Deforestation: Causes and Sustainable Solutions with Reference to India

by

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A thesis submitted in conformity with the requirements

for the Degree of Doctor of Philosophy,

Graduate Department of Forestry,

University of Toronto.

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ABSTRACT

This thesis develops a system dynamics simulation model of the deforestation process. It focuses on two measures of deforestation that must be considered simultaneously, total forest area (TFA) a geophysical measure and forest biomass (FBM) a biophysical measure. The thesis argues that deforestation is a complex and dynamic process and should therefore be examined with an integrated approach that takes into account the interrelatedness of various elements especially those between the forest sector and other impacting sectors. A system of forests, and four other sectors- agriculture, energy, socio-economic, and livestock- that compete for forest land or forest produce is developed. The process of deforestation is seen in terms of dynamic interaction between all five sectors of the model. Initially, a simple- forest sector only, model is developed to familiarize the reader with the usage of system dynamics concepts. The model is enhanced and expanded to incorporate the remaining four sectors. Three versions of the multi-sector model are developed. Model A is based only on the biophysical flows of interactions, Model B, includes the market responses in addition to the biophysical linkages, and Model C, which in addition to the biophysical and market linkages, also incorporates dynamic functions. Model C is validated by comparing the simulated behaviors of key elements such as forest area, population, livestock number, non-commercial energy consumption, agriculture
productivity, and agriculture production, with data for India. Sensitivity analyses examine the impacts of non-forestry policies on deforestation, and explore policies that may sustain forests in India.

The simulation results show that if present trends in policies to ameliorate deforestation remain unchanged the depletion of forests in India will continue and within next two decades India will be completely deforested in terms of its biomass. The most important insight obtained from these results is that policies focusing exclusively on the forestry sector will not be sufficient to sustain forests; it is essential to develop supporting policies in the other interacting sectors. Moreover, the results suggest that complete reliance on market forces will not yield sustainability because of the lack of well functioning forestry markets, the operation of non-market incentives, and the slow response times in forestry investments in India. Only a combination of forest sector polices with supporting policies in all other sectors that impact on the forestry sector can prevent deforestation and yield sustainable forestry development.
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CHAPTER ONE

1. Introduction

1.1 Deforestation: The Context

The world’s forests are vanishing under an onslaught of human development activities (Binswanger 1989, Mahar 1989, Sharma et al. 1992, Haeuber 1993), and the average rate of deforestation is increasing (Food and Agriculture Organization of United Nations (FAO)1993, World Resources Institute (WRI) 1994). One estimate suggests that the average rate of tropical deforestation alone has increased from 11.3 million hectares per annum during 1981-1985 to 15.4 million hectares per annum during 1981-1990 (FAO 1993).

While in the industrialized nations chemical pollution is the most prominent environmental issue, in the industrializing countries tropical deforestation has been singled out as the major environmental problem (World Commission on Environment and Development (WCED) 1987, Meadows et al. 1992, World Bank 1992). Deforestation leads to excessive run-off, soil erosion, desertification, and biodiversity loss (Eckholm 1976, WB 1978, Myers 1980, Nair 1985, Woodwell 1992, Myers 1993, Chakraborty 1994, Saxena and Nautiyal 1997) amongst other phenomena. In order to stall these processes it is essential that deforestation be controlled. However, policy planners have largely relied upon technical solutions in the forestry sector, such as raising plantations and protection of forests to control deforestation (Carnea 1992). These solutions have

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1 A substantial portion of this Chapter appears in Saxena and Nautiyal (1997).
failed to control the pace of deforestation which has increased in spite of the planners' best intentions.

In this thesis it is argued that the forests have to be seen to be embedded in the whole of society and the process of deforestation in the industrializing world has to be analyzed in the context of the socio-economic framework and the development pattern of society if success in stalling the process of deforestation is to be achieved. This perception could guide policy planners to achieve sustainable development of forests and the people around them. The thesis demonstrates that when deforestation is analyzed in a forestry context alone (that is, in isolation of the 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. Moreover, the thesis demonstrates that sustainable forestry practices are only possible when a systems level approach is used.

The causes of deforestation have been debated by foresters, environmentalists, geographers, and economists alike (Shaw 1989, Palo 1994), yet no consensus has been reached on major causes of deforestation. A number of independent factors have been cited, such as population, external indebtedness, income and agricultural productivity, in the past studies (Mathur 1976, Bowonder 1982, Allen and Barnes 1985, Grainger 1986, Palo et al. 1987, Rudel 1989, Scotti 1990, Kummer 1992, Chakraborty 1994, Shafik 1994, Southgate 1994). However, many of these studies have yielded conflicting, and therefore confusing results. For example, some studies conclude that population (growth,
increment, and size) has a positive relationship with the deforestation rate (Allen and Barnes 1985, Grainger 1986, Rudel 1989). Westoby (1978) on the other hand emphasized that, taken in isolation, there was no correspondence between population growth and the deforestation rate. Moreover, Palo (1994) found zero correlation between population growth and the deforestation rate. Similar conflicting results are also obtained for other factors such as agricultural productivity, income, and external indebtedness measured in terms of debt-service ratios. These conflicting results demonstrate that the role of factors that could scientifically be linked with deforestation is not known with any degree of certainty.

Deforestation is a complex and dynamic process. It appears that there is no single cause of deforestation (Shaw 1989, Shukla et al. 1989, Rowe et al. 1992, Palo 1994). Instead, there are multiple, interrelated, and dynamic causes. Dynamic in this context means that the major causes of deforestation shift with time. In explaining the process of deforestation, at a given point in time one set of relationships may be dominant. This dominance may change over time. For example, at one time population growth may be the primary cause of deforestation while at another it may be industrial demand for forest products, or the incentive to liquidate the forests in order to service foreign debt.

In addition to the dynamic nature of relationships that causes deforestation, the relationships are also functions of the level of reference used for analysis. At the local level, villagers cut down the forest for housing or fuelwood purposes. At the national level, the need to service debt may force a country to drive up agricultural exports and accelerate the conversion of forest lands to the lands for agricultural cash crop production.
Alternatively, at the national level, it may be the policies affecting land use or investment policies, such as taxes, subsidies, logging concessions, and conversion of forest to agricultural lands that affect the whole set of incentives for deforestation (Repetto and Gillis 1988). At the global level, international policies relating to trade, debt and development, such as tariff and investment agreements, have an effect on the state of deforestation (Guppy 1984, Clark 1992, WRI 1992, Repetto 1993). Thus, both temporal and spatial scales influence the process of deforestation. Obviously, the deforestation processes must be conceived of as reflecting all of these causes.

1.2 Conceptual issues

The exact definition of the term deforestation is contentious. A broad definition is the change from a primary closed canopy forest to any other use (Myers 1980). The Food and Agricultural Organization (FAO 1982) defines deforestation more narrowly as the transformation of forest land to non-forest uses where forest land includes lands under agro-forestry and shifting cultivation, and not simply closed canopy primary forests. The FAO defines forests as "ecosystems with a minimum of 10 per cent crown cover of trees and/or bamboo, generally associated with wild flora, fauna, and natural soil conditions, and not subject to agricultural practices" and deforestation as a "change of land use with a depletion of tree crown cover to less than 10 per cent [crown cover]". The differences in definition have been discussed by many authors (Grainger 1980, Lugo and Brown 1982,

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2 Two types of "deforestation" are identified: (1) "Deforestation to other wooded land" where the forest is lost but certain woody biomass remains (for example, from forest to shrubs), and (2) "Deforestation to non-wooded area" where the forest is lost and no woody biomass remains (for example, permanent agriculture or creation of water bodies). (FAO, 1993, pp. 37-38)
Grainger 1983, Melillo et al. 1985, Serna 1986, FAO 1987). However, such differences have not been adequately resolved to date.

In the past, the focus of deforestation studies has been on the geophysical unit, that is, on forest area (Allen and Barnes 1985, Grainger 1986, Palo et al. 1987, Khator 1989, Rudel 1989, 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 within the biophysical unit, that is, in the forest biomass. The FAO (1993) definition implicitly incorporates the biophysical aspect of deforestation by incorporating the crown density limit of 10 per cent. However, this definition also will not be able to capture the complete behavior of forest biomass. For example, if crown density decreases from 15 per cent to 9 per cent, the process will be termed as deforestation, but if the crown density decreases from say, 90 per cent to 15 per cent the change will not be described as deforestation under FAO definition. Indeed, the impact of change in crown density from 90 per cent to 15 per cent will be serious enough to attract attention of the forestry policy planners. The limit of 10 per cent seems to be arbitrary. Therefore, to be more realistic and to incorporate the dynamic nature of deforestation process, it will be useful to focus on the behavioral aspect of both forest area, and forest biomass in measuring deforestation. In this thesis, 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.

1.3 Past Studies

In the past, deforestation has been analyzed on a factor-by-factor basis (Bowonder 1982, Allen and Barnes 1985, Nair 1985, Grainger 1986, Khator 1989, Palo et al. 1987, Rudel 1989, Scotti 1990, Chakraborty 1994, and Shafik 1994). In this approach, various hypothesized causes of deforestation are considered without delineating the connections between them. Usually some statistical techniques, such as correlation or regression analyses, are used to analyze the assumed role that each factor plays. Feedback and dynamic mechanisms are usually ignored. Policies grounded in such analyses are therefore incomplete and usually ineffective. For example, in many parts of the world, investing in forest plantations is intended to offset deforestation trends, but these are wasted investments when the plantations are destroyed by fuelwood gatherers, landless agriculturists, or cattle grazers. Primarily, these failures occur when feedback mechanisms and the linkages between causal factors are not considered. Fuelwood gathering, agriculture expansion, and cattle grazing have been identified as factors contributing to deforestation by many authors (Mathur 1976, Lugo et al. 1981, Bowonder 1982, Bajracharya 1983, Tiwari 1983, Allen and Barnes 1985, Nair 1985, Grainger 1986, Palo et al. 1987, Rudel 1989, Scotti 1990, Burgess 1991, Southgate 1994, Chakraborty 1994), but they failed to demonstrate that these factors are in turn the consequences of the interactions of other factors in the system such as economic poverty, income and land inequality, and the influence of the elite in development planning. This thesis integrates
these various causes into one coherent framework that captures the interaction between the factors identified in the past studies.

1.4 Thesis Overview

This thesis argues that identifying the individual causal factors alone is insufficient to understand the process of deforestation and develop sustainable forestry policies. A systems approach is required (Shukla et al. 1989, Palo 1994). The deforestation process is analyzed by examining the interactions among the causal factors within the system using a systems thinking paradigm. A system, is a set of elements that are interrelated in a specified way (Meadows et al. 1992). Relationships are comprised of interrelated elements (or factors or variables). Systems are comprised of interrelated relationships and the combination of interrelated relationships is called the structure of the system. The relationships may be linear or nonlinear. Because the relationships are interrelated, and have different speeds and strengths, the structure produces the dynamic behavior in the system over time (Meadows et al. 1992, High Power Systems Incorporation 1994). A systems approach, therefore, reveals the dynamic behavior of a system precisely because it specifies the interrelationships among the systems' constituent elements.

The main purpose of this thesis, therefore, is to apply this paradigm to the process of deforestation. As a result, it provides: (1) a systems thinking approach; (2) an emphasis on the interactions between the elements; and (3) an analysis of dynamic behavior of the system with particular reference to the process of deforestation.
To capture the complex and dynamic nature of the deforestation process, a systems dynamic language, Stella, is used to model the process (Meadows et al. 1992). The model demonstrates that the process of deforestation evolves from the interactions of sectors. The model includes four other sectors besides forests - the 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 the dynamic interaction between all five sectors of the model.

The thesis constructs a computer-aided model, validates it for the period 1951-1991 and then uses it to project the future of forests under alternative scenarios. The model is based on the operational values for a single country (India), but the structure is general enough to be applicable to any country or geographical unit with appropriate adjustments in the operational values. The model is based on a carefully articulated dynamic theory of deforestation and explores, and delineates the multifaceted contours of the deforestation process in the context of a particular country. Given this structure the model can include and examine the various hypotheses suggested by previous authors.

1.5 India As A Case Study

The thesis develops a model on a national scale. A national scale is appropriate because variations (in culture, history and geography) from nation to nation are so great that it is often difficult to seek useful, and general relationships on a global scale. Further, overall management of forests is controlled by governments on national or sometimes local scales. Therefore, the decisions of national governments have a dominant effect on the state of forests, and the process of deforestation. Accordingly, the thesis focuses on
policies available to national (and sometimes sub-national) governments to control deforestation. Furthermore, attempts to control deforestation on a global scale have been notably unsuccessful because there is no global government to oversee policy compliance. Analysis on a national scale can provide an opportunity to review the relevance of results obtained previously on the global scale and provide meaningful national policy directions for controlling deforestation (Grainger 1986, Rudel 1989, Palo 1994).

This is not to deny the impact of the international economic system on national economies. The national and international economic systems are connected by the processes of trade, aid, debt and exchange rates. Therefore, at a systems level deforestation analyses for a nation should incorporate the specific effects of trade and exchange relationships on the forest sector.

India has been chosen as the case study for a number of reasons. Whereas India has only 2.4 per cent of world’s land area, it is inhabited by 16 per cent of world’s population and 14 per cent of the world’s livestock population (Dwivedi 1994). It has 0.3 hectares of land per capita, 0.9 hectares of land per standard livestock unit and only 0.08 hectares of forest per capita (WB 1993, Dwivedi 1994). Land is used intensively in India and has many competing uses. Therefore, India is an appropriate test case to examine the intense inter-sectoral interactions driving the process of deforestation.

India has the largest population in the world after China (932 million in 1995). The majority of its population (74 per cent) live in rural areas, and 80 per cent of them (about 500 million) use fuelwood and substantially depend on forests for their basic needs of fuel, fodder, and water (Saxena and Nautiyal 1997). Moreover, 235 million people live
in a state of absolute poverty (a size larger than total population of UK, France and Germany combined). Mostly women and children collect fuelwood and fetch water (Natrajan 1990, Agrawal 1992). Therefore, the state of forests have a significant effect on their lives. About 70 million tribal people live in forests and heavily depend on forests for their livelihood. These groups primarily use wood fuels for their basic needs of cooking and heating and constitute one of the largest environmentally vulnerable societies on the Earth. Increasing deforestation means increasing impoverishment for them, and a potential threat to the survival of a society, the nation, and the global economic and environmental system. Therefore, exploring and designing policies to sustain the forests in India is an issue of utmost importance. Moreover, deforestation and water pollution are India’s two major environmental problems (Khator 1989). From a national perspective, slowing the process of deforestation is a high priority issue for any step toward sustainability of development. Unfortunately, the underlying mechanisms of deforestation are poorly understood by Indian forestry planners. The model developed here will further the understanding of deforestation mechanisms.

In the North-South deforestation debate (United Nations Conference on Environment and Development 1992), it is widely believed that increasing population is a prime contributing factor to deforestation. Besides African nations, India has experienced one of the highest population increases in the past four decades. India has added about 600 million people to its population during 1951-1995. This is the second highest increment in population by any nation on Earth. India provides an excellent test case to examine and understand the role of the population in deforestation. Further, India has a
A democratic government and aspires to western developmental goals. It provides an excellent example of deforestation driven by western developmental influences and therefore provides an opportunity for developing countries to reflect on the desirability of western-style development.

This thesis first reviews and critically evaluates the contemporary approaches that have been adopted to investigate the problem of deforestation and identify the various factors in Chapter 2.

A system dynamics approach is suggested for advancing deforestation modeling, and a simple model is developed to illustrate the basic concepts of the system dynamics approach in Chapter 3. A multi-sector (five sector) model of deforestation is developed in Chapter 4. First, the five sector model is specified, then the price loops are added to this model to capture the role of the price mechanisms in ameliorating deforestation in the developing countries, and finally dynamic functions for the interacting elements are incorporated in the model to explore the sensitivity to their inclusion. These models are referred as Model A, Model B, and Model C, respectively. The final model, Model C, is validated in Chapter 5. The model results are discussed, and the impacts of forest conservation and socio-economic policies on forests are examined by using sensitivity analyses in Chapter 6. The thesis is completed by conclusions presented in Chapter 7.
CHAPTER TWO

2. Literature Review

2.1 Introduction

This chapter has two broad purposes: (1) to review the current literature on deforestation and identify the various elements (variables or factors) that have been determined to be relevant and important in causing deforestation, and (2) to review the methodological approaches adopted in the existing literature to analyze the process of deforestation.

2.2 Contemporary Literature

The contemporary literature devoted to an analysis of the process of deforestation can be conveniently placed into three major categories: descriptive, theoretical, and empirical. However, not all the works of authors fall strictly into one of these categories. For example, Grainger (1986, 1987) suggests a land use theory, and attempts to validate the theory by empirical studies. Kummer (1992) in a descriptive study of the Philippines identifies the causal factors of deforestation, and uses empirical studies to validate the identification. Nevertheless, the classification - descriptive, theoretical, and empirical - is a convenient way to organize, understand, and uncover the underlying general strengths and weaknesses of the contemporary literature on deforestation.

2 A substantial portion of this Chapter is presented in Saxena and Nautiyal (1997).
2.2.1 Descriptive Studies


Mathur (1976) identifies increasing human economic activities of mining and agriculture as causes of depletion of forest resources in India, while Baidya (1982) and Tiwari (1983) identify increasing fuelwood and fodder collections. Haigh (1984) on the other hand points out that the shortage of land is at the heart of the deforestation problem. The World Bank (1978, 1991) and the World Resources Institute (1985) focus on the roles of socioeconomic factors such as poverty, low agricultural productivity, and inequitable land distribution in tropical countries as the major factors of deforestation. The World Resources Institute (1985) also points to the role of developed countries in providing a ready market for tropical forest products. Richard and Tucker (1983, 1988) provide an historical perspective to the current deforestation in tropical countries. They emphasize that forces leading to deforestation in tropical countries emanate from the developed countries by way of their demand for tropical products such as tea from India.
cotton and peanuts from the Sahel, timber from Brazil, and rice, maize, cassava and timber from Thailand. While the World Resources Institute reports (1992, 1994) suggest that increasing human and livestock populations, poverty, fuelwood consumption and the consumption by the rich and the industrialized nations cause deforestation on a global scale in general and tropical countries in particular. It is important to recognize that even though there is no consensus in the literature regarding the roles of causal factors, these studies help identify the various causal factors of deforestation.

Rowe et al. (1992) recognize two types of factors causing deforestation. Factors such as agricultural expansion, fuelwood gathering, fodder collection, commercial logging, infrastructure and industrial development are placed in the "direct" category, while increasing population and poverty, market and policy failures, and increasing debt burdens of tropical countries are placed in the "underlying" category. The former are apparent causes of deforestation but are themselves caused by the latter. As will become apparent later in this thesis, this is an important distinction.

2.2.2 Theoretical Studies

A theory is an idea or set of ideas intended to explain observed fact. Therefore, theoretical studies of deforestation are based on, or are concerned with the ideas and abstract principles of deforestation, rather than on practical aspects of deforestation. In theoretical studies, broad theories are posited to explain the process of natural resource depletion including deforestation. For example, Ciriacy-Wantrup (1952) in his pioneering book on resource conservation identified three factors: changes of technology, changes of population growth, and changes of social institutions. A sketch of
these three factors may help in understanding the emergence of a conservation problem such as deforestation in its modern form. In general, he analysed the general principles and typical problems in the conservation but was not concerned with detailed blueprint of conservation policy for individual resources such as forests. Although not much theoretical work has been done in the area of deforestation (Kummer 1992), the theories developed in general for resource conservation or for other natural resources such as for grasslands and fisheries have increasingly been used to analyze the process of deforestation (Hecht 1985). There are three well-known examples: Hardin (1968) proposed the “tragedy of commons” theory for the degradation of common grasslands, Clark (1973) developed the “competitive exploitation” theory for the dwindling fishing resources, and Sunkel (1982), Hecht (1985) and Redclift (1987) suggested a “dependency” theory that focused on the exploitation of the natural resources emanating from the relationships between national and international economic systems. More recent theoretical approaches focus directly on the deforestation issue and include the works of Guppy (1984), Grainger (1986,1987), Blaike and Brookfield (1987), Walker (1985, 1987), Guha (1989), Somnathan (1991), and Haeuber (1993).

