent of burnt dung (fertilizer equi burnt fertilizer)
17. Fertilizer price in RS (fertilizer price)
18. Dollar value of burnt fertilizer ($value of burnt fertilizer)

APPENDIX B
Equations

$area\_in\_food(t) = area\_in\_food(t - dt) + (l\_dr + Aenc\_c\_ag) * dt$
$INIT\ area\_in\_food = 127.84*10^6$
DOCUMENT: Currently 127.84 million hectares of area is under agricultural productions (GOI, 1994, p8 table 2.2(a)).

$l\_dr = (Fpgoal - Qtcfp)/(agfY*DevTime) + (1 - area\_in\_food/area\_in\_ag)*(Fpgoal - Qtcfp)/(agfY*DevTime)$
DOCUMENT: The deviations between food production goal and the quantity of current food production divided by the agricultural yield per hectare and the time needed to develop the land for agricultural productions gives the operational value of land development rate. A second term is added to incorporate the effect of non – food on forests.

$Aenc\_c\_ag = (Fr\_Aenc\_C\_Agfp*Aenc)/shifting\_cycle$
$cultivable\_lands(t) = cultivable\_lands(t - dt) + (- l\_dr - Aplanted\_yr) * dt$
$INIT\ cultivable\_lands = 24.60 * 10^6$
DOCUMENT: There is 15.01 million of cultivable waste + 9.59 mha. of fallow lands other than current fallow (GOI, 1994, p79 table 9.1).

$l\_dr = (Fpgoal - Qtcfp)/(agfY*DevTime) + (1 - area\_in\_food/area\_in\_ag)*(Fpgoal - Qtcfp)/(agfY*DevTime)$
DOCUMENT: The deviations between food production goal and the quantity of current food production divided by the agricultural yield per hectare and the time needed to develop the land for agricultural productions gives the operational value of land development rate. A second term is added to incorporate the effect of non – food on forests.

$Aplanted\_yr = \mathrm{MIN}.(cultivable\_lands/plantation\_time\_goal, inv\_allocated/cost\_ofplanting\_ha\_yr)$
DOCUMENT: If all the cultivable area is planted within next 20 years. This is the fair assumption if the average planting rate is approximately 1.2 million hectares. Currently the average rate is 1.2 million hectare(Mukerji, 1994).

$\$worth\_nonfood\_X = nonfX*worldnonfXprice*Exc\_Rate$
$\$worth\_of\_foodX = food\_X*world\_food\_X\_price*Exc\_Rate$
$agfY = 1380$
DOCUMENT: This is the value expressed in kg for the year 1990 – 1991. Alternatively trend in agricultural yield can be used to demonstrate the affect of agricultural yield.(GOI, 1994. Agricultural statistics at a glance. p8).

$Agpgoal = Fpgoal + nonfoodgoal$
$area\_in\_ag = area\_in\_food + area\_in\_non\_food$
$area\_in\_non\_food = 30*10^6$
DOCUMENT: This is in hectares. This has been obtained from using the area in agriculture and area in food production (GOI, 1994).

$Bufferstock = 20*10^6*10^3$
DOCUMENT: About 20 million tons of buffer stock is maintained per annum.

$cost\_ofplanting\_ha\_yr = 6000$
DOCUMENT: This is the average cost of planting per hectare per year in Indian rupees(Mukerji 1994).

$DevTime = 1$
DOCUMENT: It takes about one year for the agriculturist to develop the cultivable wasteland for agricultural purposes. This assumption is based on the general observation of farmers in India.

$dom\_food\_Xprice = 4.61$
DOCUMENT: Rice is the main food production. Therefore the price of rice has been taken as indicator of domestic food price. This price is in Indian rupees per kilogram.

$foodpc\_cons = netfoodavailable$
DOCUMENT: 0.5kg/day is the average net per capita availability of food grains(GOI 1994). It is assumed that whatever is available is consumed. The amount of food in storage and transit is small in comparison to the total consumption. Therefore, it assumed to be part of net availability only (GOI, 1994).