According to Hardin (1968), the degradation of common (grassland) properties results from the growth in population, a lack of self-restraint and a lack of private property rights. Each individual seeks to maximize profits by consuming an extra increment of the common property resource and allowing the extra increments’ costs to be shared by all. But if it is rational for one individual to over-consume by one increment, then it is rational for each individual to over-consume by one increment. Consequently, each individual
competes to expand his/her exploitation of resources, with the result that the resource is depleted.

Hardin suggests population control and privatization or, at least, the designation of clear property rights as the solution for halting the resource depletion. But deforestation is a complex and dynamic problem for which a simple solution is unavailable. For example, there are successful examples of community controlled common resources, such as Arabari in West Bengal, Bishnoi's (a community in the Thar desert, India) resource use in Rajasthan, and forest village committees in Gujarat, Uttar Pradesh, Tamil Nadu, and Orissa in India, that cannot be explained by Hardin's theory (Saxena and Nautiyal 1997). In these cases societies over period of time have learned to minimize the damage to common property at the expense of individual short term benefits. These are clear examples wherein individuals working in a dynamic social context have devised institutions to share the benefits and costs of resource use. The suggestion here is that Hardin's theory focuses on two causative factors but fails to take account of (1) the difference between a sum of individuals and a society and (2) the dynamic behavior of resource users who appreciate that today’s decisions have consequences tomorrow (Vanderberg 1985, Bojo et al. 1990, Cernea 1992, Saxena and Nautiyal 1996).

Clark (1973) extends the analysis of competitive exploitation and suggests that the private maximization of net present value of profits is also central to destruction. Some biological resources have long gestation periods, and for these resources Clark argues that it is rational for an individual entrepreneur (who has a high time preference) to accelerate the level of exploitation and re-invest profits elsewhere. Therefore, in apparent contrast to
Hardin, private property ownership may lead to the destruction of resources. Also if the destruction of resources continues, there is a possibility of overshooting - destroying the resource base before regeneration strategies have time to replenish the resources, in which case the damage may be irreversible (Meadows et al. 1992). This theory illustrates a situation wherein maximization of profits can lead to unsustainable resource management.

It is likely that private and social rates of discount (or time preference) may diverge (Bojo et al. 1990, Pearce and Warford 1993) and therefore, the most desirable rate at which forests may be harvested from an individual owner's point of view is unlikely to be the best rate from the viewpoint of society (Pearce and Warford 1993). If the private rate is unsustainable, then intervention is needed both for social optimality and sustainability. It may be possible that both individual and social rates are unsustainable (Pezzey 1989), depending upon the attitude of society. For example, fishing communities in eastern Canada and the United States focus on the short-term economic values from fishing, and neglect ecological considerations, resulting in depleted fish stocks and an unsustainable fishing industry (Meadow et al. 1992, Maini and Ullsten 1993). The theory identifies one economic factor, that is, time preference or discount rate, as crucial in affecting deforestation. Forests can be conserved or destroyed depending upon the rate at which an individual or a society discounts natural wealth like forests. However, the discount rate itself is influenced by the socio-economic conditions in which people live. Therefore, the socio-economic conditions become an important policy lever to impact deforestation (Cernea 1992).
The dependency theory shifts the focus away from internal economic factors to external factors that affect the production system and lead to degradation (Sunkel 1982, Hecht 1985, Redclift 1987). In brief, since the internal economy is linked to the external economy, those international forces which govern the external economic scene can affect internal environmental decisions. For example, World Bank funding for cattle ranches in Amazon forests acted as an incentive for the Brazilian government to convert Amazon forests to grazing lands (Hecht 1985). Rowe et al. (1992) suggest that the requirement to earn foreign exchange to pay back external debts, or to improve the national balance of payments, compels countries to liquidate their natural resources. Unlike Hardin and Clark this theoretical framework emphasizes the role of linkages with the global economy in the deforestation process.

Guppy (1984) emphasizes the role of internal political factors in deforestation. Control by elite members of society is one of them. According to Guppy, much forest destruction is a calculated attempt by the local elite either to directly enrich themselves or to avoid dealing with the problems of poverty and landlessness. Thus, the forest is a means to assuage social discontent and provide an income stream to those who control access to their use. The real issue underlying forest conversion is not land shortage but land distribution and access. Guppy suggests that inequity, both in land ownership and access to public resources, contributes to deforestation.

Guppy (1984) identifies four separate but related factors. On the surface, population growth and land shortage, while underneath, the inequitable social conditions resulting from the political motivations of local elite, and the international context. Guppy
stresses the international context of deforestation, pointing to two external influences on deforestation. First, governments of developed nations have provided support to governments of less developed nations, which in turn have become increasingly centralized and enamored of large scale infrastructure development projects such as dams, roads, and colonization programs. Large areas of forest are diverted as a direct result. Second, the demand for tropical forest products largely emanate from the markets of developed nations. Consequently, this commercializes community attitudes in tropical countries, orienting them toward forest exploitation. This is possible because the interests of the elite coincide with the interests of outsiders who prop up these elite for their own interests of access to natural resources.

In general, Guppy (1984) finds that the low market value of the forests and forest products compared with other land uses is promoting deforestation. He suggests formation of a timber cartel, an Organization of Timber Exporting Countries (OTEC), analogous to the Organization of Petroleum Exporting Countries (OPEC), by the seventeen tropical countries that represent 92 per cent of world export trade in tropical timber value, over 92 per cent by volume, and 90 per cent of the remaining tropical forests by area. According to Guppy, a 50 per cent price increase by OTEC would generate sufficient funds for forest regeneration and conservation. “Although OTEC would be self-financing, its start would have to be funded...[and], unless coordinated actions of this sort is undertaken, the tropical rain forests of the world are doomed” (Guppy 1984).

Grainger (1986, 1987) offers a deforestation model based on national land use. He focuses his attention on the use of land within individual nations. The conversion of forest
land to non-forest uses is the major process that connects the forestry with other sectors of the economy. According to Grainger, the driving forces behind this process are population growth and increased per capita income which increase the demand for food and wood. The supply and demand of forestry products and their prices are the most important considerations. The accessibility of forest resources, the time and effort invested in forest protection, the efficiency of utilization, and the economic incentive to invest in forest plantations are also relevant factors. Grainger tests his theoretical model using a cross sectional statistical analysis of 43 countries to verify the importance of the identified factors in a static framework. He identifies two factors: the population increase, and the area logged, as the most important causes of deforestation.

Using the underlying logic of optimization theory (earlier propounded by Faustmann 1849, Clark 1973) Walker (1985, 1987) uses the concept of maximization of net present value of profits to develop two models. One is designed to assist in decision making by the commercial logger, regarding the abandonment of a concession to the agriculturist after completion of logging, and the other to assist in decision making by the landowner regarding the allocation of land to forest preservation or agriculture. He identifies two factors that have profound effects on deforestation. One is the length of concessions to loggers and the second is the type of species to be replanted. If the length of concession is short then the logger will not replant the logged area unless the species is growing fast enough to provide the discounted benefits greater than the costs of harvesting and planting. In all other cases, the logger will dedicate the logged areas to alternate uses and will thus facilitate deforestation.
Similarly, the owner will decide to use land for forest or agriculture depending upon the expected net discounted benefits for each of the alternate activities. The owner will attempt to maximize the net present profits from land. If the species are of a long rotations, the price of forest timber is low (or even not sufficiently rising high to compensate for the discounting factor), and the discount rates are high, then there exists an economic (financial) rationale for the owner to use land for uses other than forestry. The owner will not plant after harvesting the forest and will preferably use the land for other alternative uses.

Blaike and Brookfield (1987) base their theoretical construct on the observation that a multiplicity of environments, national and regional histories, cultures, and socio-economic forces operating in the Third World exists, and consequently no single cause of land degradation exists. Rather, an explanation that claims international validity, must be able to encompass a wide variety of circumstances. Blaike and Brookfield call their approach "regional political ecology." It is "regional" because it deals with variation in land resources, "political" because it deals with the political economy of land use decisions, and "ecology" because it deals with environmental relationships between the environmental and socioeconomic spheres and among the different scales from family on up to global perspectives. In addition to the multiplicity of interests among persons in society, Blaike and Brookfield note that the state is not neutral. Most of the time the state takes an extractive approach to natural resources and serves the interests of the elite who are not directly affected by environmental degradation and rural poverty. Therefore, the elite shows little interest in conservation or rural investments. Blaike and Brookfield also
emphasize the roles of foreign aid and markets in exacerbating resource extraction. In short, they emphasize the regional, political, and ecological factors of deforestation.

Guha (1989) analyzes the popular initiatives to stem deforestation in the Himalayas: called the Chipko Movement. He argues that western-style development in general and industrialization in particular is unlikely to be replicated in the Third World on account of ecological constraints. If forests are seen simply as being commodities raised primarily for profit, irrespective of the needs of the people and society encompassing it, the links between the forest and the society will be broken. And the forests will be destroyed by the members of the same society that once used to conserve and promote it. Therefore, it is necessary to identify and re-establish the links between forests and society that has been broken because of the commercialization of forest products. The success of the Chipko Movement (hugging a tree to save it from cutting) can be directly understood in terms of recognizing and invoking the links between forests and society by the leaders of Chipko. Conceptually, the theory provides an opportunity of introspection for the development planners.

While Hardin (1968) focuses on the growth in population, a lack of self-restraint and a lack of private property rights as the reasons for explaining degradation of common property, Somnathan (1991), in his analyses of deforestation and ecological degradation in a central Himalayan region, argues that a fundamental reason for deforestation is the prevailing system of property rights (and not population growth), which denies the local people certainty about future benefits from forests. Therefore, to preserve forests the present structure of rights of use and control over forest lands must be changed. However,
the destruction of village forests which were primarily controlled by the locals can not be
explained by this theory. Further, 85 per cent of the forests in Nagaland, India, is
controlled by the local people (Dwivedi, 1994), but still the destruction of forest is
continuing unabated (Forest Survey of India 1993).

Hauber (1993), in his historical review of deforestation of the post independent
India, identifies the role of inappropriate developmental polices in deforestation.

"Indian deforestation has been exacerbated by the way policy choices were structured to
fulfill a particular set of development goals. The goals of rapid industrialization, self
reliance, and egalitarian development were great but the policy choices to achieve these
goals were flawed."

Over the years, increased agricultural production was pursued through land
clearing rather than land reform (both land intensive and capital intensive techniques were
blocked for want of land reforms), and industrial demands were emphasized over other
demands and productive uses of forests resources, and virtually all forest resources were
reserved for industrial use. Under this theory it is the choice of developmental strategy and
political context that have exacerbated both population and industrial demand pressures on
forest resources in India.

2.2.3 Empirical Studies

While empirical knowledge or study is based on practical experience rather
than on theories, theory can be tested empirically, and then the validated theoretical
knowledge can be interpreted for operational (management) uses. There are several recent
empirical studies (models) that attempt to identify and explain the role of factors causing
deforestation on a global, and on a national scale (Allen and Barnes 1985, Grainger 1986,
Palo et al. 1987, Panayotou and Sungsuwan 1989, Reis and Margulis 1990, Bilsborrow and Geores 1994, Kummer and Sham 1994, Rudel 1994, Reis and Guzman 1994, Shafik 1994, Southgate 1994). However, their results are often conflicting and, therefore, unsettling. For example, Allen and Barnes (1985), Grainger (1986), and Panayotou and Sungsuwan (1989) found that the population increment has a significant positive effect on the annual change in forested areas, while Westoby (1978) emphasized that, taken in isolation, there was no correlation between population factors and deforestation. Palo (1994) also found zero correlation between population growth and forest cover. Kahn and McDonald (1994) found that both the population and population growth were statistically insignificant in explaining deforestation. Kummer and 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 $r^2$-square is only 0.05 and when population density is regressed against the deforestation the $r^2$-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 and McDonald (1994) supported the Burgess 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, while Capistrano's (1990) results 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 and Ingram (1990), Panayotou and 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 GDP per capita was not a significant factor in explaining the deforestation rate.

While Constantino and Ingram (1990), and Katila (1992) observed a significant and negative relationship 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) report that agricultural productivity has a significant and positive effect on deforestation density.
Table 2-1: Summary of the Recent Deforestation Studies

<table>
<thead>
<tr>
<th>Study</th>
<th>Unit of analysis</th>
<th>Dependent factor</th>
<th>independent factors</th>
<th>Methodology &amp; sample size</th>
<th>Nature of analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lugo, Schmidt &amp; Brown (1981)</td>
<td>Nation</td>
<td>per cent Forest Cover</td>
<td>-population (pop), +energy use</td>
<td>C.S., Linear Regression, 30</td>
<td>Static</td>
</tr>
<tr>
<td>Allen &amp; Barnes (1985)</td>
<td>Nation global</td>
<td>Deforestation rate(D.R.)</td>
<td>+pop increase, + increase in farmland, +wood-use,</td>
<td>C.S., Linear Regression 39</td>
<td>Static</td>
</tr>
<tr>
<td>Palo, Mery and Salami (1987)</td>
<td>Nation (global)</td>
<td>per cent FC</td>
<td>+pop increase, +area logged</td>
<td>C.S., Linear Regression, 60</td>
<td>Static</td>
</tr>
<tr>
<td>Rudel (1989)</td>
<td>Nation (global)</td>
<td>D.R.</td>
<td>+pop increase, +availability of capital</td>
<td>C.S., Linear Regression, 36</td>
<td>Static</td>
</tr>
<tr>
<td>Panayotou and Sungurvan (1989)</td>
<td>Province</td>
<td>per cent FC</td>
<td>-pop density, +wood price</td>
<td>C.S., Linear Regression, 64</td>
<td>Static</td>
</tr>
<tr>
<td>Scotti (1990)</td>
<td>Nation (global)</td>
<td>per cent FC</td>
<td>+pop density, +road</td>
<td>C.S., Linear Regression, 47</td>
<td>Static</td>
</tr>
<tr>
<td>Reis and Margulis (1990)</td>
<td>Municipality (Brazil)</td>
<td>per cent</td>
<td>+pop density, +crop area</td>
<td>C.S., Linear Regression, 167</td>
<td>Static</td>
</tr>
<tr>
<td>Burgess (1991)</td>
<td>Nation (global)</td>
<td>Deforestation Level of</td>
<td>+population growth, +GDP per capita, +debt service ratio as per cent of exports, +total roundwood production, +food production per capita</td>
<td>C.S., Linear Regression, 44</td>
<td>Static</td>
</tr>
<tr>
<td>Burgess (1992)</td>
<td>Nation (global)</td>
<td>Change in closed forest area</td>
<td>-pop density, +real GNP per capita in 1980, -roundwood production per capita</td>
<td>C.S., Linear Regression, 44</td>
<td>Static</td>
</tr>
<tr>
<td>Kahn and McDonald (1994)</td>
<td>Nation (global)</td>
<td>Deforested area</td>
<td>-population, +forested land area, +annual change in public external debt</td>
<td>C.S., 2 Stage linear regression model, 54</td>
<td>Static</td>
</tr>
<tr>
<td>Capistrano (1994)</td>
<td>Nation (global)</td>
<td>Depletion of broadleaf</td>
<td>-pop, +GDP per capita, -debt service ratio</td>
<td>C.S., Linear Regression, 45</td>
<td>Static</td>
</tr>
<tr>
<td>Kummer and Sham (1994)</td>
<td>Province</td>
<td>Forest area cover</td>
<td>-population, road density</td>
<td>C.S., Linear Regression, 68</td>
<td>Static</td>
</tr>
<tr>
<td>Chakraborthy (1994)</td>
<td>Nation (India)</td>
<td>Reserved forest area</td>
<td>-livestock unit, per capita income, -net rate return, fuelwood and charcoal production</td>
<td>T.S., Linear Regression</td>
<td></td>
</tr>
</tbody>
</table>

Notes: C.S. = cross-section, T.S. = Time series; Nation (global) - A cross-section of nations

Most of these deforestation studies are cross-section studies, covering different samples, and over different time periods. It can be inferred that roles of factors change across samples and over time. Moreover, when deforestation is analyzed at the isolated factor level such as population, agriculture productivity and income, the roles of various factors are found to yield conflicting results. Table 2-1 summarizes the findings of recent deforestation studies. It lists the causal factors identified, the methodology adopted and the nature of the analyses.
2.3 Critique

The descriptive literature helps identify the relevant factors that contribute to deforestation. While this is an essential starting point, these studies lack empirical verification, and do not point out the relative importance of the factors. Further, in general, these studies tend to ignore the dynamic interrelationships among the factors.

The theoretical approaches: including the tragedy of commons, competitive exploitation, and dependency theories, tend to focus on one or a few factors and overlook the other relevant interrelationships. These include interrelationship between growth of population and a need to expand the area under food production, or between the population and forest biomass removal for energy consumption or between the forest and livestock sectors or between mining, hydel dams, roads, irrigation and other infrastructure projects and forest diversions. Deforestation is also driven by the dynamic interplay among the web of these interrelationships and this is ignored in these theories.

Guppy’s (1984) theoretical construct is useful, and highlights the significance of a few relationships in explaining deforestation. This is also true of Grainger’s (1986, 1987) models. Although his theoretical model incorporates various important internal factors, he does not incorporate the external demand for timber and agriculture products in his model. Further, while Guppy emphasizes international linkages, Grainger overlooks the international linkages and focuses on the national factors. Moreover, Grainger’s empirical model includes only two explanatory factors: population growth and area logged. In summary, these theoretical constructs can be usefully extended by incorporating other identified interrelationships in a diverse and richer set of interrelationships.
Walker's (1987) optimization models are founded on a very restricted vision of deforestation, that is, deforestation by commercial logging. Further, given the current low real prices of timber (Guppy 1984), the crucial factor influencing deforestation is the discount rate, but how the discount rate for natural resources like forests be determined remains a theoretical question that continues to be discussed in the literature.

The theoretical framework of Somnathan (1991) does not explain how the locals will behave under the under different development choices, including the dynamic pressures of the growing numbers of human bodies and livestock. He also does not answer the issues of forests interactions with other sectors. The incompleteness of the argument emerges from an exclusive emphasis on one set of factors - property rights - in explaining the process of deforestation. The argument neglects the interactions of property rights with others factors, and the effect of changes in the values of the society. There is a need to understand the operational dynamics of forest use in the changing intersectoral interactions.

Haeuber's (1993) explanation is revealing but overlooks the underlying reasons for distorted policy choices. India is a democratic government, but like in many other democratic governments (including the USA), the rich and industrial interests orient the rules of government at the cost of the vulnerable, weak, and the poor sections of society. This is evident from the low investment allocation for the energy needs of the rural and poor population. In India 1 per cent of investment is allocated to the development of non-commercial energy while 80 per cent of the rural population are dependent for their cooking energy needs on non-commercial energy forms. Further, investments on forests is
about 1 per cent of total public outlay (Dwivedi 1994, Mukerjee 1994) while most of rural population (women and children) in general and the tribal population in particular depend on forests for the basic needs (fuelwood, fodder, and other non-timber products), and investment in rural and small scale industries is low although these industries generate more employment in general and rural employment in particular than the large-scale capital intensive units.

Overall, these theoretical constructs develop their arguments on one or at most a few relationships. Yet, few of the relationships have been examined empirically in a framework where the linkages between them have been highlighted. To understand the process of deforestation it is necessary to build a comprehensive model that incorporates these theoretical arguments in a holistic framework. A framework that demonstrate not only “what (one factor) is related to what (another factor)”, but how one factor is related to another factor, and how the conjunction of interrelationship changes over time is needed.

Similarly, the empirical studies fall short for several reasons. Where they do quantify the relationships between a limited number of explanatory factors they do not always measure deforestation or the factors consistently. For example, Kummer and Sham (1994), point out that the results of many of the empirical studies (for example, Lugo et al. 1981, Palo et al. 1987, Panayotou and Sungsuwan 1989, Reis and 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, most of the empirical studies are cross sectional and have failed to incorporate the implications
of different initial amounts of forest cover, and different historical timings of the process of deforestation in their analysis. Since the initial forest cover of the geographical units and the time the process of deforestation began were different, the findings of most of the cross sectional studies are time and region specific. Furthermore, the term population pressure has been used casually, and several factors 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 the 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 areas) or high (in urban areas). Therefore, results using these factors may indicate conflicting implications for the relationship between population pressure and deforestation.

There are several empirical studies of deforestation on a national scale. For example, Khator (1989), Reis and Margulis (1990), Kummer (1992), Chakraborty (1994). These studies do not link the dynamics of forest land systems with the nation’s economic system. While they did use econometric analysis, these analyses suffer from the limitations of most empirical studies being based on simple linear multivariate regression methodology, and neglecting possible non-linear effects, interactions and dynamic feedback between the factors. This reflects the fact that, the focus of the recent studies on the causal factors of deforestation rather than on the interactions of factors means that they largely overlook the nature of the deforestation process.

In general, the approach adopted by the previous authors to investigate the deforestation process has been partial, linear and static, while deforestation is a complex,
dynamic and holistic process. For all of the above-mentioned reasons, more encompassing, more integrated, more dynamic, and more empirically verified analysis is needed as a guide to policy formulation. In order to be effective in slowing or reversing the rate of deforestation, policies must be focused on those specific factors that (a) can be changed by policy instruments, and (b) will reliably make a difference at the time that an intervention is considered. And for this purpose, analyses are useful only to the extent that they mimic the real world with some reliable degree of precision. None of the deforestation analyses to date have been capable of serving these functions.

In summary, descriptive studies have pointed out causal factors, theoretical studies have given some insight into parts of the process and empirical studies have tried to test the theories of deforestation. But all the major theories and factors have not been put together in one model. This is objective of this thesis and the focus of the next two Chapters.
3. A Simple System Dynamics Model of Deforestation

3.1 Introduction

Korzukhin et al. (1996) divide forest management models into two main categories: empirical and process. "Empirical models seek principally to describe the statistical relationships among data with limited regard to an object's internal structure, rules or behavior. In contrast, process models seek primarily to describe data using key mechanisms or processes that determine the object's internal structure, rules, and behavior" (Korzukhin et al. 1996). Using this division, it is suggested that the deforestation models to date are empirical models and not process models. A process model enhances the general understanding of a given problem and helps in developing a policy design to control the problem because such a model provides structural insights about the working of some real world system and is able to reproduce the real system's behavior, at least approximately, under the conditions and policies under consideration. Moreover, such a model also clarifies why different policies lead to different results (Meadows and Robinson 1985). Under this classification the model of deforestation developed in this thesis can be designed as a process model.

There are a number of distinct modeling methods that may be used to model deforestation. These include linear programming, input-output, econometric, stochastic

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3 A substantial portion of this Chapter is presented in Saxena and Nautiyal (1997)
simulation, and system dynamics models. Each modeling method is itself based on a model of how modeling should be done (Meadows and Robinson 1985). These modeling methods differ in their information bases, mathematical procedures, and the use to which the model is to be put. For example, “Econometric models are generally based on statistical data, they typically contain a mixture of simultaneous and lagged relationships, they are predominantly linear, and they are solved by iterative simultaneous equation techniques. (while) complex dynamic models with non-linear and lagged equations necessarily must be solved by simulation techniques (difference equations) because they are too mathematically complex to be solved analytically.” (Meadows and Robinson 1985, p 23). In the past, simulation modelers have attempted to represent a real system by mimicking with the computer the actual (but simplified) forces, motivations, and influences that they believe make the system work. This thesis examines the process of deforestation. It uses the system dynamics simulation technique to reproduce the process of deforestation.

3.2 **System Dynamics**

A system is any set of interrelated elements, and is composed of two kinds of entities: elements, which are generally visible or measurable objects or flows, and relationships, which are connections that are postulated to exist between these elements (Meadows and Robinson 1985). System dynamics, as the name implies, is concerned with questions about the dynamic tendencies of complex systems. System dynamics methodology is a subset of simulation modeling, and is practiced in a variety of disciplines. This methodology has been used in the past to model the complex dynamic
processes in engineering, economics and ecology (Meadows and Robinson 1985, Meadows et al. 1992). System dynamics includes not only the basic idea of simulation, but also a set of concepts, representational techniques, and beliefs that make a definite modeling paradigm. The central concept is the idea of a feedback. A closed chain of causal relationships forms a feedback loop. System dynamics models are made of many such loops linked together. They are ideally closed system representations, where most of the elements occur in the feedback relationships are endogenous; that is, solved for within the model. When some elements are believed to influence the system from outside, it is represented in the system as an exogenous factor in the model. Philosophically system dynamics attempts to take all relevant factors into consideration, thereby minimizing the use of exogenous factors.

Non-linearities are also considered important in explaining system behavior. “Non-linear relationships can cause feedback loops to vary in strength, depending upon the state of the system. Linked non-linear feedback loops form patterns of shifting dominance—under some conditions one part of the system is very active, and under other conditions another set of relationships takes control and shifts the entire system behavior” (Meadows and Robinson 1985, pp. 37-38). A model structure composed of several feedback loops linked non-linearly can produce a wide variety of complex behavior patterns. A final distinguishing feature of the system dynamics paradigm is its emphasis on operational mechanisms rather than on observed correlations. System dynamics models are usually intended to be used at the general-understanding or policy design stages of decision making as compared to econometric models that “are made for the purpose of precise,
short-term prediction of aggregate economic factors” (Meadows and Robinson 1985, p 50). Econometric models are least applicable to questions of general understanding that range across disciplines, over long time horizons, and into circumstances that have not been observed historically.

The system dynamics methodology was developed by J.W. Forrester during the 1950s (Forrester 1961, Forrester 1968, Forrester 1971, Meadows and Robinson 1985). The first system dynamics models addressed such common problems as inventory fluctuations, instability of the labor force, and falling market share (Forrester 1961). Forrester (1961) modeled complex industrial processes by using system dynamics modeling concepts. The success of “Industrial Dynamics” led to the publication of “Urban Dynamics” (Forrester 1969), and later, Forrester proceeded to develop “World Dynamics” (Forrester 1971). The system dynamics concepts were popularized by the publication of “The Limits to Growth” (Meadows et al. 1972). The focus was primarily on the conclusions of the study and less attention was paid to the underlying structure of the model (Foot 1977). Later, system dynamics modeling concepts were used in management sciences (Foot 1977) and more recently, Meadows et al. (1992) published “Beyond the Limit” using an interdisciplinary global model. This is a general understanding process model of the world as one system.

System dynamics models have also been used in natural resources modeling. Examples include “The Eutrophication of Lakes” (Anderson, 1973), “DDT Movement in the Global Environment” (Randers 1973), and “The Discovery Life Cycle of a Finite Resource: A Case Study of U.S. Natural Gas” (Naill 1973). Anderson (1973) provides a
simulation study of one pollution problem- eutrophication. This study of eutrophication was conducted to test the relative effectiveness of alternative pollution removal policies. The model was based on "Dynamo"- a language of system dynamics modeling, and concluded that "no control policy based on removal can succeed indefinitely in holding pollution to acceptable levels when the generation of pollutant grows exponentially" (Anderson 1973, p. 117).

Randers (1973) illustrates the relative ease with which system dynamics assumptions can be understood and analyzed. The study surveys the empirical literature on DDT, a pollutant of extreme persistence, and incorporates the available information into a model that traces DDT flows from the time the pesticide is first applied on land to its ultimate appearance in marine fish. It illustrates the process through which incomplete empirical data may be incorporated into formal system models for sensitivity analysis and evaluation of policy alternatives.

Naill (1973) developed a system dynamics model of the natural resource discovery process, applied to the natural gas industry as an example. This model permits one to test, through simulation, the probable effects of alternative regulatory policies. The model concludes that in case of finite, nonrenewable resources such as the fossil fuels the normal behavioral mode in the initial period is that of unrestricted growth in supply, followed by a transition when growth is slowed, and finally a decline in supply. This model offers a useful experimental tool for determining how the various technological, physical, economic, and political factors might alter the pattern of growth and decline.
System dynamics models were also suggested to be used as a tool in environmental policy design (Meadows and Meadows 1973, Randers and Meadows 1973). Later, a computer simulation model “Fish Banks, Ltd.” was developed by Meadows et al. (1991). The model is essentially a sophisticated version of the famous “tragedy of the commons” described by Hardin (1968), and focuses on three important factors determining the dynamics of any nation’s fishing industry: the companies bank balances, the size of companies fleets, and the size of countries fish stocks. The model is an effective educational tool for teaching the basics of managing a nation’s fishery resource.

These are examples of the use of system dynamics modeling in different disciplines, and their success in developing “general understanding models” that can be useful for assessing and designing appropriate policies. The model developed in this thesis is in the same genre. It is designed to analyze the complex process of deforestation and to explore policies for sustaining forests using this proven methodology. Moreover, closed loop thinking, which is the important feature of the system dynamics technique corresponds well with the issue of conservation of resources: it emphasizes an accounting of material and energy flows and conservation of mass and energy.

While econometric techniques can be used to estimate relationships used in the system dynamics models, an econometric model is not possible for this purpose. Inadequate data especially limit the applicability and usefulness of econometric models for studies of industrializing nations, where data problems are especially discouraging (Meadows and Robinson 1985). Moreover, “One use that is clearly beyond the limits of econometric modeling is the exploration of conditions or policies that differ significantly
from those that pertained during the historical period from which the model parameters were estimated. The quasi-causal relationships in an econometric model may resemble the real system sufficiently to indicate how the unchanged or only slightly changed system may proceed into the short-term future. But they are too rigidly tied to past behavior to represent correctly the response of the system to totally new policies” (Meadows and Robinson 1985, p 52.), which is what sustainability usually requires. Finally, in most econometric models the estimated parameters remain constant. However, the system dynamics technique offers flexibility, and parameters and factors are treated as “elements” of a system, and elements can be a constant or a variable function. The longer the period of analysis the less likely an element is to remain constant. Since issues of sustainability emerge over reasonably long time periods the flexibility of system dynamics provides an extremely important additional feature.

This Chapter develops a process model of deforestation based on the forest sector alone using system dynamics concepts. The model is then expanded to include other sectors in the following Chapter.

### 3.3 Building a Model

The past studies have identified the factors impacting on the deforestation process; For example, population, agricultural productivity, fuel wood removal, industrial wood removal, fodder removal, agriculture and timber trade. Besides the identification of causal factors five additional steps need to be taken to build a system dynamics model. Figure 3-1 illustrates the various steps required to understand the deforestation process within the system dynamics modeling methodology.
• **Classify** the *identified* factors of deforestation according to their *nature* into the generic building blocks: stocks, flows and the converters. For example, forest area is identified as a stock; whereas change in forest area identified as flow.

*Figure 3-1: Steps in Building a System Dynamics Model*

- **Construct** a set of *relationships between factors* to explain the process of deforestation.

- **Develop** the causal chain of interconnections (feedback loops\(^4\)) by specifying the relationships. The relationships are specified in precise language of mathematical equations (hereafter referred as systems equations).

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\(^4\) Two kinds of feedback loops are distinguished. Positive loops tend to amplify any disturbance and to produce exponential growth. Negative loops tend to counteract any disturbance and tend to move the system towards an equilibrium point or goal (Meadows and Robinson 1985).
• Calibrate and Simulate the model to *monitor the performance of the system*. The model is calibrated by using information on the behavior of the elements of the system. The sources of information can be a controlled physical experiment, statistics, economic theory and even intuitive judgment. “Even intuitive judgments or summary statistics are better inputs to urgent decisions than no information at all. Improved long term policies can often be designed in the absence of precise data as long as the underlying structure of the environmental system is understood. It is the basic structure of the causal relationships that determine a system’s possible behavior modes, not the exact value of its components. While individual coefficients will change over time, the underlying structure typically does not. Effective environmental policies are those that produce the desired behavior mode in the system” (Meadows 1973, p. 312).

• Reiterate the process until the system in question is capable of reproducing historical performance. This is called model validation. Deforestation models developed on the above steps will have sufficient potential to explain the processes of deforestation, and will assist in exploring and developing alternative policy sets for ameliorating deforestation in the future.

In summary, building a systems dynamic model of deforestation involves identifying factors, classifying the factors carefully into the generic building blocks (stocks, flows, converters, and connectors), building a model structure based on theoretical and operational thinking, calibrating and simulating the model to understand the structure,
validating the structure by reproducing historical behavior of elements, and projecting
dynamic behavior for future, perhaps under alternative policy scenarios.

3.3.1 Generic Building Blocks

The models in the system dynamics language, Stella⁵, are built by the use
of the generic building blocks: stocks, flows, converters and connectors (High

Stocks are signified by rectangles. A stock is an accumulator and can be used as a
*barometer* for the system. Stocks reflect conditions within the system at one point in time.
When one takes a snapshot of the system, all flows cease and accumulations remain.
Therefore, the accumulation will reflect the state of a system at any point in time. These
stocks act as a buffer in the system because they accumulate. The feedback processes in
the system do not operate instantly, and the timing of the system behavior depends on the
presence of stocks that create inertia or delays. These inertial elements are also referred to
as state factors or levels (Meadows and Robinson 1985). They build or decline whenever
their associated rates of inflow and outflow are out of balance with one another. Further,
they can act as consumable resources which produce flows and are depleted; or as
catalysts which generate flows but are consumed at a much slower pace than that of the
flow itself (HPS, 1994). For example, as noted in Section (3.4), forest biomass (FBM)
and total forest area (TFA) are *resources* of a forest sector. Forest biomass is a
consumable resource while total forest area acts like a catalyst since it supports the growth
of FBM as well as being a resource itself. In this example, a stock (forest area) facilitates

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the production of forest biomass. Consider another example: lumberjacks use chain saws to cut down trees but neither a lumberjack nor a chain saw wears out during a typical day of tree harvesting. The Lumberjack or chain saw acts as catalysts in the harvesting of a tree. In none of the examples is the stock depleted at the same pace as the production flow.

\textit{Figure 3-2: Representation of Stocks and Flows}

Figure 3-2 illustrates a picture of stocks connected by flows. Flows are signified by a pipe (or conduit), with a spigot as a flow regulator, and an arrow attached to indicate the direction of flow. Flows fill and/or drain stocks (HPS 1994. pp. 57-58). Flows can be: unidirectional or bi-directional, and are indicated by a single arrow or double arrow, respectively. The specific volume of the flow is calculated by the algebraic expression put into the flow regulator. Flows represent activity in a system. In the proposed deforestation model, production, removal, and change in forest area are examples of flows in the system.
Flows are of two types: conserved, and non-conserved. A conserved flow depletes a stock, and simultaneously replenishes another stock or in other words, begins from a stock and pours into another stock. For example, the flow area planted per year, depletes the stock of cultivable lands, and replenishes the stock of area planted (see Section 4.2) in the proposed model. The non-conserved flows on the other hand represent infinite sources and sinks for flows, and are shown by a cloud at the end. For example, the flow production, is represented as a non-conserved flow in the proposed model (see Section 3.4).

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 (HPS, 1994 pp. 64-70). They are sometimes used to substitute for a stock concept. 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, and as a consequence, there are no delays between successive converters in a closed loop chain. Converters can be used as intervening factors in the closed loops which connect stocks with flows. In this intervening role, the converter is used to make explicit details of the logic sequence that feeds into a particular flow regulator. For example, in deforestation modeling it is convenient to substitute a population converter for a population stock because the processes of inflows and outflows to the population stock require an elaborate demographic sector with substantial data requirements which is considered unnecessary in this application.
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 a wire carrying electricity and flows in terms of a pipe carrying water. Connectors do not take any numeric values. Connectors reflect assumptions about "what depends on what." For example, in the model 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. Figure 3-3, presents converters and connectors in a hypothetical structure.

Figure 3-3: Representation of Converters and Connectors

Connectors in the diagram below are linking: stock 1 to converter 1, converter 1 to converter 2, converter 2 to flow 2, biflow to flow 2
3.4 A Simple System Dynamics Model of Deforestation

A system is a set of interrelated relationships coherently organized for some purpose. In the proposed model, the process of deforestation is analyzed as a set of interrelationship within the Forest System. Deforestation can be visualized as reduction in the Total Forest Area (TFA) or the Forest Biomass (FBM) as the result of interactions between the elements within the forest system. The levels of these two stocks are important; but even more important are their trends because they focus on the behavioral dynamics of these two elements. If the trend of either TFA or FBM is declining, deforestation is occurring and therefore, sustainable forestry practices need to be designed so as to avert the downward trend in TFA and FBM.

In its simplest form, the following set of elements are identified, classified, and connected by the equations in the system (see, Table 3-1). The elements are based on the past studies and an understanding of the deforestation process. The underlying interrelationships between the elements of the system are expressed by equations (the algebraic expressions) which represent the structure of the system. These equations are discussed in the model structure (Section 3.4.1 and Appendix I). A pictorial representation of the model is shown in Figure 3-4.

The elements that are hypothesized to cause deforestation can be gleaned through the past studies. Building the structure from those elements is an important task in understanding the deforestation process. Elements can be combined in different ways and properties of the system will depend on the ways in which the elements are combined, that is on the model structure.
There are many analogous examples in other sciences that recognize the
significance of structure and explain different behavior on the basis of different structural
bonding (linkages in structure). For example, graphite, and diamond have the same
element, carbon, but they have different properties because they have different bonding
structure of carbon atoms. Similarly, “Alcohol” (C₂H₅OH) and “Ether” (CH₃OCH₃) have
the same elements, and even the same number of atoms in a molecule: two carbons, six
hydrogen and one oxygen, but the two have different properties. People drink alcohol, but
if people drink ether they will die. The importance of translating elements into structure is
no less crucial in building a model of the deforestation process.

Table 3-1: Elements of the Simple Model

<table>
<thead>
<tr>
<th>Stocks</th>
<th>Flows</th>
<th>Converters</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Forest Area (TFA)</td>
<td>Change in Forest Area (Ch FA) - A bidirectional flow filling and draining the stock TFA.</td>
<td>Forest area encroached (FAenc)</td>
</tr>
<tr>
<td>Forest biomass (FBM)</td>
<td>Production per year (Production) - Inflow to the stock FBM Removal per year (Removal) - Outflow from the stock FBM</td>
<td>Fraction of forest area encroached (ffenc)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Diversion per year (diversion)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Diversion for infrastructure</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other diversion</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Productivity per hectare per year</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(productivity ha yr)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Total forest biomass removal per year (total removal yr)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fraction of forest biomass removed (fraction removed)</td>
</tr>
</tbody>
</table>

3.4.1 Model Structure

As noted in Section (1.2), the behavior of total forest area (TFA) has been
the primary focus of past deforestation studies. In this model, the focus in not only on the
TFA, but also on forest biomass (FBM). This incorporates both the geophysical and
biophysical aspects of the deforestation process. These are the two stock elements in the model. The dynamics of TFA at any time \((t)\) is influenced by the value of forest area at time \((t-dt)^6\), and the bi-flow element, change in forest area.

\[
TFA(t) = TFA(t - dt) + (- Ch_{FA}) * dt
\]

*Equation 3-1*

**Figure 3-4: A Simple Model of Deforestation**

A Simple System Dynamics Model: A Case Study of India

Table 3-2 & Figure 3-2 illustrate the scenario of India when actual data are used under optimistic assumptions: that productivity does not fall despite a higher rate of forest biomass removal than the rate of production, total removal of forest biomass per year does not grow but remains same and the percentage of forest area encroached remains frozen at 1.1% of the total forest area.