$foodtrade = (food\_X - food\_M)$
$food\_M = 1000000000$
DOCUMENT: About 1000 thousand tons on average was the quantity of food imported per year during 1981

– 1993. This is expressed here in units kilograms(GOI, p 71, Table 5.1 (a)).

food_X = *Qtcfp*fr_food_XQ*
food_X_price_ratio = *world_food_X_price/dom_food_Xprice*
Fpgoal = *Qfood_cons + foodtrade + Bufferstock*
Fr_Aenc_C_Agfp = .8
DOCUMENT: About 80% of the forest area encroached is converted to agricultural farm lands, rest is for housing, village and farm paths

inv_allocated = 8e + 009
DOCUMENT: This is the average value for the planting investment per year. And this is expressed in Indian Rs.

netfoodavailable = 182.5
DOCUMENT: It is assumed that net per capita available food is consumed. This is in kg/year.

nonfM = 50000*170
DOCUMENT: About 50000 bales of 170 kg of cotton is imported.

nonfoodgoal = *nonftrade + Qnonfcons*
nonfpccons = 50
DOCUMENT: It is assumed that about 50 kg of nonfood items are consumed per capita for example jute, cotton, rubber, and other fibres.

nonftrade = (*nonfX* − *nonfM*)
NonfXdom_price = 12.42
DOCUMENT: This is the price of cotton in Indian rupees taken as indicator to reflect the price of non food agricultural based exports. It is one of the most important nonfood agricultural land based export.

nonfXprice_ratio = *worldnonfXprice/NonfXdom_price*
plantation_time_goal = 20
DOCUMENT: This is in years. The goal is to plant all cultivable lands in next 20 years.

planting_inv_yr = *cost_ofplanting_ha_yr*Aplanted_yr*
pop = 8.28e + 008
DOCUMENT: This is population of year 1990, derived from the census of 1991. Alternatively a trend can be used to realistically account for the change in population. This can be done to demonstrate the affect of population

Qfood_cons = *pop*foodpc_cons*
Qnonfcons = *nonfpccons*pop*
Qtcfp = *area_in_food*agfY*
shifting_cycle = 10
DOCUMENT: let us assume that the shifting cycle is 10 years.
worldnonfXprice = 38.53
DOCUMENT: This is the price of cotton lint of same quality (medium staple) at London port in Indian Rs.

world_food_X_price = 6.71
DOCUMENT: This is the price of the same variety of Kakinada rice at Thailand port expressed in Indian Rs in year 1991(Bhatiya, 1994)

fr_food_XQ = GRAPH(*food_X_price_ratio*)
(0.00, 0.0015), (0.2, 0.0025), (0.4, 0.003), (0.6, 0.004), (0.8, 0.005), (1, 0.005), (1.20, 0.0055), (1.40, 0.0055), (1.60, 0.0055), (1.80, 0.006), (2.00, 0.0065)
DOCUMENT: This assumed that the food export price ratio which is the price ratio of the food exports in the world market and the domestic market rise maximum to 2. This means that due to trade the world price just can be double of the domestic prices. This range was decided by observing the price ratio trend of the major food items such as rice, and wheat.

nonfX = GRAPH(*nonfXprice_ratio*)
(0.00, 8.5e + 006), (0.2, 1.1e + 007), (0.4, 1.3e + 007), (0.6, 1.5e + 007), (0.8, 1.7e + 007), (1, 1.9e + 007), (1.20, 2e + 007), (1.40, 2.1e + 007), (1.60, 2.3e + 007), (1.80, 2.4e + 007), (2.00, 2.5e + 007)
DOCUMENT: The non food export price ratio has a maximum range of 2, as world price can maximum be double of domestic price. The quantity of non food exports is about 250, 000,000 kg

cost_per_mtoe_of_alt_energy = 26700
DOCUMENT: This is in millions of Indian Rs per million tons of oil equivalent.
equi_FW_waste = *natual_gas_burnt_ and _wasted * FWperunit_ equivalent_ of_nat_gas*

frncemtoe = .53891
DOCUMENT: This is the fraction of non commercial energy in total energy, when the total energy consumption is expressed in million tons of oil equivalent. The source of data has been Mehetre (1990). First, the given value is used to understand and appreciate the interactions between the elements of the system. Later the trend function will be used.

frnce_rural = .79
DOCUMENT: This is observed that about 80% of the non commercial energy (NCE) is used in rural areas. The exact value of this fraction has been obtained after fitting a trend function for the fraction of NCE in rural areas and estimated value of year 1990 is used. The data source has been "Energy Scene in India".

fr_alt_energy = *supp_alt_energy_mtoe/RnceCons*
FWFr_ncecons = (1 − *fr_alt_energy*)
DOCUMENT: Trend function for the fraction of fuel wood energy in total non commercial energy is fitted by using the set of values spread over a period of 30 years 1954 – 1984. The value of 1990 is estimated from this trend function. In general about 2/3 is the share of fuel wood in NCE expressed in Mtoe (Mehetre, 1990).