---

*6 \(t-dt = -(t-1) = 1\), since the flows are measured annually*
The flow- "change in forest area" is further influenced by the set of elements classified as converters, and listed in Table 3-1. Changes in forest area occur due to encroachments, diversions, and planting, and this flow can be bi-directional.

\[ Ch_{FA} = \text{enc	extunderscore of	extunderscore FA} + \text{Diversion} - \text{area	extunderscore planted} \]

"Encroachment" (enc_of_FA ) refers to the conversion of forest lands to agricultural use by landless people. Diversions refer to forest-depleting infrastructure developments such as dams, mines, roads, or buildings. These two processes reduce the forest area while a third process, forest planting, increases area if arable wastelands are regenerated and included in forest area. TFA usually represents the legal land-use classification of a country's land. For this reason, planting outside a legally mapped forest may not be considered to increase the forest area per se unless the area planted outside the forests is legally declared as to be included in forest area. It is assumed that the plantation outside the forest are legally declared as a protected type of forest, hence the plantation outside the forest land can be included to increase the legally mapped forest area.

After identifying the determinants of TFA, the next step is to inquire into the dynamics of encroachment, diversion and planting processes. This enhances the understanding of the deforestation process. Forest lands act as a land reservoir for future encroachers. Encroachment of forest area depends on the availability of forest area and the fraction of it that could be encroached. The fraction of encroachment is primarily influenced by the growing numbers of landless people who requires land for subsistence farming. Foresters have observed that the number of encroachments increases in direct proportion to the number of landless people (Mishra 1994). In the case of India,
encroachments are indirectly encouraged by the government’s policy of giving formerly-landless people entitlement to those lands that they illegally encroached in the past. The policy of legalizing past encroachments acts as an incentive for current and the future encroachers. The number of landless people grows with the growth of population if there are no policies to redistribute land ownership. However, the land that can be redistributed is always limited, especially in any highly populated country.

\[
enc_{of \ FA} = TFA*faenc
\]  \hspace{1cm} \text{Equation 3-3}

The diversion of forest lands depends on the availability of alternative non-forest lands for the purposes of mining and infrastructure development. In cases, where alternative non-forest lands are not available, forest lands are diverted. When forest land diversion is necessary, the area diverted could be minimized by building smaller dams, narrower roads, and high rise buildings. Nonetheless even these developments can encroach on forest lands. There can be diversion for other purposes. For example, in inflationary times the productive function of land is replaced by the storing wealth function.

\[
\text{Diversion} = \text{div}\_\text{for}\_\text{infra} + \text{otherdiv}
\]  \hspace{1cm} \text{Equation 3-4}

The size of the area that could be successfully planted depends primarily on the amount of investment allocated for this purpose, the state of planting technology, the arable land area suitable for forest plantations, and the stated goal of achieving a target percentage of land under forest cover. All these act as constraints on the size of the area that could be planted. Clearly, there are linkages between the investment policies within the economic system and the state of forest system. These linkages are often overlooked
at the macro level of economic planning, and this is particularly true in India. However, for the sake of simplicity, the simple model assumes that the annual size of area planted outside what is currently classified as forest land remains the same from year to year.

The system dynamics approach highlights the fact that restraining diversion conserves total forest area. Therefore, minimizing encroachment and diversion and maximizing forest planting will steer total forest area in the direction of the intended goal.

Forest biomass (FBM) is another stock factor whose dynamics must be understood. The stock of FBM at any one time is the net accumulation of productive inflow (forest area times productivity per unit of area) minus the outflow measured in terms of forest biomass removal.

\[ FBM(t) = FBM(t - dt) + (Production - Removal) \cdot dt \quad \text{Equation 3-5} \]

\[ Production = TFA \cdot productivity\_per\_hectare \quad \text{Equation 3-6} \]

\[ Removal = FBM \cdot fraction\_removed \quad \text{Equation 3-7} \]

The outflow is dependent on the demand for fuelwood, industrial wood, and fodder supply. There are other demands for non-timber products but the major removal of biomass is for the above-mentioned categories. Realistically, the annual biomass removal is likely to increase due to population growth and growth in the forest industry. The demand for fuelwood indicates the lack of availability of alternative energy sources at reasonable prices. Rural people and the urban poor are especially dependent on fuelwood.

In India, eighty percent of energy consumption for cooking, especially in rural areas, is in the form of fuelwood (Dwivedi 1994, Khoshoo 1994). Consumption of fuelwood is increasing, and is expected to continue to increase in the near future. Also, the share of
fuelwood energy as percentage of total non-commercial energy consumed is not declining (Mehetre 1990). Therefore, under current forest policies there is no foreseeable way within the forest sector to satisfy fuelwood demand.

The total energy consumed is the sum total of the different forms of energy available. If there were significant investments in supplying alternative forms of energy, the proportion of fuelwood energy use could decrease. However, the incentive for investing in alternative energy sources depends on the per unit cost of producing useable energy and the technology to deliver the energy to those who need it. This could be achieved if the share of alternative forms of energy exceeds the share of fuelwood in total non-commercial energy consumption. However, in India the share of alternative forms of energies is static at 35 per cent of the total non-commercial energy and is assumed in the model (Mehetre, 1990).

The demand for industrial wood in India is positively correlated to the level of literacy and the level of GNP per capita. India is still a industrializing country and both causal factors are expected to increase, which will increase the demand for industrial wood supplies. However, in the simple model, the industrial wood removal has been assumed to remain constant.

The fodder removal per year from forest lands depends on the total units of livestock, the per capita fodder removal by a standard livestock unit, and the proportion of livestock units grazing in forest lands. Even if both the proportion of livestock units grazing in forest land and the per unit fodder removal are held constant, the number of livestock units are increasing, thereby increasing the total fodder removal from forest
lands. Thus, all three major removals from forests are likely to increase. But for initial
illustrative purposes the total removal is frozen at the current rate.

3.4.2 Model Estimation/Operationalization

The model can accommodate information from any relevant information base. The forest model is operationalized by using different information sources. The sources from which values have been used in model equations are shown in Appendix I. The model is simulated by giving initialization values to its elements in the form of
"Initial" types of equations. These equations are as follows:

\[ \text{INIT TFA} = 64010000 \quad \text{Equation 3-8} \]

This is measured in hectares FSI (1991, 1993).

\[ \text{INIT FBM} = 4196000000 \quad \text{Equation 3-9} \]

This is measured in cubic meters and the data is for 1987 (FSI, 1987).

\[ \text{productivity per hectare} = 0.8 \quad \text{Equation 3-10} \]

In 1990, the forest productivity per hectare was 0.0.8 cubic meter/ ha/year (Mukerji, 1994). This value has been used in the model, despite ongoing forest degradation and soil erosion.

\[ \text{ffaenc} = .011 \quad \text{Equation 3-11} \]

The fraction of forest area encroached have been frozen to the current level of 1.1 percent of the total forest area, or 0.7 million hectares (FSI 1987; Mukerji 1994), despite the growth in numbers of encroachers.
\[ div_{for\_infra} = GRAPH(\text{TIME}) \]

(1993, 8022), (1994, 6015)

\[ otherdiv = GRAPH(\text{TIME}) \]

(1993, 21460), (1994, 3051)

Actual values of forest area diversions have been used (MEF, 1994).

\[ total\_rempyr = 315000000 \]

Equation 3-14

In 1990, total forest biomass removals were 315 million cubic meters (m\(^3\)) per year,
consisting of: 40 million m\(^3\) of fuelwood removal, 12 million m\(^3\) of industrial wood
removal, and 263 million m\(^3\) of fodder removal (Mukerji 1994, Chaturvedi 1994).

\[ area\_planted = GRAPH(\text{TIME}) \]


There is 1441000 ha of forest plantation per year (FAO, 1993). Out of which about 1
million of plantations are in existing forest area and remaining 0.441 million hectares are
on lands other than forest area. It is this area that brings change in area under forest
cover.

The unit of time simulation is one year, and the time horizon for the model
simulation is set at 35 years starting in 1990. This period is long enough to demonstrate
the major trends in deforestation through the interplay of economic and forest policies.
After specifying the equations in the model, the model can be simulated to explore the
implications of this operational structure for the process of deforestation.

3.4.3 Model Results

The main features of the results are summarized in Figure 3-5 and Table 3-2, and reveal the following features of forest dynamics in India.

In Figure 3-5, there are five curves: 1 FBM: Forest Biomass, 2 TFA: Total Forest
Area, 3 Ch FA: Change in Forest Area, 4 Production: FBM Production Per Year, 5
Removal: FBM Removal Per Year. These curves show the behaviors of these five
elements as projected by the Simple Deforestation Model.

- Deforestation is occurring and reaching serious levels in India. The results indicate that
  the total stock of forest biomass (FBM: curve 1) is rapidly declining, and the stock of
  4196 million m$^3$ of present Forest Biomass (FBM) will be entirely gone by the year
  2006. This represents a sharp contrast to India’s currently stated policy of increasing
  the country’s forested area to 33 per cent of the total geographical area in most of the
  planning documents (GOI 1952, GOI 1988, MEF 1994). This is because the total
  removal of forest biomass is far exceeding the total production of forest biomass.
There is a large discrepancy between production (52 million m³ per year) and removal (315 million m³ per year). Thus current rate of removal is about six times greater than the current rate of production. Consequently, there will be a sharp decline in the availability of forest products in the form of fuelwood, fodder, and industrial wood.

Figure 3-5: Results of the Simple System Dynamics Model

- Total Forest area (TFA: curve 2) is also declining but at slower rate than FBM. TFA increases due to forest plantations is partially offsetting the negative impact of forest encroachment and forest diversions. However, to completely offset the losses due to

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*In Figure 3-5, the numbers on vertical axis show the scales for the five chosen elements (1: FBM-Forest Biomass, 2: TFA-Total Forest Area, 3: Ch FA-Change in Forest Area, 4: Production-FBM Production Per Year, 5: Removal-FBM Removal Per Year) in their respective units, and the horizontal axis shows simulation time displayed in years. The five curves show the behavioral patterns of the five chosen elements as projected by the Simple Deforestation Model.*
Decline in change in forest area (Ch FA: curve 3) is declining over time. This is due to the enactment of Forest Conservation Act (1980) which is prohibiting forest area encroachment and diversions. However, despite the enactment of Forest Conservation Act (1980), the encroachments and diversions are still continuing, and are often regularized for political reasons. For example, the Indian Government legalized many encroachments in the provinces of M.P. and Gujarat on the eve of elections (Mishra 1994).

Production inflow (curve 4) is declining even when the productivity per hectare of forest has been assumed to remain unchanged at 0.8 m³ per hectare level, because the other production input—the forest area, is declining.

Forest biomass removal (curve 5) is disproportionately higher than forest biomass production inflow before 2006, and after 2006 the removal is constrained to the level of inflow. This is because presently forest biomass consumption is higher than the silviculturally available production, and the forest biomass inventory is being used. After 2006 the rate of removal will be limited to the current rate of production per year, that is 47.48 million m³ about 15 per cent of current rate of removal (315 million m³).
Table 3-2: Results of the Simple System Dynamics Model

<table>
<thead>
<tr>
<th>Years</th>
<th>FBM (cum)</th>
<th>TFA (ha)</th>
<th>Ch FA (ha)</th>
<th>Production (cum)</th>
<th>Removal (cum)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>4,196,000,000.00</td>
<td>64,010,000.00</td>
<td>302,348.54</td>
<td>50,912,191.64</td>
<td>315,000,000.00</td>
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<td>302,806.04</td>
<td>50,670,886.70</td>
<td>315,000,000.00</td>
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<td>1992</td>
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<td>63,336,715.84</td>
<td>322,453.28</td>
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<td>63,024,062.54</td>
<td>329,206.90</td>
<td>50,171,982.49</td>
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<td>62,713,108.24</td>
<td>295,660.19</td>
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<td>315,000,000.00</td>
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<td>48,560,797.07</td>
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<td>275,772.48</td>
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<td>242,550.71</td>
<td>46,071,639.06</td>
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<td>212,557.13</td>
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</tr>
</tbody>
</table>

FBM: Forest Biomass, TFA: Total Forest Area, Ch FA: Change in Forest Area, Production: FBM Production Per Year, Removal: FBM Removal Per Year, cum: Cubic meter, Hectare: ha
3.5 Discussion and Conclusions

By employing a simple system dynamics approach, these results reveal the shortcomings of current forest policies in India. One current policy, for example, is to restrict diversions of forest land area. This has been embodied in the “optimistic” operational values of the model. However, the results indicate that deforestation will continue even if this policy is successful: forest biomass will continue to be eroded from the nation’s forests. And even if we were to optimistically assume that the current rate of afforestation on non-forest lands were sufficient to offset the forest area losses due to encroachment and diversions, it would be insufficient to offset the rate of biomass removal. The current rate of planting will not be sufficient to offset these biomass removals. Thus deforestation will continue, despite optimistic assumptions about the effects of current policies. Current policies have narrowly focused on the legally mapped area of forest land while overlooking the rapid erosion of biomass from these same forest lands.

Why is there such a rapid depletion of forest biomass? Once again, a clearer insight of the deforestation process can be gained by using a systems model approach. There are two elements that deplete forest biomass: first, a major portion of the nation’s energy consumption currently comes directly from forests in the form of fuelwood; and second, a substantial portion of the nation’s livestock fodder comes directly from the forests by way of forest grazing.

In order to reduce the amount of biomass removed from India’s forests, an attractive alternative to the consumption of forest biomass for fuelwood must be identified
for rural communities. The following may be a possible solution, but the point here is to illustrate, once again, that a systems thinking approach is required. By increasing the energy efficiency of readily available fuel sources, it is likely that the demand for forest fuels will decrease. Presently animal and agricultural wastes are directly burned in rural areas, but the energy output can be increased. For example, biogasification of animal dung will increase heat efficiency from 14000 BTU (British thermal unit) to 20500 BTU per kg of animal dung (Tyner 1978 pp. 121-122). This is a substantial increase in energy output. Investments in biogasification therefore has the potential to decrease the loss of forest biomass. This substitution is also environmentally benign and hygienically clean. Energy co-generation\(^7\) is another possibility.

Livestock grazing in forests can also be reduced by examining the interrelationships between forests and the socio-economic fabric. Strategic policies can be devised that encourage substitution of fodder from forest’s grazing for fodder from agriculture and a reduction in the need for livestock. In particular the following are possible examples: increasing the productivity of livestock though hybrid breeding, providing tractor rental services for replacing bullock power for agriculture and transport operations, and improving rural transport. Direct regulation through increased penalties for illegal grazers is also suggested to reinforce those policies aimed at substitution and reduction of livestock numbers.

\(^7\) Energy co-generation is the production of usable energy as a by-product of industrial activities. For example, in the milling of sugar cane, the cellulose wastes are used to produce steam, which in turn is used to operate the mill and generate electricity as a useful by-product.
Consequently, policy reform is urgently needed not only in the forest system per se, but in those aspects of the socio-economic system that drive forest biomass depletion. None of this is meant to deny the importance of policies aimed at restricting encroachments and diversion, because these are important causes of deforestation in India. To offset these losses, there is an urgent need to plant trees on currently non-forested lands, and this need is over and above the need to reforest areas within existing forest lands. In order to sustain existing forest land, encroachments must be discouraged. The practice of granting land title to those who illegally encroach on forest land must be abandoned. Rural population growth and associated increase in landless people is the driving force behind forest encroachment. Policies aimed at further reducing the rate of population growth are strongly indicated. Reducing the rate of population growth would also help to slow the increasing demand for fuelwood. Given that livestock grazing is the largest cause of forest biomass removal, policies aimed at regulating forest grazing, and reducing the total number of livestock units, are both suggested if forest sustainability is to be achieved.

Expanding the model would enhance the understanding of the relative influences of, and interactions among, a number of relationships such as: 1) the extent to which increases in the urban poor affects TFA and FBM; 2) the increase in agriculture productivity that would be required to release the area for forests and thereby facilitate increase in TFA due to plantation of lands; 3) the extent to which investments in producing alternative energy sources could reduce the depletion of forest biomass in the form of fuelwood; and 4) the degree to which livestock grazing effect the forest biomass.
The model can be expanded by understanding the various dynamic linkages that affect both the TFA and FBM. It should be noted that the effect of these relationships works only in conjunction with other relationships in the system. Focusing on just one relationship without considering other relationships may not yield accurate results. For example, focusing on the encroachment problem alone will not necessarily stabilize the total forest area if the factors that influence the rate of forest land diversion are ignored. Similarly, focusing on the use of fast growing tree species will not necessarily offset forest biomass removal unless the influences on the demand for biomass are understood.

This Chapter has outlined the features needed for advancing the art of modeling the deforestation process. It introduces a new way of analyzing deforestation. Because deforestation is a dynamic process driven primarily by the interrelationships among various factors structured in a specific way of feedback loops, a systems dynamic approach is used. Previous models have tended to examine individual factors in isolation. The importance of focusing on the relationships among the various factors that contribute to deforestation cannot be overemphasized.

The system dynamics concepts have been illustrated by constructing a simple model of forestry sector using deforestation in India as an example. The preliminary results are unsettling. Far from achieving India's stated goal of covering 33 per cent of the nation's landmass with forests, the simple system dynamics model indicates that current forest policies and practices in India are not adequate to conserve the existing forests past the year 2006. Even if the current rate of forest biomass removal is stabilized, the current
stock of forest biomass will be depleted rapidly. The current rate of forest planting will fail to offset forest losses due to encroachment and the diversion of forest lands to other uses.

Even within the context of this simple model of deforestation, there is an urgent need for policy makers to understand that deforestation in India is governed by a multiplicity of factors that are interrelated over time. Before it is too late to reverse the current deforestation trend, the model suggests that policies must be designed to address several factors simultaneously. Probably, the greatest efficacy can be achieved by reducing population growth, investing in alternative energy sources, curbing the use of forests for livestock grazing, and vastly increasing investments in afforesting non-forested lands, but these policies will be explored in the next Chapter with an appropriate multi-sector model.

The thesis argues that deforestation must be seen not in terms of one or few causative factors, but in terms of entire system. It is essential to look beyond individual causative factors in isolation. As this simple model clearly demonstrates, it is the interrelationships among factors which drive the system. This is the key to understanding deforestation that is pursued in this thesis.
CHAPTER FOUR

4. A Multi-Sector Model of Deforestation

4.1 Introduction

In this Chapter a multi-sector model is constructed to facilitate an improved understanding of deforestation process. In this multi-sector model the process of deforestation is seen in terms of a system wherein the forest sector interacts with four other sectors: the agriculture, livestock, socio-economic, and energy sectors that compete for forest land, or forest produce. This multi-sector model embodies the elements of the simple model (Chapter 3). The process of deforestation is modeled in terms of the dynamic interrelationships within and among these sectors. While no single element of this model is new, the synthesis of component parts bring the process of deforestation into a much more complete picture. This is an attempt to comprehend the behavior of the whole system rather than discussing the component parts in isolation.

The model incorporates the various theoretical strands suggested by past authors. It includes, (1) a population hypothesis which suggests a positive association between the population increment and the deforestation rate, as has been suggested by many authors: Allen and Barnes (1985), Grainger (1986), Palo et al (1987), and Scotti (1990); (2) a poverty hypothesis which suggests a positive association between economic poverty and the deforestation rate, as has been suggested by Westoby (1978), World Bank (1978), Nair (1985), World Commission on Environment and Development (1987), Bojo et al

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* A substantial portion of this Chapter is presented in Saxena et al. (1997 A)
(1991), and United Nations Conference on Environment and Development (1992); and (3) a dependency hypothesis which suggests a positive link between internal and external economies suggested for example by Sunkel (1982) and Hecht (1985). It is suggested that increasing dependency (expressed by falling exchange rates and deteriorating terms of trade) increases the deforestation rate.

The model also incorporates the theoretical emphasis of Grainger (1986) on the role of internal economic factors contributing to deforestation, and Guppy’s (1984) contrasting arguments and emphasis on the role of external economic trade and the internal political dominance of elite in development planning.

The specific purpose of the model is to incorporate all of these factors into one model to reproduce the deforestation process in an accurate manner. The focus of the model is on the interactions of forests with the other sectors of economy. Therefore, elements relevant in explaining the needed interactions are included in the multi-sector model. The multi-sector model has three variants: Model A, emphasizes only the biophysical perspective of interactions between the sectors; Model B, incorporates price related interactions into Model A; and Model C incorporates dynamic functions to represent the changing behavior of interacting elements over time into Model B. The theoretical foundations of the model are expressed by the structure of the model, and are specified through equations. The equations are discussed in this Chapter, and a complete list of equation is presented in Appendix II. The model emphasizes that the process of deforestation has to be envisioned and analyzed at a systems level to capture the complex and dynamic process of deforestation. Because deforestation is an dynamic outcome of the
web of interrelationships between the elements of interacting sectors, it is likely that the combination of intersectoral policies will be necessary to sustain forests. Such policies are explored in Chapter 6, after the validation of the Models A, B and C in Chapter 5.

4.2 A Multi-sector Model (A)

The process of deforestation is clearly distinguished by the use of two distinct stock elements: TFA and the FBM (see Section 1.2). Operationally the process of deforestation has been seen by the downward movement of either of these two stock levels. Often, in the past (for example Allen and Barnes 1985, Grainger 1986, Palo et al 1987, Rudely 1989, Scotti 1990, Kummer 1992, Chakraborti 1994), the analysis of deforestation was confined to the analysis of forest area without considering the fact that the modification in the behavior of the two stocks can possibly be influenced by a different set of policies. As indicated at the outset of this document, TFA is a geophysical stock that indicates the surface of the area legally under the category of forests while FBM is a biophysical stock that expresses the level of forest resources over that area. Although they are connected, that the dynamics of their behavior patterns may be subjected to different policy influences because their natures are different. Therefore, it would be appropriate to consider the dynamics of the two stock elements separately.

Figure 4-1, illustrates a multi-sector model of deforestation process evolving from the interactions of the five sectors: Forest, Agriculture, Socio-Economic, Energy, and Livestock. This sector order is chosen to reflect the perceived importance in the past literature to the process of deforestation.
Figure 4-1: A Multi-Sector Model of Deforestation
Each sector is modeled to illustrate the influence of interactions on the process of deforestation. The complete list of the elements (with symbols) in each of the above sectors are provided in Tables A2 to A6 (Appendix IV).

4.2.1 An Enhanced Forest Sector

The forest sector in the multi-sector model builds on the simple model outlined in Chapter 3. It expands the dynamics of forest area by incorporating the dynamics of “forest area encroached” and “forest area diverted”, and treating the land area flows as conserved flows. Further, it also expands on the dynamics of forest biomass by incorporating the values of “productivity” of three main class of forests (closed, open, and mangrove) and the productivity of plantation forests. The loop of removal of forest biomass is also expanded (see Forest Sector in Figures 4-1, and 4-2).

The dynamics of forest area is illustrated by the relationship between the stock of total forest area (TFA), the stock of area encroached (Aenc), the stock of area diverted (Adiv) and the stock of area planted (Aplanted). The stock of TFA is filled and drained by the three flows that determine the change in forest area per year. The three flows are one inflow, Forest area increase per year (Forest area increase), and two outflows of Area encroached per year (Aenc yr) and Area diverted per year (A div yr)\(^9\).

\[
TFA(t) = TFA(t - dt) + (FA_{Iyr} - A_{encyr} - A_{divyr}) \cdot dt \quad \text{Equation 4-1.}
\]

The stock - Aenc is filled by the inflow of area encroached per year (Aenc yr). However, the most of the area encroached is utilized for agriculture purposes. Therefore,

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\(^9\) Note that where the simulation period is one period, \(dt = t \cdot (t - 1) = 1\). In the model the flows are measured per year.
for land use indication, this stock has been illustrated to be drained by the outflow-area encroached converted for agriculture (Aenc c ag).

Figure 4-2: Illustration of Relationships in the Forest Sector

\[ A_{enc}(t) = A_{enc}(t - dt) + (A_{enc \ yr} - A_{enc \ c \ ag}) \cdot dt \]  

Equation 4-2

The stock-area diverted (Adiv) is filled by the inflow of diversion per year (Adiv yr) and does not have any outflow in this model.
\[ A_{div}(t) = A_{div}(t - dt) + (A_{div \ yr}) \cdot dt \quad \text{Equation. 4-3} \]

The stock - area under forest plantation (A planted) has inflow - area planted per year (A planted yr) from the stock of the cultivable land (shown in agriculture sector), and there is an outflow the - Forest area increase per year to TFA (FAI).

\[ A_{planted}(t) = A_{planted}(t - dt) + (A_{planted \ yr} - FAI) \cdot dt \quad \text{Equation. 4-4} \]

The dynamics of forest biomass are illustrated through the behavior of FBM (see Figure 4-3). The stock - FBM is filled by the inflow of production per year (Prod yr) and it is drained by the outflow of removal per year (Rem yr).

\[ FBM(t) = FBM(t - dt) + (Prod \ yr - Rem \ yr) \cdot dt \quad \text{Equation. 4-5} \]

The inflow (Prod yr) is the summation of the algebraic products of the stock - TFA and the value of the converter - weighted productivity per hectare per year (wt prod ha yr), and the stock of area planted (A planted) and plantation productivity. The two production flow terms are separated to illustrate the difference in the productivity of area under plantations outside forest area, and the average productivity in forests. The weighted productivity in forests is the weighted average of productivity of different types of forests

\[ \Rightarrow Prod \ yr = \{TFA \cdot wt \ prod \ ha \ yr + A \ planted \cdot plantation \ productivity\}. \quad \text{Equation. 4-6} \]
The forests can put under three different classes: closed, open, and mangrove. Therefore, the weighted average productivity in forests is the sum of the product terms of dense forest area ($DFA$) and average productivity of dense forest area (that is, mean annual increment - $a_{inc\ DFA}$), open forest area ($OFA$) and the average productivity of open forest area (mean annual increment - $a_{inc\ OFA}$), and mangrove forest area and ($MnFA$) the average productivity (mean annual increment of mangrove forest area - $a_{inc\ MnFA}$). In addition to this production flow from the forests, there is production flow available from the plantations outside forests.
\[ \text{O wt productivity per year} = \left\{ \text{DFA} \times \text{ainc DFA} + \text{OFA} \times \text{ainc OFA} + \text{Mn Fa} \times \text{ainc Mn} \right\} / \left( \text{DFA} + \text{OFA} + \text{Mn Fa} \right) \quad \text{Equation 4-7} \]

\[ \text{ODFA} = TFA \times \text{FrDFA} \quad \text{Equation 4-8} \]

\[ \text{O OFA} = TFA \times \text{FrOFA} \quad \text{Equation 4-9} \]

\[ \text{OMn FA} = TFA \times \text{Fr Mn FA} \quad \text{Equation 4-10} \]

\( O \) is the symbol for the converter, and has been used in the beginning of a equation for a given converter (see, for example Equations 4-7, 4-8, 4-9 and 4-10). The magnitudes of DFA, OFA, and Mn Fa are in turn determined by the product of the size of the total forest area and the respective fraction of forest under each of the three categories of the forests such as fraction under dense forests (Fr DFA), fraction under open forest (Fr OFA), and fraction under mangrove forests (Fr Mn FA). The sum of the fractions is equal to unity. The fraction under each of the three categories of forests are the outcome of several forces including both biological and economic forces. For example, over a period of time the fraction of dense forest may increase either due to biological upgradation of open forests or due to increased conservation efforts or both. Similarly, the fraction of open forests may change due to degradation of dense forests or through afforestation measures on the bare forest lands.

The drain from the stock- Forest biomass, is indicated by outflow -the removal per year (Rem yr). The outflow Rem yr is the sum of the removal of wood per year (Rem W yr) and the removal of non-wood per year (Rem NW yr). These two categories of
removals from forests are greatly influenced by the socio-economic fabric and the size of livestock sector surrounding the forests because they affect the two wood and non-wood removals respectively.

\[ Rem_{yr} = Rem_{W yr} + Rem_{NW yr} \quad Equation. 4-11 \]

To understand how the dynamics of removal takes place, the forestry sector’s interaction with the agriculture, socio-economic, energy and livestock sectors now needs closer examination.

4.2.2 Forests and the Agriculture Sector

The forest sector is linked to the agricultural sector primarily by its link with the stock of TFA. There are both direct as well as an indirect links. The forest sector is directly linked to the agricultural sector by the stock of forest area encroached. The stock of forest area encroached builds up from the outflow of the stock TFA and merges into the agriculture sector particularly in the stock of area under food production.

The indirect link comes into play by the competition for the unused- cultivated waste lands that can either go under forests or under agriculture production. Already most land has been put to one production use or other but there is some land that is not fit for agriculture or forestry. These lands are left under the category of cultivable waste lands, and can either be put to agriculture or to forestry provided some investments are done to amend the lands. The increased pressure on land due to increased demands of both the categories of land uses have accentuated the competition between land development for agriculture and for forest plantations.
The interactions between the agriculture and forestry sectors are illustrated through the dynamics of the two major stocks of the agriculture sector: the *cultivable lands* and the *area in food*. The elements of the agriculture sector that operationally affect these two stocks and the various linkages between them are shown in Figure 4-4, and are tabulated in Table A-3 (Appendix IV).

*Figure 4-4: Illustration of Relationships in the Agriculture Sector*
In any nation, the stock of the cultivable lands is limited by its geographical boundaries. This stock is connected to the stock of "area in food" by the land development rate (ldr). Further, there is another flow, Aplanted yr, that connects the stock of cultivable land to the stock of area planted (Area planted) in forest sector.

\[
\text{cultivable lands}(t) = \text{cultivable lands}(t-dt) + (\text{-ldr} - \text{Aplanted yr}) \times dt \quad \text{Equation. 4-12}
\]

The magnitudes of these flows are determined by the algebraic expression one puts in for the Aplanted yr and land development rate (ldr), respectively. The land development rate connects the two stocks of area in food and the cultivable land. The cultivable land stock in turn is connected to the stock of area planted by the-flow area planted per year (A planted yr).

The flow of area planted per year is governed both by the physical and the financial constraints. The physical constraint is determined by the ratio of the values for the plantation time goal, that is the assumed time period in which cultivable waste lands may be fully planted and the stock of the cultivable lands available for plantation. If necessary investment for plantation is being made then the physical constraint comes into play, otherwise the plantation rate is subjected to a financial constraint. The financial constraint is determined by the ratio of plantation investment allocated and the cost of the plantation. Therefore, operationally the rate of plantation per year is determined by the minimum of the two ratios and is governed by a switching equation.

\[\Rightarrow A \text{ planted yr} = \text{MIN}[(\text{Stock of cultivated lands/plantation time goal}), (\text{investment allocated/ cost of planting per ha. per year})] \quad \text{Equation. 4-13}\]
The required investment for the annual planting (planting inv. yr) can be estimated from the algebraic product of the flow area planted per year (Aplanted yr) and the average cost of plantations. It is well understood that the cost of planting varies with the planting site, the type of species planted, whether plantation is irrigated or non-irrigated, nature of plantation and its density. However, the required investment may not be the same as the investment allocated, and generally the allocation of investment is much below the requirement in India (Mukerji, 1994). Therefore, the value of "investment allocated" is assumed taking into consideration the average value of the investments allocated in past for plantations in forestry sector. The average values for the converters - the annual cost of planting per hectare (cost of planting ha yr) and the investment allocated (inv. allocated yr) have been based on past data.

The "land development rate", is determined by the food production goal (Fpgoal), the quantity of current production (Qtcfp), the agricultural yield for food production (agfY) and the time needed to develop the land, that is, the development time (Dev time). The deviation between the goal of food production (Fpgoal) and the quantity of current production (Qtcfp) expressed as a ratio to the agricultural yield for food production (agfY) and the time needed to develop the land (Dev time) gives the operational magnitude of the bi-flow (land development rate) in hectares per year. Figure 4-5, illustrates the elements influencing land development rate.
Given the food production yield per hectare and land development time, as the deviation between the goal for food production and the quantity of current food production increases, the magnitude of land development rate increases. Conversely, given a deviation between the goal for food production and the quantity of current food production, an increase in the agricultural yield will be accompanied by a decrease in land development rate. Further, if the deviation between the goal and the current production wazuzu is very small, the effect of agricultural yield will not be discernible.

There is another flow, the “forest area encroached converted for agriculture crop production” \((A_{\text{enc c ag}})\), that connects the stock of the “area in food” to the stock of “area encroached” \((A_{\text{enc}})\). Operationally, the volume of this flow is the ratio of the

\[
ldr = \frac{(F_{\text{goal}} - Q_{\text{fp}})}{(agY)*DevTime} \]

Equation. 4-14
product of the values of the fraction of the encroached area converted for the agricultural food production \((Fr\ Aenc\ C\ agfp)\) and the stock of area encroached \((Aenc)\), and the value of the converter shifting cycle.

\[
\Rightarrow Aenc\ c\ ag = (Fr\ Aenc\ C\ Agfp*Aenc)/shifting\ cycle\quad\quad\quad\quad\quad\text{Equation. 4-15}
\]

A decrease in length of shifting cycles tends to increase the flow of encroached forest area under agriculture use and vice-versa. Thus, in a land scarce country like India, the stock of total forest area is interlinked to the stock of area in food.

The area in food in conjunction with the agricultural food yield per hectare determines the quantity of current food production. The quantity of current food production in turn affects the land development rate for agricultural food production and the stock of area in food and thus completes the feedback loop. This feedback loop signifies that the area in food production is both cause and effect of land development rate. (see Figure 4-6, for the relationships of “area in food” with the land development rate).

\[
O\ Qtcfp = area\ in\ food*agfy\quad\quad\quad\quad\quad\text{Equation. 4-16}
\]
There is another loop that affects the land development rate (ldr). It operates by affecting the value of the converter - the food production goal. Operationally, the food production goal (Fpgoal) is the sum of the values of the three converters: the quantity of food consumed (Qfood cons), the quantity of food traded, and the quantity kept as a buffer stock.

\[ O_{Fpgoal} = Q_{food cons} + Food trade + Buffer stock \]  \hspace{1cm} \text{Equation. 4-17}
Therefore, if the production goal changes either because of domestic food consumption or due to the change in quantity of food traded or due to buffer stock requirements, the land development rate will also change. The incorporation of a trade element helps in understanding and appreciating the theoretical argument of dependency theorists that trade can lead to increased land development for agricultural exports crops which, in turn, can intensify the competition between agriculture and forests for land. Similarly, the inclusion of the domestic food consumption element accounts for the population impact on the land development rate and its consequential impact on land competition between the forest and the agriculture. The quantity of food consumed is in turn determined by the size of population (pop) and the per-capita food consumption (foodpc cons).

\[ O \text{food cons} = \text{pop} \times \text{foodpc cons} \quad \text{Equation. 4-18} \]

Therefore, the variations in the values of these two converters will effect the quantity of food consumption. A trend value of the population can be used to analyze its eventual effect on the land development rate. Alternatively, the value of population can be taken for a single year.

It is assumed that per capita consumption is limited by the availability of the net per-capita food so a trend value for the net food availability at the national level have been determined with the help of time series data. However, for understanding the model dynamics, a constant (1990) value has been used for this converter.

Besides the consumption of food, the food production goal depends on the targets for food trade and the buffer stocks (see Figure 4-5). For the buffer stock converter an
average value of buffer stock has been assumed. Food trade is the balance of quantity of food exported (food X) and food imported (food M).

\[ \text{Food trade} = \text{food } X - \text{food } M \quad \text{Equation. 4-19} \]

Therefore, the quantity of food traded can be positive or negative or zero depending upon the magnitudes of food exports and imports. If the quantity of food exports exceeds the quantity of food imports, food production will exceed food consumption by the excess amount traded. This export driven increase in the quantity of the food production goal will increase the deviation between the goal and the current quantity of food production. Consequently, the impact of an increase in the food production goal will be to increase the land development rate. If imports exceed exports the effect of the food production goal on the land development rate will be reversed.

Further, if the balance in food trade is maintained then there will be no apparent affect on the land development rate. At a more desegregated level the land development rate might change by the ratio of the yields of the crops exported and imported. But in this aggregated model these details have not been modeled.

In order to understand the deforestation process, exports are more meaningful than imports because they have a positive impact on the land development rate and eventually on land competition between forests and agriculture, when land is the limiting factor. Operationally food exports will be a fraction of the quantity of food produced. Therefore, the two converters, the quantity of food produced and the fraction of food produced that is exported, will determine the quantity of food exports. The fraction of food exports will positively vary with the price ratio of food export in world market (world food X price)
and in the domestic market that is, the domestic price of the exportable food \( \text{dom food X price} \). The change in this price ratio has a significant impact on the fraction of food exported. The exchange rate between foreign and domestic currency is the important converter that affects the price ratio between world and domestic markets. For example, if the domestic (rupee) currency is devalued then the unit value of food exports in foreign (dollar) currency decreases and the quantity of food exported will increase (assuming a positive price elasticity of food exports). The magnitude of the increase will be affected by the price and the income elasticities of food exports of exporting and the importing countries. The increased quantity of food exports will increase the food production goal and again the linkages that connects the food production goal and the development rate will be operationalised to enhance the land development rate.

The world food export (dollar) price has another impact on the fraction of food produce exported. The unit value of food exports in dollars, and the quantity of food exports determine the dollar (foreign exchange) worth of exports. A rise in unit value of exports increases the dollar worth of the given quantity of food exports while a depression in the unit value will decrease the dollar worth of exports. Consequently, when the world food dollar prices fall, the country will have to step up the quantity of food exports if it intends to achieve the same level of foreign exchange earnings as was before the change in unit value of exports. The outcome of the increased quantity of exports will be to increase the production goal or to decrease the food consumption. If the production goal increases then given the trend in the food yield the efforts for land development for agricultural food will have to be increased. Operationally, the land development rate will increase. These
linkages illustrates that the exchange rate and the world prices could possibly affect the land development rate and eventually the stock of total forest area and the process of deforestation. These loops illustrate the theoretical framework of the dependency approach in the model’s operation.

The non-food agriculture production goal has effects similar to those of the food production goal. The “non-food production goal” (non-food goal) is determined by the sum of the values of the two converters representing the “quantity of domestic non-food consumption” (Qnonfcons) and “quantity of non-food trade” (nonftrade). (see Figure 4-7). The quantity of non-food consumption is the product of the non-food per-capita consumption (nonfpcccons) and the population (pop). This relationship has been shown by the use of two converters for each of the two above elements connecting the quantity of non-food consumption (Qnonfcons). The quantity of non-food trade is the balance of non-food exports (nonfX) and non-food imports(nonfM). The quantity of non-food exports will always be some fraction of quantity non-food production(Qnonfp). Therefore, there are two converters, the quantity of non-food production (Qnonfp) and fraction of non-food quantity exported (FrnonfXQ) connecting the quantity of the non-food export converter (nonfX).

If the country is exporting, then the fraction of the quantity of non-food exports (FrnonfXQ) will vary positively with the price ratio of non-food exports (nonfXprice ratio) between world non-food export price (worldnonfXprice) and domestic price of non-food exportable (NonfX price). The increase in the world non-food export price will stimulate the increase in the fraction of exports. Operationally this will push up the goal of
non-food production resulting increase of area under non-food agricultural crops. The increase in area under non-food production may be at the cost of area under food grain. Consequent upon the pressure to increase food production, it is assumed that the additional area for non-food production will eventually be drawn from the stock of cultivable land. This will intensify the competition between total forest area (TFA) and the area for food from the available cultivable land.