FWperunit_equivalent_of_nat_gas = 2100/1111
DOCUMENT: 2.1 million ton of Fuel wood is equivalent to 1 mtoe. 1111 million cubic meter of natural gas is also equivalent to 1 mtoe. Therefore, 1 cmt of natural gas is equivalent to 2100/1111 kg of fuel wood

(Mehetre, 1990, p 26, Table 5.2).

inv_on_alt_energy_for_rural_area = 800000
DOCUMENT: This is expressed in Million Indian Rs.

MtoeCMTfw = 2.16845*10^6*10^3
DOCUMENT: This conversion factor converts the value of fuel wood energy in terms of fuel wood weight in kg (Mehetre 1990, p26 Table 5.2). This can be derived by using the conversion factor values from the National Energy Data Profile 1989. In World Energy Council(1990). London. U.K.

natual_gas_burnt__and_wasted = 20*10^6*10^3
DOCUMENT: 19.27 cubic meter of natural gas is flared(p 168 VIII FYP, GOI 1992).

NCEmtoe = *TEmtoe*frncemtoe*
no_urban_that_could_replacefwcons = *equi_FW_waste*/ *Upcfwcons*
RnceCons = *frnce_rural*NCEmtoe*
DOCUMENT: This element is the product of fraction of nce used in rural areas and the total non commercial energy used in the country.

supp_alt_energy_mtoe = (*inv_on_alt_energy_for_rural_area*)/(*cost_per_mtoe_ of_alt_energy*)
TEmtoe = 199
DOCUMENT: This is the estimated value of total energy consumption for 1990. This is expressed in million tons of oil equivalent. The value has been estimated by using total energy data from Mehetre (1990). Later a trend function can be utilized.

Aenc(*t*) = *Aenc*(*t* − *dt*) + (*Aenc_yr* − *Aenc_c_ag*) * *dt*
INIT *Aenc* = 700000
DOCUMENT: This is the forest area encroached expressed in hectares(FSI, 1987)

Aenc_yr = *av_size_of_encroachment*no_encroachers_yr*
Aenc_c_ag (IN SECTOR: Agriculture Sector)
Aplanted(*t*) = *Aplanted*(*t* − *dt*) + (*Aplanted_yr* − *increase_FA*) * *dt*
INIT *Aplanted* = 18900000
DOCUMENT: This is the area under plantations in year 1990(FAO, 1993).

Aplanted_yr (IN SECTOR: Agriculture Sector)
increase_FA = *Aplanted_yr*
A_div(*t*) = *A_div*(*t* − *dt*) + (*Adiv_yr*) * *dt*
INIT *A_div* = 1500000
DOCUMENT: About 1.5 million hectares of forest land is diverted up till 1990 (MEF, 1994).

Adiv_yr = *div_for_infastructure* + *other_diversions*
FBM(*t*) = *FBM*(*t* − *dt*) + (*Prod_yr* − *Rem_yr*) * *dt*
INIT *FBM* = 4085690000*10^3
DOCUMENT: This is FAO (1993) data and is expressed in KG. Biomass is defined as the total amount of above − ground organic matter present. This does not include undergrowth which is less than 5% of the above ground biomass density, forest floor fine litter, and lying and standing dead wood.

Prod_yr = (*TFA*wt_prod_ha_yr*) + DELAY((*Aplanted *plantation_productivity*), 10,18900000*4000)
Rem_yr = (*Rem_NW_yr* + *Rem_W_yr*)
TFA(*t*) = *TFA*(*t* − *dt*) + (*increase_FA* − *Aenc_yr* − *Adiv_yr*) * *dt*
INIT *TFA* = 64.01*10^6
DOCUMENT: This is the area under forest cover in 1991 as per the Forest survey of India (1993). FAO give only 51.7 million hectare far below the estimates given by the FSI. FSI estimates are based on latest satellite imagery conducted for the period 1989 − 1991.

increase_FA = *Aplanted_yr*
Aenc_yr = *av_size_of_encroachment*no_encroachers_yr*
Adiv_yr = *div_for_infastructure* + *other_diversions*
ainc_0fa = 500
DOCUMENT: This is the average value of annual increment in kg per hectare and is calculated from the data provided for different states (National Forest action Plan, 1994).

ainc_Dfa = 1000
DOCUMENT: This is the average value of mean annual increment expressed in kg/ hectare/year and the average is taken over all the dense forest areas of all the states. This value is calculated by the data provided for National Forestry Action Plan for India (MEF, 1994).

av_size_of_encroachment = 0.2
DOCUMENT: This is in hectare. On average one acre of land is encroached.

div_for_infastructure = 12000
DOCUMENT: This is the average forest area diverted per year during the period 1981 − 1994 (MEF, 1994).