Figure 4-7: Illustration of Determinants of Non-Food Agriculture Production

These linkages of world food price and non-food prices with the exports of food and non-food products highlight that the incidence of the change in the world prices of agriculture exports is on the area under agriculture but the impact generally is on the total area under forests (because eventually encroachment on forest is a source of the increase
in agriculture area). The linkages reflects the dependency theoretical framework: fluctuations in the world economy as reflected by the decrease in world prices of agricultural products could possibly force the indebted nations to increase the area under export crops to sustain foreign exchange earnings. As a result there is an increased flow of land from forests to agriculture crop productions that is, the land development rate is positively affected. In summary, the external fluctuations stimulate the fluctuation in the internal economies which in turn effects forest land diversions.

4.2.3 Forests and the Socio-Economic Sector

The structure of the society and the economy has a significant influence on the stock of total forest area (TFA) and the stock of forest biomass (FBM). The various socio-economic elements that affect the forest sector are shown in Figure 4-1, and are given in Table A-4 (Appendix III).

The structure of the society and the economy influence the stock of total forest area. As pointed out in section (4.2.1), the dynamics of TFA depends on the dynamics of the inflow and outflows that bring a change in forest area (Ch FA). The dynamic behavior of TFA is governed by the dynamic patterns of the inflow - area planted per year (Aplantedyr), and outflows - area encroached per year (Aenc yr), and the area diverted per year - (A div yr).

Operationally, the magnitude of the inflow - area encroached per year, is the algebraic product of the number of encroaches per year and the average size of encroachment measured in area per (encroacher) person.
The value of the number of encroaches per year in turn is determined by the fraction of the rural population that encroach the forest lands for survival needs and the rural population. Therefore, the two values of the fraction of rural population encroaching forest lands (fr RP inc) and the size of the rural population (RP) determines the converter - the number of encroaches per year (no encroachers yr).

\[ \text{no encroachers yr} = \text{fr RP inc} \times \text{RP} \]

The size of encroachment, on an average, is the ratio of total forest area encroached and the total number of the population encroaching the forests. Therefore, the average size of the encroachment varies according to the size of forests and the size of encroaching population. The increment in rural population is of particular significance in many developing countries because the rural population constitute the major part of the population (74 per cent in India in 1991) and most of the rural areas are often in proximity to the forests. Moreover, the industrial sector in most of the developing countries is usually dominated by large, capital intensive units which are urban based, and often the service sector is also confined to few urban pockets only. As a result a large share of rural population seeks employment through land based economic activities such as agriculture, forestry, and mining. Thus, the share of rural population in conjunction with the growth and capital intensity of industrial and service sector largely determines the nature of economy and has profound impact on the forestry sector. For example, when the rural population increases without the corresponding growth in the rural economy, the rural population finds neighboring forests useful for self employment. Either they cut wood...
illegally to sell in illegal fuelwood/timber markets or they clear the forests for agricultural food production (although primarily for their own consumption). Further, inequality in land ownership in general, and in rural areas in particular, accentuate the process of encroachment. The landless tend to encroach unprotected lands, especially the forest lands. These are the most vulnerable because of the vastness of these lands and low numbers of staff available to protect them. In summary, the increment in rural population has strategic links with the state of forests, particularly the area of forests.

The rural population is determined by the size of the total population (pop) and the fraction of population residing in rural sides (fr pop R). The whole demographic sector determines the size of the population. Trends in population can be taken to reflect the overall impact of changes in social attitude, family planning technology, female literacy and health services on the size of population. These linkages highlight the role of population in eventually affecting the size of total forest area. The variation in the size of population over a period of time can examine the hypothesis that the population size, growth and the increment interact negatively with the area under forests (see section 6.2)

Another inflow negatively affecting the TFA has its linkages with the socio-economic sector. This is the area diverted per year (Adiv yr). The magnitude of this flow is determined by the converters- “diversion for infrastructure” (div for infrastructure) and “other diversions” (other diversions).

The value of the diversion for infrastructure converter is the sum of the values of the converters that contain the values of diversion for the development of infrastructure such as irrigation, mining, roads, hydol dams, thermal, and transmission lines. The
diversions for these purposes are dependent on the scale of these operations. For example, the scale of an irrigation dam influences the area that will remain under water, the area required for canals and for other construction needs. Issues arise about the frequency and the scale of projects. Operationally, the area diverted for several small projects may sum up to a diversion for a single large project, but qualitatively, the effect on the forests may be different. While this qualitative difference is recognized, it has not been incorporated into this operational model because the required quantifiable elements were not available. These effects have been left for future research.

The converter - "other diversions", is also interlinked with the elements of the socio-economic sector. The forest area can be diverted for "other purposes" such as cattle ranching or may be used for holding land in the expectation of value appreciation. For example, in times of inflation the purposes of holding land transforms from its productive attributes into its wealth storing attributes. In Brazil, over the 1970s and 1980s the lands were diverted from forests not for their productive services but for storing wealth. In inflationary times, in many developing countries the land prices either moves faster or at least keep up with the general price rise and thus becomes an instrument of increasing or maintaining wealth. As a result, with the increase in real land prices, the forest land diversion will increase. These theoretical linkages emanating from socio-economic sectors have not been explicitly modeled because of the lack of appropriate and available quantifiable elements. However, an average effect of these linkages has been incorporated into the model by using the average values for forest diversions and encroachments.
There are a number of additional links that affect the forests, particularly the forest biomass (FBM). The value of the outflow—the removal of forest biomass (Rem yr)—is governed by the values of the two converters: the removal of wood per year (Rem W yr) and the removal of non-wood per year (Rem NW yr). The removal of non-wood per year (largely fodder) is determined by the links between forests and the livestock sector, and therefore, is dealt with separately in section 4.2.5.

\[ \Rightarrow Rem \ yr = (Rem \ W \ yr) + (Rem \ NW \ yr) \]  \hspace{1cm} \textit{Equation. 4-22}

The wood outflow per year is determined by the sum of the values of the two converters, the removal of industrial wood per year (Rem IW yr) and the removal of fuelwood per year (rem FW yr).

\[ \Rightarrow Rem \ W \ yr = Rem \ IW \ yr + rem \ FW \ yr \]  \hspace{1cm} \textit{Equation. 4-23}

The industrial wood is removed for two reasons: internal industrial wood consumption (IWC) and external industrial wood trade (IW trade). Therefore, the two converters that represents the removal of industrial wood per year for consumption (IWC) and industrial wood trade (IW trade) determine the removal of industrial wood year (Rem IW yr) converter.

\[ \Rightarrow Rem \ IW \ yr = IWC + IW \ trade \]  \hspace{1cm} \textit{Equation. 4-24}

Industrial wood consumption varies with the state of industrial development and the population living standard. A trend value or the average value for this converter can be used to analyze the effect of industrial wood consumption on biomass depletion rate. The industrial wood trade is the balance between the quantity of industrial wood exports and
imports. There are various industrial products that can be traded such as sawn wood, wood pulp, pit-props, paper and paper boards and other industrial wood. However, a round wood equivalent is used to represent the various product of industrial wood exports or imports. This aggregation simplifies the web of industrial wood movement generally illustrates the impact of industrial wood trade on the forest biomass depletion. It also incorporates the impact of exchange rate on the industrial trade balances in wood.

The removal of industrial wood for trade is the balance between the requirement for wood exports (IW X) and for wood for imports (IW M).

\[ O_{IW\, trade} = (IW\, X) - (IW\, M). \]  

Equation. 4-25

The exports of industrial wood in conjunction with unit values of exports determine the domestic (rupee) currency worth of industrial wood exports. The domestic (rupee) currency worth of industrial wood exports in conjunction with exchange rate determine the foreign (U.S dollar) currency worth of industrial wood exports. This is also the case with industrial wood imports. The trend of industrial wood exports and imports along with unit values of exports and imports, and the exchange rate determine the net dollar worth of industrial wood trade. This illustrates that if net foreign (dollar) currency worth of wood trade falls as a result of a devaluation or depreciation in exchange rate, then a possibility exists that a country could drive up the quantity of wood exports to retain the level of foreign exchange earning or it may reduce the level of imports. However, reduction in imports is often politically a more difficult decision than a decision to drive up the wood exports. These linkages capture the operational relationship between the world forest economic order and the depletion of domestic forest biomass.
Another form of wood removal is for energy use. The fuelwood removal per year (Rem FW yr) is the quantity of fuelwood consumed by the relevant dependent population. Therefore, the product of the values of the two elements indicated by the two converters: the number of fuelwood dependent population (no FW dep pop) and the per capita consumption of fuelwood(CpcFW), determine the volume of fuelwood removal. Figure 4-8 illustrates the linkages that affect fuelwood removal.

\[ O \text{ Rem FW yr} = \text{no FW dep pop} \times \text{CpcFW} \]

*Equation. 4-26*

*Figure 4-8: Illustration of Relationships in the Fuelwood Dynamics*

Fuelwood is also consumed in small scale business enterprise, such as brick manufacturers, tea shops, and highway motels. However, this quantity of removal being very small, is not accounted for in this model.
In India more than 80 per cent of the population in rural areas use fuelwood for household cooking needs (Bowonder 1982, Khoshoo 1994). However, in the urban area use of fuelwood is restricted to cooking fuel needs of the urban poor population (U poor) only. Therefore, the size of the fuelwood dependent population (no FW dep pop) has been taken to be the sum of the size of the rural population and the size of the urban poor population. The product of the size of the rural population (R pop) and fraction of rural people consuming fuelwood (Fr. R pop dep fw) determine the rural fuelwood consumers, while the product of the urban poverty ratio (U pov ratio) and the size of urban population (size U pop) determines the size of urban poor fuelwood consumers. Therefore, the two converters, the size of urban population (size U pop) and the urban poverty ratio (U pov ratio) are connected to the urban poor population (U poor) converter and their values determine the value of the number of urban poor people.

The values of the three converters, rural population (R pop), fraction of rural people consuming fuelwood (fr R pop dep fw) and the urban poor population (U poor) determine the value of the fuelwood dependent population (no FW dep pop).

\[
O\ no\ FW\ dep\ pop = R\ pop \times fr\ R\ pop\ dep\ fw + U\ poor \quad \text{Equation. 4-27}
\]

\[
O\ U\ poor = (size\ U\ pop) \times (U\ pov\ ratio) \quad \text{Equation. 4-28}
\]

In addition to considering the affect of the fuelwood dependent population (no FW dep pop) on fuelwood removal, the behavior of another converter - the consumption per capita of fuelwood, needs to be determined. Consumption per capita of fuelwood is the weighted consumption per-capita of the rural and urban populations. This stratification
between the rural and urban fuelwood consumption incorporates the distinct effects of a division in society and the nature of their respective economies on fuelwood removal. Therefore, there are four converters: the size of rural population (Rpop), rural fuelwood consumption per capita (Rpcfwcons), size of urban population (Upop) and the urban fuelwood consumption per capita (Upcfw cons) that simultaneously govern the value of the consumption of fuelwood per capita (CpcFW).

\[ O \text{CpcFW} = Rpop \times (Rpcfwcons) + Upop \times (Upcfwcons) \quad Equation. \ 4-29 \]

As explained earlier, the size of the rural population is dependent on the size of the population of the country and the fraction of that population residing in rural areas. The ratio between the size of rural population along with total fuelwood consumption by rural people (TRFWC) determines the value of the rural per capita fuelwood consumption.

\[ O \text{Rpcfwcons} = (TRFWC) / (Rpop) \quad Equation. \ 4-30 \]

This equation suggests that TRFWC is an important element that connects the energy sector with the forest sector. As a result, the energy sector policies that could substitute fuelwood consumption by enhancing other alternative sources of energy, particularly in rural areas, will have a significant impact on the state of forest biomass in India.

4.2.4 Forests and the Energy Sector

Fuelwood represents about 65 per cent of the total non conventional energy consumed in India (Chaturvedi 1994, Dwivedi 1994, Khoshoo 1994). Moreover, the major share of the total fuelwood consumption is accounted for by the rural areas. Therefore, the dynamics of rural fuelwood consumption is analyzed in greater detail than
the urban counterpart. Nevertheless, the dynamics of urban fuelwood consumption is of strategic importance because it is this type of consumption that can more easily be substituted by other forms of energies. However for the sake of simplification the value of urban fuelwood consumption is illustrated only through the interplay of two converters, urban per-capita fuelwood consumption (Upcfwcons) and the size of urban population (size of Upop). The past trend values of the two converters, urban per-capita fuelwood consumption (Upcfwcons) and the size of urban population (size of Upop) have been utilized to incorporate their effects on the average consumption of fuelwood per capita of dependent population.

The magnitude of total fuelwood energy consumed in rural areas (TRFWC) is product of two converters, the fraction of energy consumed as fuelwood in rural areas (Fr FW EC) and the total energy consumed in rural areas (RTE Cons).

\[ \textit{OTRFWC} = \textit{Fr FW EC} \times \textit{RTE Cons} \]  
\hspace{1cm} \textit{Equation. 4-31}

The fraction of fuelwood energy consumed in rural areas in turn is determined by the availability of other alternative forms of energy in rural areas. Therefore the values of the two converters, the total energy consumed in rural areas (RTECons) and the supply of alternate forms of energy in rural areas (supp alt energy mtoe) determine the fraction of alternate energy (Fr alt energy), which in turn affects the share of fuelwood energy in total energy consumed in the rural areas.

\[ \textit{OFr FW EC} = \{1-(supp alt energy mtoe)/(RTECons) \} \]  
\hspace{1cm} \textit{Equation. 4-32}
The supply of alternate energy (sup alt energy) depends upon the ratio of the investment in alternative forms of energies and their average per unit costs. Here the unit is taken to be as the standard unit - the per million tons of oil equivalent (cost per mtoe of alt energy). These connections have been captured by the use of the converters, the investment on alternative energies (inv. on alt energy for rural areas) and the cost per unit of alternative energy (cost per mtoe of alt energy).

The fraction of fuelwood energy consumed in rural areas is a key element, and can be influenced by the availability of other alternative forms of energy in rural areas. It is shocking to note that about 20 million cmt of natural gas is wastefully burnt in India (VIII Five Year Plan 1990). It amounts to a waste of much needed energy and suggests that a large amount of fuelwood removal could possibly be averted if the flaring of the natural gas is curtailed and the gas is supplied to the rural areas. However, this illustrates the poor coordination between the forest and energy sectors. The saved natural gas could possibly be provided to many urban poor or rural homes. The number of urban homes that could get energy if gas is not burnt is dependent on the ratio of the two converters- the natural gas burnt and wasted and the urban per capita fuelwood consumption. There is another energy loop in the model that connects the livestock sector and energy sector through the utilization of biogas potential and its significance will be dealt in the livestock sector.

4.2.5 Forests and the Livestock Sector

The relationships between the elements is shown in Figure 4-9 and the list of elements of the livestock sector are provided in Table A-5 (Appendix III). The removal of non-wood product (fodder) is mainly governed by the number of live stock, especially
since the quantity of concentrated feed given is low in India (Chaturvedi, 1994). To arrive at the single livestock number in terms of fodder consumption, a standard livestock unit is used. Following Rao (1994) the following weights are used: 1 buffalo = 1.5 cow units, sheep = 0.4 cow units, goats = 0.5 cow units (Rao 1994). In most of the developing countries a significant percentage of livestock graze in forests. In India, about 30 per cent of the total live stock graze in forests (Dwivedi 1994) and on average about 58 per cent of the forests areas are grazed (FSI 1987, Chaturvedi 1994). Biologically the fodder requirement is 2 per cent of the weight of the standard cattle unit (weighing 250 kg) that is, 5 kg. per day (Rao 1994). Therefore, the fodder removal per year from forests is the algebraic product of the values of the three converters depicting the fraction of the forests grazing in the forests (fr lstk grazing in forests), livestock unit number(lstk no), and fodder required per unit per year (fodder req. per unit per yr).

\[ \text{Orem fodder yr} = \text{lstk no} \times \text{fr lstk grazing in forests} \times \text{fodder req. per unit per yr} \]

*Equation. 4-33*

*Figure 4-9: Illustration of Relationships in the Livestock Sector*
The livestock number has a significant relationship with energy consumption in India, as the dung is one of the major biofuels in rural India. The other biofuels are agricultural wastes and fuelwood (Mehetre, 1989). An equivalent fuelwood can be generated by the burning of animal dung. If the efficiency of dung collection and dung burning is improved through biogasification, then the efficiency of fuelwood substitution improves. Consequently the fuelwood removal rate will be decreased. The total dung availability is the algebraic product of the efficiency of collection and total amount of dung production. The total dung collected is either burnt in absence of fuelwood or used as manure in the agricultural field. In India, about 50 per cent of dung is burnt (Singh 1988). However, dung burning is equivalent to the burning of fertilizer. On the one hand the potential fertilizer is burnt while on the other hand India imports 12 million tons of fertilizer at the expense of the valuable foreign exchange. This apparent contradiction is largely ignored in the economic development literature because of the lack of perspective on systems linkages. If fuelwood supply could be increased to the point of complete replacement of dung burning, the country could save a substantial amount of foreign exchange. The potential saving can be estimated by calculating the total equivalent of fuelwood burnt, which gives total equivalent of fertilizers burnt by using respective conversion factors. Another possible policy is to develop biogas plants that could provide energy to replace the fuelwood and the bio-slurry to replace the fertilizer. The quantity of biogas energy that could be obtained from the dung can be estimated from the livestock sector by using the converter for the quantity of dung burnt. The energy possibly could be made available from the gasification of that animal dung. It is important to include these
linkages in the model to be able to explore the impacts of alternative policies that can impact the deforestation process.

The various links between forests and the four other sectors - agriculture, socio-economic, energy, and livestock sectors illustrates a comprehensive theoretical framework. It includes the various previous theoretical arguments for deforestation (see Chapter 2). For example, the inclusion of population element incorporates the effect of population changes in food production and forest biomass removal linkages. The dependency arguments are incorporated by the inclusions of dynamic elements for trade in agricultural products (both food and non-food), forest products (timber trade), and exchange rate fluctuations. In conjunction with the external trade elements the inclusion of forests area diversions for dams, mining, hydel projects, and cattle ranching highlight the role of international institution and the dominance of elite in national decision making. Further, the inclusions of energy structure elements (such as the fractions of commercial and non-commercial energy, and the fraction for various components of non-commercial energy) and their relationship with forest removal show how the energy development that neglects the needs of the rural and the poor population will impact on deforestation. The explicit inclusion of poverty ratios incorporates the poverty hypothesis, and illustrates the process by which the poor population, both in rural and urban areas, exacerbates the process of deforestation. In summary, the model incorporates the various theoretical strands in the past literature in a holistic approach and provides an understanding of the deforestation process at a systems level.
4.3 Model A with Price Feedbacks (Model B)\textsuperscript{10}

The model developed in the previous section (4.2, now called Model A) can be criticized, especially by the economists, for the lack of price responses to the forest biomass scarcity resulting from deforestation. This is a common criticism of system dynamics models (Nordhaus 1973). In this section the model is extended to explicitly incorporate price feedbacks. For convenience the extended model is referred to as Model B. Before incorporating the price responses in the model, it is useful to understand the debate concerning the impact of natural resource scarcity on growth in general, because different theoretical arguments can be then used to model price responses to such facts as increasing FBM scarcity.


The classical economists such as Marshall, and Ricardo, argued that fixity in the supply of arable land and a declining land quality when combined with the expansion in production will eventually constrain economic growth. In their view, natural resource scarcity will ultimately negatively impact economic growth.

\textsuperscript{10} A substantial portion of this section is presented in Saxena et al (1997 c)
The neoclassical economists (for example, Dasgupta and Heal 1979, Houthakker 1983, Baumol 1986, Bower 1987) however, challenged the classical paradigm and suggested that the means of escaping from increasing scarcity lies in the market mechanism. According to this view natural resource scarcity will sow the seeds of its own amelioration, since the scarcity of resources will eventually trigger price increases which, in turn, reduces demand and stimulates a host of resource augmenting mechanisms. These include substitution of alternative resources, increased efficiency in use of resources, and increased exploration for new reserves, recycling, technical innovations in resource exploration, extraction, processing, trade, and transformation. In summary, the neoclassical school argues for the efficacy of market institutions in ameliorating scarcity. If the resource markets are working according to the precepts of the neoclassical school, then resources are being allocated efficiently over time, and no policy intervention is required. For example, in a perfect market the scarcity caused by deforestation would result in appropriate price signals that would in turn bring about investments in the forestry and other sectors (Hyde et al. 1996) and a reduction in the demand for forest products. These investments would result in increased production from forests and bring about a new economic equilibrium where the supply and demand for forests would balance each other. However, Ciriacy-Wantrup (1963) indicated the weakness of assumptions in neoclassical theories to understand the relationship between scarcity and resource conservation. He pointed out the relevance of the concepts—uncertainty, long time horizon, and irreversibility to understand the process of resource conservation. He suggested that the pattern of resource utilization and the net benefit streams from the
resource utilization are significantly impacted by the state of uncertainty, rate of time preference, and the phenomenon of irreversibility. However, uncertainty, rate of time preference, and likely hood of irreversible damages in turn depend on the socio-economic conditions of the individuals and society engaged in utilizing the resources. Therefore, the biophysical interaction between a resource and the resource consumers becomes an important leverage in influencing the utilization pattern of the resource.

The biophysical analysts clearly focused on the biophysical interaction between the resource and resource consumers. These analysts view the relation between resource scarcity and its process of amelioration differently. These scholars argue that basic physical and ecological laws constrain our economic choices and are not correctly reflected in the economic models and market price signals (Ayres and Nair 1984, Cleveland et al 1984, Hall and Hall 1984, Daly and Cobb 1989, Cleveland 1991). These scholars, therefore, advocate strong policy initiatives to ameliorate resource scarcity. The biophysical analysts emphasize that there are massive, yet unmeasured, throughput transfers from the environment to the economy; that is, massive quantities of natural resources are poured into the resource-harvesting process, substituting in an unmeasured way for reductions in capital and labor use and these are not adequately accounted for in the traditional market mechanisms and economic measures (Cleveland 1991). For example, the forestry sector in India is measured to contribute less than 2 per cent of measured GNP (World Bank 1993). This is because much forest produce does not go through markets (Dwivedi, 1994). Further, this figure does not take into account the numerous non-market benefits (oils, medicinal plants, silk, resins, dyes, fibers, and leaves)
or the vast amounts of fuelwood, fodder, and industrial timber removed for personal use and trade that are not traded through markets. It also ignores environmental benefits of forests not only to India but also to the rest of the world (Woodwell 1992, World Bank 1993).

In addition to the absence of markets, there are situations where markets fail, especially in forestry. First, the well known existence of externality occurs in the forest process (Ciriacy-Wantrup 1963, Bojo et al. 1991, Rowe et al. 1992 Woodwell 1992). For example, deforestation depletes forest stock, which in turn impairs the watershed functions of forests. However, this loss may not be recorded in the market system. Moreover, because of the externality cost associated with forest use, there is a divergence between the private and social costs of non-forest land uses and commercial timber harvesting, and the market fails to appropriately guide these decisions. Second, because forests produce several goods and services, the problem of valuing joint products and non-market environmental services further limits the efficacy of market solutions. Third, the conflict between time horizon of people now living and the needs of future generations creates a bias in favor of exploiting forests now versus conserving for future. Finally, undefined, or poorly defined, and poorly implemented property rights creates open access to forests, and retards successful forestry investments. All of these failures weaken the operation of market system (Ciriacy-Wantrup 1963, Bojo et al. 1991, Rowe et al. 1992). Accordingly, in addition to market linkages, it is essential to understand the biophysical links that drive the forest biomass removals.
This thesis suggests that all the three views—Classical, Neoclassical, and Biophysical have their merits. Therefore, it is important to incorporate the linkages reflecting all the views in a system approach to any environmental problem such as deforestation. Since a system incorporates several linkages, these linkages may act as negative and positive feedbacks. Inherently, the arguments of the Neoclassical writers focus on strong negative feedbacks. Accordingly, focusing exclusively on one set of linkages may lead to incorrect results and mislead the resource policy planners. Increasing scarcity results in price increases that ultimately result in decreasing scarcity. However, the success of the relationships between scarcity and the processes that may ameliorate the scarcity will depend on the strength and speed of the various responses. Because the strength and speed of these relationships will vary from location to location, and from time to time, the merit of various solutions for ameliorating resource scarcity will vary depending upon the location and time of the problem. A system dynamics model can capture these effects.

The case for a multifaceted approach is particularly prudent in developing economies where markets and market mechanisms in the forestry sector may not be well developed or widespread in their use and impacts. In developing countries, especially for those facing deforestation and forest biomass scarcity, either markets for forestry resources largely do not exist or if they exist, they are not fully developed. As a result, the market mechanisms may not be significantly useful in influencing the dynamics of the forest sector.
In this section, the multi-sector model is extended to incorporate the linkages suggested by the Classical economists including the fixity of the stock of land, the standard Neoclassical economic perspective including the efficacy of market mechanisms, and those suggested by the Biophysical perspective, highlighting the significance of extractive biophysical linkages (for example, as emphasized in multi-sector model A). The efficacy of market mechanisms in ameliorating deforestation is examined on two levels. First, the theoretical validity of price linkages in alleviating forest biomass scarcity are examined. Second, the price linkages are modeled and the two systems profiles are compared: the profile (as produced by multi-sector model A) illustrating only the biophysical linkages, and the profile (as produced by multi-sector model B) incorporating both the biophysical and price linkages in the system. The first level of examination offers an opportunity to analyze if markets are functioning in the forestry sector of developing countries in general, and in India in particular. The second level of analysis will assist in discerning the impacts of market mechanisms on the dynamic profiles of key forestry stocks and hence, their effectiveness in preventing increasing scarcity of forest resources.

4.3.1 Examining the Role of Price

The role of price in arresting deforestation is examined in two steps. In the first step, various linkages in the suggested relationships between scarcity and price signal responses are introduced as negative feedback relationships. Further, their relevance to a developing country in general and to India in particular is evaluated. In the second step, the causative chain of connections between increasing prices and increasing removal representing the positive feedback relationships are discussed and introduced to represent
the total effect of price increases on biomass scarcity. It is demonstrated that the outcome of the effect of price on deforestation will depend upon the speed and strength of the various responses that connect scarcity and price increases.

4.3.1.1 Negative Feedbacks

The relationship between forest biomass scarcity and the rise in prices seems to be clear. However, to make this relationship operational various assumptions must be made. The various linkages assumed to make the relationship operational are represented in Figure 4-10.

As the process of deforestation progresses, it depletes forest biomass. The resulting scarcity is theoretically accompanied by the rise in price that decreases demand and attracts entrepreneurs to invest and to make profits from the rising prices. The increased investment flows eventually results in an increase in the production of forest biomass, and the scarcity of forest biomass is reduced. The reduction in scarcity abates further price increases. Thus, the relationships between deforestation and biomass scarcity, results in price increases which results in demand decreases and, investment increases, which increases the supply of forest biomass which acts to slow the original process of forest depletion. These relationships represent two negative feedback loops. On closer scrutiny, one observes that the operation of supply side negative feedback loop hinges on the operation of four linkages between these variables. The first is between deforestation and biomass scarcity, the second is between the forest biomass scarcity and price increases, the third is between price increases and increases in investment flow, and the fourth is between investment flow increases and the increase in biomass production.
Unfortunately, all four of these linkages are almost non-operational in developing countries in general and in India in particular.

**Figure 4-10: Illustration of Negative Feedback Loops between Scarcity and Price**

In addition to the supply response to the forest biomass scarcity, theoretically there is a demand response that suggests a reduction in the consumption of forest biomass due to increase in price of forest biomass. However, the demand response is weakened by the fact that much forest biomass removal is not traded through markets. In India, 90 per cent of the forest biomass removed is for the fuelwood, but the removal is not recorded in the markets. The fuelwood is generally consumed by the poor people (Dwivedi, 1994). These people do not have income to purchase alternative forms of fuel but obtain fuelwood for free as a forest “right” or by illegally removing from public forests. Fuelwood demand substitution is weak in a poor society and, especially for the poor people, the fuelwood demand response seems to be inelastic to price response (Mercer and Soussan, 1992). It is observed that rising income rather rising prices are the predominant factor in fuelwood substitution (Barnes 1986). The substitution of fuelwood is further weakened by the non-
availability of alternative fuels such as kerosene, especially in the rural areas, and the availability of fuelwood at no cost or at relatively low cost. Thus, the two main links that drives fuelwood substitution are access to dependable supplies of alternative fuels and income (Mercer and Soussan 1992). However, these links are weak in most of the developing countries, and in India particular. As a result the negative demand loop is very weak.

In developing countries, particularly in the case of India, the positive relationship between the progression of the deforestation process and forest biomass scarcity is well established (World Bank 1993). However, it is possible to visualize a scenario where even when deforestation may be progressing the scarcity is not perceived or measured. There are four main reasons. First, the very nature of forests with a long gestation period results in a need for a very large inventory to produce the output on a regular basis. With a very large inventory, it is difficult to perceive scarcity when the inventory is being used up. For example, in Canada, large forests areas have been logged but have not been fully planted (either by natural or artificial regeneration), and forest diversions (for infrastructure needs) have not been fully compensated. The deforestation problem is not perceived, primarily, because Canada has a very large inventory. In Canada, the average forest area per capita is very high (14.2 ha. per person). Second, many forest goods and services may not enter markets, and so do not have observable prices. Therefore, the depletion of inventory is not recorded by the markets. In addition, although the inventory may be low, the market may not see the depletion of inventory because of government ownership and bureaucratic apathy. A significant percentage of unrecorded removals depress the price signals in a way
that depletion of the inventory and the true physical scarcity are not reflected in the
markets. For example, in India a significant percentage of fuelwood and fodder removals
are unrecorded (about 80 per cent). For example, 40 million cubic meter is the recorded
fuelwood production, while the estimated fuelwood consumption is 235 million cubic
meter (Mukerji, 1994). The gap between production and consumption clearly highlights a
significant percentage of unrecorded removals. Although inventory may be low, the goods
may be physically scarce, but so far as the inventory exist, this may not turn into market
scarce goods.

Finally, although forest biomass scarcity clearly exists, it is not perceived at a
national scale because it does not hurt the people who make the decisions at the national
level. India does not import fuelwood or fodder and hardly imports industrial wood.
Rather, until the 1980s it exported more wood products than it imported (Government of
India 1987). Scarcity is perceived at a local scale and mostly hurts the poor and the
vulnerable groups of the society, especially women and children (Agrawal, 1986). These
groups do not have purchasing power to influence the market, or sufficient time and
institutions to challenge the decision making process at national or regional levels. Nor can
they direct investment allocations to redress their pressing problems. Ironically, even if the
planners know the problems facing the local population, the elite’s influence, interests, and
“wisdom” usually prevail. For example, investment allocations in the energy sectors in
India do not address the energy problems of rural and urban poor people. Allocations are
skewed in favor of the needs of tiny powerful sections of elite who are the politicians,
bureaucrats, industrialists, and zamindars (Reddy and Prasad 1977, Goldenberg et al.)
1988). Consequently, there are both economic and political reasons that explain the weak linkages between deforestation and perception of FBM scarcity.

The second linkage assumes that forest biomass scarcity is transmitted to the market; that is, the increased demand tends to push up the average forest biomass prices in forest biomass market. However, it is important to note that increased scarcity does not transmit instantaneously and automatically to the market. The delay in transmission may lead to the complete destruction of forestry resources in a locality. In that event, the forestry resources of neighboring locality are being used. And in many cases, there are increases in the resource prices, but in most of the cases the increases in prices reflect just the cost of transportation and not the cost of irreversible damages that might have occurred due to depletion. Further, it is the intervening element "income spent", that translates physical scarcity into market scarcity, and in turn triggers the market mechanism. Unfortunately, in most of the developing world and, especially in India the poor people are primary consumers of forest biomass in India, and poor people do not have income. However, income is required to purchase goods from the market. In the absence of employment and income generation opportunities, it is much more economically efficient for the poor people to invest their own time and walk longer hours to gather fuelwood and fodder than to spend money on purchasing fuelwood and fodder. The poor people substitute their time, which they do have, for income, which they do not have. In economic parlance, this substitution of time for income occurs because the expected opportunity cost of time invested is less than the expected economic gain from fuelwood or fodder gathering. Under this scenario, the increased scarcity does not push
up the prices; instead it translates into an increase of time investment in the collection of fuelwood and fodder. The increased scarcity therefore, increases the hardships faced by the poor. Their physical exhaustion further impoverishes them by reducing the time they might have for education, skill development, and the search for gainful employment. Thus, increased scarcity does not automatically translate into price increases, but rather into increased physical stress, further forest biomass depletion, and in turn, decreases in the opportunities for human development. As a result, many poor people find a lucrative job opportunity in illegally removing the forest biomass, especially fuelwood and industrial wood. A survey of 170 households in 9 villages in Bihar showed (fuelwood) head-loading served as a major source of income for one fifth of the households (World Bank 1993). After satisfying their needs, they sell a fraction of the fuelwood to adjoining towns or cities at prices much below the cost of raising plantations, which continues to exacerbate forest biomass depletion and scarcity. Thus, the market in absence of appropriate management institutions and equitable socio-economic conditions, instead of providing a solution to the deforestation problem, is facilitating deforestation. Further, this discussion points out a need to extend the linkage between scarcity and price. This could probably be done by providing gainful income generating opportunities so as to increase the opportunity cost of time while reinforcing it by severing the penalties associated with illegal removals of FBM.

In a market economy, the price signals will direct the investment flow to maximize the allocative efficiency of investment. However, in most developing countries price signals do not respond to natural resource scarcity. And even if it is assumed that the price
signal responds to scarcity, the investment flow to the afforestation activity does not correspond with the price increases that is, the linkage between the price rise and investment flow may be weak or broken. This is especially true when the scarce resource is owned by the public sector and the hypothesized private sector responses are replaced by public institutions. The current allocation of investment by the planning commission and regional governments is neither related to the biomass scarcity nor to the price rises. The allocations may not be purely arbitrary; however, they are definitely not market driven.

Indeed, the strength of the linkage between the price rise and investment flow depends on the ownership pattern of a resource, and the time preferences of the resource owners. For example, about 90 per cent of the forests are publicly owned in India, and the time preference of governments which are elected only for a short time period of five years is generally high. These governments give priority to investments with summary gestation periods and emphasis on the short term economic achievements. Unfortunately, by nature of forestry projects, the returns on forestry investments have long gestation period, and therefore forestry investments do not attract much public funds.

In India, forests do not seem to be important to financial planners, as the accounted financial contribution of forests to the financial flows are low. The forestry sector contribute less than 2 per cent measured GNP. Public investment is low and is not related to forest biomass scarcity (World Bank 1993). Investment for afforestation was 0.39 per cent of the total public sector outlay in the First Five Year Plan. It varied from 0.46 per cent to 63 per cent of total public outlay during Second to Fifth Five Year Plans.
It rose to 0.71 per cent in the Sixth, to a little over 1 per cent in Seventh and dropped to 0.95 per cent again in the Eighth Five Year Plan (Dwivedi 1994). Outlays to forestry was less than 1 per cent of the total public sector outlay during 1951-1995, although the price index of timber increased from 100 in 1970-71 to 2398 in 1992-93 (Saxena, 1994). In summary, the linkages between price rises and investment flows are weak in India. This is as much true for other industrializing nations such as Bangladesh, Nepal, Pakistan, and Srilanka.

The assumption that increased investment flow will increase forest biomass flow seems to be working in industrializing countries only in a very restricted manner (World Bank 1993, Chaturvedi 1994). Perhaps because the linkage carries with it two more assumptions to make it work. The first assumption is that the investments are successful; that is, the afforestation activities result in successful plantations. The second assumption is that the plantations will survive until maturity to provide the increased forest biomass. However, it is observed that only 41 per cent of the plantations are successful in India (Chaturvedi 1994). The remainder either die because of natural plantation mortality (this includes transplantation shock, adverse soil and temperature conditions, and diseases) or are consumed because of heavy grazing pressures. Further, if they survive the first few years of establishment, they are prone to removal or damage by fuelwood collectors before maturity (World Bank 1993). The gestation period between the investment flow and forest biomass outflow is long and is full of uncertainty. As a result there is no immediate increase in forest biomass, even after an increase in the investment flows in the forestry sector.
It is during the plantation maturation period that the positive feedback loops work speedily and forcefully, while the negative feedback loops remain dormant. Therefore, the relationships between increased scarcity, price increases, demand decreases, investment increases, forest biomass supply increases and reductions in scarcity as envisioned by Neoclassical economic theory, operate in a very limited way or do not operate in most developing countries. There is a need to extend the conventional Neoclassical theoretical argument of negative feedback loops by incorporating the other positive relationships emanating from the scarcity and price rises of forest biomass.

4.3.1.2 Positive Feedbacks

As noted above, forest biomass scarcity generates another set of pressures on the forest biomass: the pressures of often illegal forest biomass removals. As deforestation continues, the forest biomass scarcity increases, and the average price increases at local levels. While the returns on illegal forest removals increases, the risks involved in forest offenses do not correspondingly increase. For example, in the state of Rajasthan, one truck load of teak (approximately 8m³) has an illegal market value of 4000 dollars while the maximum punishment if apprehended and found guilty is 400 dollars. Even, if the probability of being caught is 50 per cent, it is economically rational and lucrative to illegally remove teak from the forests: since the expected returns are much higher than the expected costs. This scenario is true for many locations. Therefore, with the rise in prices of forest biomass, the illegal trade kicks in at an accelerated pace. This increases the amount of forest biomass removed illegally and dampens the rise in forest biomass prices in the legal market, which thus acts as a disincentive to private forest
investors. The World Bank (1993) observed that output from private fuelwood plantations can not compete with the illegally removed fuelwood supply. Therefore, private plantations fail to be a rational economic proposition in the context of developing countries in general, and India in particular. The other adverse effect of illegal forest biomass removal is that it usually degrades the forests, further increasing deforestation and consequently the forest biomass scarcity.

Moreover, in India the salaries of forest protection staff are low, yet they are asked to control "a high return-low risk" illegal activity at considerable personal risk. There is no link between expected benefits (wages) and the increased expected costs, so there is no incentive to increase policing. In addition, to minimize the personal risk it is tempting to become involved in this economically rewarding illegal activity. The result is that collusion with offenders becomes an economically rational activity, and deforestation continues.

Figure 4-11: Illustration of Negative and Positive Feedback Loops between Scarcity and Price
Figure 4-1 incorporates in addition to the often emphasized negative feedback loop (the relationships between the scarcity and market mechanisms that tend to decrease demand and increase investments to counteract the increasing scarcity), the other positive as well as negative loops that are operational in the forestry sectors of a developing nation. The positive loops include the relationships between the increasing scarcity of forest biomass resource, the changing (here, increasing) return to risk ratio in illegal removal of forest biomass, increasing degradation of forests, and the increasing scarcity. The additional negative loop is the relationships between increasing scarcity and increasing resource price, increasing resource price and increasing tendency to illegally remove, which in turn triggers the chain of relationships: given demand increasing supply of the resource, depresses the price of the resource, and in turn, diminishes the profitability and tendency to invest for augmenting the resource. In summary, the market mechanism is not singly confined to the often argued and emphasized negative price loops but may extend into various other positive and negative relationships. Therefore, the role of markets will be determined by the interaction of more than one relationship. The market institution may reduce the scarcity, or may aggravate the scarcity depending upon the strength and speed of various relationships that emanates from the relationships between scarcity of resource and the price increases of the resource in the context of developing countries, particularly in the case of India.