D_FA = *TFA*Fr_D_FA*
Fr_D_FA = 0.603
DOCUMENT: This is the value of fraction as per the FSI (1993). Alternatively, a trend value of this fraction can be taken. However for the present, the value given by FSI (1993).

Fr_OFA = 1 − *Fr_D_FA*
no_encroachers_yr = *fr_R_pop_engaged_in_encroachment*Size_R_pop*
other_diversions = 12500
DOCUMENT: This is the average value of diversion during 1980 − 1994 (MEF, 1994).

O_FA = *TFA*Fr_OFA*
plantation_productivity = 4000
DOCUMENT: This is estimated that productivity of forest plantation is 4 ton/ha/yr (Chaturvedi 1994). This may vary as per the nature of the species and the plantation site. However, on average the productivity of 4 ton/ha/year is fairly acceptable figure by the foresters. Here, the unit is kg/ha/year.

Rem_NW_yr = remfodder_yr
Rem_W_yr = Rem_FW_yr + Rem_IW_yr
*wt_prod_ha_yr = (ainc_Dfa*D_FA + ainc_0fa*O_FA)/(D_FA + O_FA)*
*$value_of_this_burnt_fertilizer = total_fertilizer_equi_burnt *fertilizer_price *Exc_Rate*
bgascon = 1.06
DOCUMENT: This is the 1.06 cubic meter of gas available from 1 kg of cow dung. In (p 18, Chatterji, M. 1991).

*bgas_burnt = bgascon*total_dung_burnt_yr*
dung_fr_burnt = .6
DOCUMENT: 60% of the collected is burnt (Singh, 1994).

dung_per_lstk_unit_yr = 5400
DOCUMENT: This is the fresh manure production per head in kg/year (Chatterji, M. 1990 p18 Table 1.10). Energy content is 753 million TCE and the calculated amount of manure(ton/year) is 64.9*10^8. Calorific value is 500 BTU/ft^3. The maximum amount of biogas in case of cow manure is 1.06m^3/kg.

Exc_Rate = .057
DOCUMENT: This is the exchange rate of Indian 1RS = .057US$ in 1990.(FAO, 1992 pxli). Alternative will be to use trend for 1981 – 1992. However, here value of exchange for 1990 is used for the present to understand the interaction between exchange rate and export price.

fertilizer_eq_of_brunt_dung = .2
DOCUMENT: The assumption is that atleast 20% of the total weight of dung can provide 1 unit weight of fertilizer.

fertilizer_price = 4.843
DOCUMENT: In 1990 – 91 Indian government imported 2.758 mton worth 13358.2 million Rs. The average price estimated is 4843 Rs per ton. This is price in Rs/kg.

fodderreqper_unit_per_yr = 5*365
DOCUMENT: 5 kg per unit perday is required (Rao,1994).

fr_dung_collected = .80
DOCUMENT: 80% of the dung is collected.

fr_lstk_grazing_in_forests = .30
DOCUMENT: 30% of the total livestock graze in forests. About 100 million livestock unit graze in forests. This is about 30% of total livestock (Dwivedi, 1994).

fw_equivalent_of_dung_burnt = 0.27392
DOCUMENT: 20 million tons of fuel wood would be needed to replace 73 million tons of air dry cowdung (Singh, 1988 p91).

lstk_no = 321*10^6
DOCUMENT: This is the standard livestock number in India in 1990 (Rao 1994).

*remfodder_yr = fodderreqper_unit_per_yr*fr_lstk_grazing_in_forests*lstk_no*
*thermal_energyeq = bgas_burnt**(500)*(9)
DOCUMENT: 500 Btu of energy is obtained from 1 cubic feet of gas. It is converted to cubic meter by multiplying by 9.

*total_dung_available = dung_per_lstk_unit_yr*fr_dung_collected*lstk_no*
*total_dung_burnt_yr = dung_fr_burnt*total_dung_available*
*total_equi_FW_burnt = fw_equivalent_of_dung_burnt*total_dung_burnt_yr*
*total_fertilizer_equi_burnt = fertilizer_eq_of_brunt_dung*total_dung_burnt_yr*
*$worth_of_IWM = Rs_worth_of_IW_M*Exc_Rate*
*$worth_of_IWX = Rs_worth_of_IW_X*Exc_Rate*
*CpcFW = (Size_R_pop * Rpcfwcons + size_U_pop*Upcfwcons)/(Size_R_pop + size_U_pop)*
fr_pop_R = 0.75
DOCUMENT: 75% of the population is living in rural areas. In beginning, only the average value of the fraction is used. However, a trend value of this fraction can be taken to be more realistic than the fixed fraction.

fr_R_pop_dep_fw = .80
DOCUMENT: 80% of the rural population is dependent on fuel wood (Khoshoo, 1994).

fr_R_pop_engaged_in_encroachment = 0.0017
DOCUMENT: This is assumed that .17% of the rural population flows to neighboring forests and encroach forests.

IWcons = 16*10^6
DOCUMENT: On an average 16 million tons of IW was consumed in India during 1981 – 1992. This figure has been estimated by using IW data from FAO (1993). Average figure has been used to keep it simple and understand better the role of IW cons. Alternatively, a trend function for IW consumption can be used. However, this will used in later versions of this model.

IW_M = .5*10^6
DOCUMENT: The industrial wood imports are converted from their volume units into weight units by using a conversion factor of 1.33 CMT/MT. The values have been obtained from FAO (1993) and averaged over 1981 – 1992.
IW_traded = (IW_X – IW_M)
IW_X = 4*10^6
DOCUMENT: The quantity of industrial wood exported has varied over a period of time depending upon host internal and international economic interlinks. The values of Industrial round wood exports are given in volume units(cubic meter) FAO Year Book (1993). These have been converted to weight units of Millions of tons by using a conversion factor of 1.33 cmt/MT and a average value has been used to make it simple. Alternatively, a trend function can be utilized.

*no_FWdep_pop = (fr_R_pop_dep_fw*Size_R_pop + size_U_poor)*

Rem_FW_yr = (*CpcFW*)∗(*no_FWdep_pop*)
Rem_IW_yr = *IWcons* + *IW_traded*
Rpcfwcons = (*TRFWC*)/(*Size_R_pop*)
Rs_worth_of_IW_M = *IW_M*∗*Unit_value_of_IW_M_in_Rs*
Rs_worth_of_IW_X = *IW_X*∗*Unit_value_of_IWX_in_RS*
Size_R_pop = *fr_pop_R*∗*pop*
size_U_poor = (*U_pov_ratio*)∗(*size_U_pop*)
size_U_pop = *pop* − *Size_R_pop*
DOCUMENT: A trend can be put for the size of urban population. The trend could be an indicator of various socio-economic forces determine this element of the system. Presently only the 1991 value of urban population is used to understand the interaction.

TRFWC = (*FWFr_ncecons*)*(*RnceCons*)∗*MtoeCMTfw*
Unit_value_of_IWX_in_RS = 2500
DOCUMENT: This is the average unit value of industrial exports over 1981–1992 and is expressed in Indian Rs. The unit value in $ have been converted by using the exchange rates of Rs for US $. The data has been used from Forest Products Year Book (FAO 1993).

Unit_value_of_IW_M_in_Rs = 1800
DOCUMENT: A unit value of Industrial round wood imports has been given in $ after using exchange rates of $ with Indian Rs. Here, the unit value of Industrial wood imports have been used in Indian Rs to highlight the role of exchange rate on the $ worth of Industrial imports. The Rs values have been estimated from FAO (1993) Unit value estimates. Average value in Rs is taken to understand the interactive role of Industrial imports and the exchange rate.

Upcfwcons = (0.384/1.38)∗1000
DOCUMENT: Percapita consumption in Urban areas is expressed in kg per year. It has been estimated from the figures of National Forestry Action Plan(NFAP 1994). Conversion factor is 1.38 cum/MT (FAO 1992, p xvii).

U_pov_ratio = .4012
DOCUMENT: This is the poverty ratio in 1987 − 88 by the planning commission report on the expert group on estimation of proportion and number of poor (GOI, 1993, p58).