For the purpose of illustrating the above-mentioned concepts in particular, the multi-sector model in Section 4.2 was enlarged to include the above feedbacks. The investment for forestry plantation has been assumed to increase so as to illustrate the
operation of negative feedback loop. A graphical equation is used to illustrate this assumption. The positive feedback loop is also incorporated by assuming linkages between changing average FBM price which in turn positively affects the return to risk ratio, and increases the removal of FBM by non market channels. The increase in illegal removal is assumed to increase the degradation of forests; that is, the share of dense forest is negatively affected by the increased illegal removals. This eventually affects the share of open forest. Operationally, the productivity of forests decreases because of illegal removals from forests. The modified equations for the expanded multi-sector Model (B) are given below. The remainder of the relationships operate as specified in multi-sector Model (A), and are based on biophysical perspective. The equations are presented in the Appendix II.

In the multi-sector Model B, investment allocated (inv. allocated) is determined by a graphical function (Equation. 4-34) which varies positively with the percentage change of FBM price instead of an average given value used in multi-sector model A.

\[ Inv. \text{ allocated} = Graph(\text{percenchin av fbmprice}) \quad \text{Equation. 4-34} \]

It is also assumed that percentage change in average FBM price varies (percenchin av fbmprice) positively with the percentage increase in removal to FBM ratio according to the graphical function Equation 4-35.

\[ \text{percenchin av fbmprice} = Graph(\text{percchinrrmtofbm}) \quad \text{Equation. 4-35} \]
Further, it is assumed that with the rising prices, and given risk, the illegal removal increases, and therefore the fraction illegally entering market increases. A negative graphical function Equation. 4-36 illustrates this relationship.

\[ \text{fremkt} = \text{Graph (perceninh av fbmprice)} \quad \text{Equation. 4-36} \]

\[ \text{fr ne mkt} = (1-\text{fremk}) \quad \text{Equation. 4-37} \]

Furthermore, illegal removals negatively affect the stock and productivity of forests, and therefore the fraction of dense forests is assumed to decrease with the rise in illegal removals. A graphical function illustrates this relationship in Equations. 4-38. Equation 4-39 is a derived function. In India the fraction of mangrove forest is very small, hardly 1 per cent, therefore this Fr Mn FA has been assumed as constant in the simulations.

\[ \text{Fr DFA} = \text{Graph(fr ne mkt)} \quad \text{Equation. 4-38} \]

\[ \text{Fr OFA} = (1- \text{Fr DFA}- \text{Fr Mn FA}) \quad \text{Equation. 4-39} \]

### 4.4 Model B with Dynamic Functions (Model C)

So far the models do not take into account the changes in various elements with the passage of time. Therefore, to make it more relevant for predicting what might happen in the future, the usually constant elements must be replaced by time dependent (dynamic) functions. Time is a surrogate factor for all those factors that cause changes to these elements. Multi-sector Model C builds these dynamic functions into Model B.
To see how the driving elements changed over the years, past data were collected for as long a time series as possible. Driving elements are those elements that initiate an operational relationship such as population, livestock number, and the exchange rate. In the case of population, the data were available from census figures every ten years. However, for some elements such as the fraction of livestock grazing, the fraction of dung collected, and the cost of planting only one figure was available. In most cases between one and forty data points were available to assess trend functions.

4.4.1 Methodology

In general, the methodology adopted for operationalizing an appropriate dynamic function was as follows:

- The historical data were plotted on a scatter diagram.
- Any expected policy goal was included on the above scatter diagram (for example, a population goal assumed to be 1200 million by 2021).
- The possible functional forms that are consistent with the theoretical rationale for each of the elements was identified.
- The curve of best fit was estimated for each of the possible functional forms, and the appropriate statistical tests evaluated using a curve fitting software.
- The problem of auto correlation so common to time series data was checked and where appropriate a correction technique to obtain more efficient estimates of parameters was used.
Each estimated function was then evaluated using the projected values to check if the future values are theoretically consistent and reasonable.

The following sections describe the estimated functional forms for each of the driving elements. A Table provides their projected values for the period 1951-2065 (see Appendix V), and these functional forms are presented in Figures in Appendix VI.

4.4.2 Population Dynamics

The dynamic function for population was derived by using population census data. The data for the elements related to population including the rural-urban composition, is given in Table 4-1. These data show that since 1921 population in India has been growing, and that the percentage in rural communities is decreasing.

To approximate the dynamic behavior of the total population over the past nine decades, a sigmoid function was chosen with the following parameters:

\[ y = \frac{a + b}{1 + \exp(-c-x/d)} \]

where \( x \) : year, \( y \) : population, \( a, b \) and \( c \) are constants.

<table>
<thead>
<tr>
<th>Census Yr.</th>
<th>Rural</th>
<th>Urban</th>
<th>Total Pop</th>
<th>Per cent rural</th>
<th>Per cent urban</th>
</tr>
</thead>
<tbody>
<tr>
<td>1901</td>
<td>243</td>
<td>26</td>
<td>269</td>
<td>89.2</td>
<td>10.8</td>
</tr>
<tr>
<td>1911</td>
<td>226</td>
<td>26</td>
<td>252</td>
<td>89.7</td>
<td>10.3</td>
</tr>
<tr>
<td>1921</td>
<td>223</td>
<td>28</td>
<td>251</td>
<td>88.8</td>
<td>11.2</td>
</tr>
<tr>
<td>1931</td>
<td>246</td>
<td>33</td>
<td>279</td>
<td>88</td>
<td>12</td>
</tr>
<tr>
<td>1941</td>
<td>275</td>
<td>44</td>
<td>319</td>
<td>86.1</td>
<td>13.9</td>
</tr>
<tr>
<td>1951</td>
<td>299</td>
<td>62</td>
<td>361</td>
<td>82.7</td>
<td>17.3</td>
</tr>
<tr>
<td>1961</td>
<td>360</td>
<td>79</td>
<td>439</td>
<td>82</td>
<td>18</td>
</tr>
<tr>
<td>1971</td>
<td>439</td>
<td>109</td>
<td>548</td>
<td>80.1</td>
<td>19.9</td>
</tr>
<tr>
<td>1981</td>
<td>524</td>
<td>159</td>
<td>683</td>
<td>76.7</td>
<td>23.3</td>
</tr>
<tr>
<td>1991</td>
<td>629</td>
<td>218</td>
<td>847</td>
<td>74.3</td>
<td>25.7</td>
</tr>
</tbody>
</table>

(Source: INDIA 1994, P. 20)
The theoretical rationale for choosing such a function is that growth rate of population depends not only on the magnitude of population \((y)\), but also on the difference between some upper bound for the stable level (say \(L\)) and the current level of population, that is, \((L-y)\). Some upper bound for the stable level of population may always be envisaged purely on physical and biological grounds. As with most biological populations, a logistic function seems a reasonable (Clark, 1976). However, in case of humans it is assumed that population moves from some positive level (say some level in 1901) to some higher stable level (say in 2021), so a variant of logistic function-sigmoid function is used. This incorporates the behavior of population which does not grow at a constant rate, but grows at an increasing rate, then at a decreasing rate, and eventually becomes zero. The equation summary is given below in Table 4-2.

The fitted equation follows the historical data (1900-1991) well (Table 4-2). The above fitted equation assumes that population planners attain the future population stabilization goal level; that is, 1200 millions in 2021. Despite the decreasing growth rate, the total population will continue to increase because of a large population base, and even with the stabilization goal, the population will only stabilize in 2200 at 1336 millions.

Table 4-2: Population Equation Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Std Error</th>
<th>t-Value</th>
<th>95 per cent Confidence Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>244.4955805</td>
<td>6.884353914</td>
<td>35.51467335</td>
<td>228.152595 260.8386014</td>
</tr>
<tr>
<td>b</td>
<td>1091.685676</td>
<td>30.69576743</td>
<td>35.56469727</td>
<td>1018.815865 1164.555488</td>
</tr>
<tr>
<td>d</td>
<td>17.17780982</td>
<td>0.82957019</td>
<td>20.70687933</td>
<td>15.20846263 19.147157</td>
</tr>
</tbody>
</table>
The past trends in rural and urban population indicates that the percentage of rural population is declining but at a very slow rate. Further, this model includes the identity (per cent urban = 100-per cent rural). Theoretically, as the country modernizes, the urbanization increases, but there is always some level of rural population. The equation for the percentage of rural population is fitted by using data from Table 4-1. The Lorenzian function is the best fit and incorporates the needed theoretical attributes of percentage of rural population (see Table 4-3).

The fitted equation:

\[ y = \frac{a + b}{1 + \left(\frac{x-c}{d}\right)^2}, \]  
where \( x \): year, \( y \): percentage of rural population

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Std Error</th>
<th>t-Value</th>
<th>99 per cent Confidence Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>46.05781936</td>
<td>20.55252557</td>
<td>2.240981003</td>
<td>-30.1442544 122.2598931</td>
</tr>
<tr>
<td>b</td>
<td>43.44851635</td>
<td>20.58812382</td>
<td>2.110367935</td>
<td>-32.8855441 119.7825768</td>
</tr>
<tr>
<td>c</td>
<td>1906.465094</td>
<td>7.020956106</td>
<td>271.5392412</td>
<td>1880.433674 1932.496513</td>
</tr>
<tr>
<td>d</td>
<td>-116.333527</td>
<td>47.59374426</td>
<td>-2.44430289</td>
<td>-292.795636 60.12858247</td>
</tr>
</tbody>
</table>

The projected values from the fitted equation suggests a fall in the percentage of rural population. However, with an increasing total population the actual number of people residing in rural areas increased in past and possibly will increase in the future. This dynamic behavior of the rural population is the outcome of the interaction between two operational elements: total population and the fraction of the population that is rural. The increase in rural population is of significant concern to the forester, particularly because the energy, employment and land use policies impact on deforestation. It is hypothesized that an increase in the rural population, without a corresponding increase in rural
employment and changes in the rural energy consumption structure, may adversely affects both total forest area and forest biomass.

4.4.3 Energy Dynamics

To demonstrate the dynamic relationships of energy consumption with forests, it is necessary to examine the various operational elements of energy consumption. First, the implications of increasing total energy consumption must be considered. Second, and more importantly, the consequences of structural changes on energy consumption between commercial and non-commercial energy consumption must be examined. Third, it is important to link the relevance of the non-commercial energy consumption structure to consumption of fuelwood (FW), agricultural waste (AG w) and animal dung, to the forestry sector. These requirements suggests that the dynamic functions for total energy consumption, the fractions of commercial and non-commercial energy consumption, and the fraction of fuelwood in non-commercial energy consumption are essential to understand the implications of the energy sector on the process of deforestation in India.

The behavior of total energy consumption in India with available data for the 1954-85 is presented in Table 4-4.

**Table 4-4: Total Energy Consumption (Million tons of oil equivalent), India**

<table>
<thead>
<tr>
<th>Year</th>
<th>Commercial</th>
<th>Non-Commercial</th>
<th>Total</th>
<th>Fraction of Non-Commercial</th>
</tr>
</thead>
<tbody>
<tr>
<td>1954</td>
<td>18.37</td>
<td>63.33</td>
<td>81.7</td>
<td>0.775</td>
</tr>
<tr>
<td>1961</td>
<td>27.63</td>
<td>73.4</td>
<td>101.03</td>
<td>0.7265</td>
</tr>
<tr>
<td>1966</td>
<td>36.36</td>
<td>80.81</td>
<td>117.77</td>
<td>0.687</td>
</tr>
<tr>
<td>1971</td>
<td>44.76</td>
<td>86.91</td>
<td>131.67</td>
<td>0.66</td>
</tr>
<tr>
<td>1976</td>
<td>58.5</td>
<td>98.15</td>
<td>156.95</td>
<td>0.6255</td>
</tr>
<tr>
<td>1985</td>
<td>78.74</td>
<td>104.5</td>
<td>182.83</td>
<td>0.5715</td>
</tr>
</tbody>
</table>

Source: (Mehetre, 1990)
Table 4-4 shows that the total energy consumption in India is increasing, and consumption of both commercial and non-commercial energy have also increased over time. The non-commercial form of energy consumption has remained the dominant component of total energy consumption. Nevertheless, the fraction of non-commercial energy has dropped from 77.5 per cent to 57 per cent during 1954-1985 while the fraction of commercial energy has risen from 22.5 per cent to 43 per cent over those three decades (1954-1985). The most important aspect of non-commercial energy consumption is the rural-urban share of non-commercial energy consumption. The historical data for the fraction of non-commercial energy consumed in rural areas is shown through Table 4-5.

**Table 4-5: Fraction of Non-Commercial Energy Consumed in Rural Areas, India**

<table>
<thead>
<tr>
<th>Year</th>
<th>Fraction of Non-Commercial Energy Consumed In Rural Areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1954</td>
<td>0.84375</td>
</tr>
<tr>
<td>1961</td>
<td>0.843537</td>
</tr>
<tr>
<td>1966</td>
<td>0.835366</td>
</tr>
<tr>
<td>1969</td>
<td>0.828571</td>
</tr>
<tr>
<td>1971</td>
<td>0.825137</td>
</tr>
<tr>
<td>1972</td>
<td>0.824468</td>
</tr>
<tr>
<td>1973</td>
<td>0.822917</td>
</tr>
<tr>
<td>1974</td>
<td>0.821429</td>
</tr>
<tr>
<td>1979</td>
<td>0.809091</td>
</tr>
</tbody>
</table>

Source: (Mehetre, 1990)

The table indicates that the share of non-commercial energy has been slightly reduced over the period 1954-1979. However, the non-commercial form of energy consumption still has overwhelming importance in the energy consumption profile of rural India. More than 80 per cent of non-commercial energy is consumed in rural areas.

Further insight into non-commercial energy consumption can be obtained by breaking down the consumption structure of non-commercial energy. The structural components of non-commercial energy consumption are presented in Table 4-6.
Table 4-6: Non-Commercial Energy Consumption (Mtoe), India

<table>
<thead>
<tr>
<th>Year</th>
<th>Fuelwood</th>
<th>Ag. Waste</th>
<th>Adung</th>
<th>Total</th>
<th>Ffw</th>
<th>Fagw</th>
<th>Fadung</th>
</tr>
</thead>
<tbody>
<tr>
<td>1953-54</td>
<td>41.09</td>
<td>11.09</td>
<td>11.15</td>
<td>63.33</td>
<td>0.65</td>
<td>0.175</td>
<td>0.175</td>
</tr>
<tr>
<td>1960-61</td>
<td>47.43</td>
<td>12.85</td>
<td>13.12</td>
<td>73.4</td>
<td>0.645</td>
<td>0.175</td>
<td>0.18</td>
</tr>
<tr>
<td>1965-66</td>
<td>52.04</td>
<td>14.11</td>
<td>14.4</td>
<td>80.55</td>
<td>0.646</td>
<td>0.175</td>
<td>0.179</td>
</tr>
<tr>
<td>1970-71</td>
<td>56.14</td>
<td>15.25</td>
<td>17.54</td>
<td>86.91</td>
<td>0.646</td>
<td>0.175</td>
<td>0.18</td>
</tr>
<tr>
<td>1975-76</td>
<td>63.38</td>
<td>17.23</td>
<td>17.54</td>
<td>98.15</td>
<td>0.645</td>
<td>0.175</td>
<td>0.18</td>
</tr>
<tr>
<td>1984-85</td>
<td>67.52</td>
<td>18.65</td>
<td>18.32</td>
<td>104.49</td>
<td>0.646</td>
<td>0.179</td>
<td>0.175</td>
</tr>
</tbody>
</table>

Source: (Mehetre, 1990)

Table 4-6 indicates that consumption of fuelwood, agricultural waste and animal dung have increased over the years (1954-1979), and their shares (defined as fractions: fFW, fAGw, fAdung) have remained close to 65 per cent, 17.5 per cent and 17.5 per cent respectively, with no discernible trends. Clearly fuelwood dominates other components in total non-commercial energy consumption.

This energy consumption structure has profound implications for the stock of forest biomass. First, total energy consumption is increasing and the non-commercial component contributes significantly (57 per cent) to the total energy consumption. Second, it is observed that about 80 per cent of non-commercial energy is consumed in rural areas. Third, fuelwood is the major form (65 per cent) of non-commercial energy consumption. Therefore, rural energy issues such as the structure and the nature of energy consumption are of paramount importance to sustainable forestry.

For the purpose of capturing these issues, dynamic functions for total energy, the fraction of non-commercial energy consumption, the fraction of non-commercial energy consumption in rural areas and the fraction fuelwood in non-commercial energy consumption have been used in the model. For total energy consumption, the best fitted equation is found to be of linear form (see Table 4-7).
\[ y = \{a + bx\}, \text{ where } x: \text{ year, } y: \text{ total energy consumption} \]

Table 4-7: Total Energy Equation Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Std Error</th>
<th>t-Value</th>
<th>99 per cent Confidence Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>-6453.9132</td>
<td>275.9982484</td>
<td>-29.38388887</td>
<td>-7724.12587</td>
</tr>
<tr>
<td>b</td>
<td>3.343386432</td>
<td>0.140181824</td>
<td>23.85035618</td>
<td>-2.698234325</td>
</tr>
</tbody>
</table>

The fitted equation reveals that total energy consumption has been increasing in past and it is projected to be increasing in the future. This is not surprising because the increase in energy consumption is positively correlated with increase in gross national product (GNP), and population (Singh 1992), and both the GNP and population are increasing in India (World Bank 1992).

For the operational dynamics, it is essential to detail the structure of economy and the energy paths adopted, that is the energy consumption by different economic sectors, and different population scenarios for understanding the dynamics of total energy consumption. However, the main focus of the thesis is on the dynamics of forestry sector. Accordingly, without losing the focus, the thesis alternatively uses time as a surrogate factor to reflect upon the dynamics of the total energy consumption in India.

It is important to note that the fraction of the non-commercial energy in total energy consumption is declining in India (Figure 4-15). However, this rate of decline is not sufficient to offset the rising energy consumption. Consequently, the consumption of total non-commercial energy increases. Further, the fraction of fuelwood consumption is largely

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11 I am using a dynamic function in the model rather than introducing explicit relationships between population, GNP and energy because in the model these relationships can only be operational at much desegregated level.
constant. The outcome of the interaction between these energy elements will be more withdrawal of fuelwood from forests for energy needs, and the forest biomass will deplete faster than the current rate of depletion. These forecasts are supported by the observed behavior in the structural components of energy consumption (Tables 4-4, 4-5, 4-6).

The derivatives of the fitted equation (Table 4-8) for the fraction of the non-commercial energy (fRnce), suggests that the rate at which the fraction of non-commercial energy is falling is decreasing over time. Therefore, India will be dependent on non-commercial sources of energy in the future.

*Table 4-8: Non-Commercial Energy Equation Summary*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Std Error</th>
<th>t-Value</th>
<th>95 per cent Confidence Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>2063.018239</td>
<td>194.5757602</td>
<td>10.60264771</td>
<td>927.7646403 - 3198.271838</td>
</tr>
<tr>
<td>b</td>
<td>1.538407196</td>
<td>0.152395921</td>
<td>10.09480559</td>
<td>0.649252156 - 2.427562237</td>
</tr>
<tr>
<td>c</td>
<td>-340.15252</td>
<td>32.41410468</td>
<td>-10.4939662</td>
<td>-10.4939662 - 151.032205</td>
</tr>
</tbody>
</table>

The important issue is how this pattern of non-commercial energy consumption changes in rural areas. The best fitted equation (see, Table 4-9), and the first and second derivatives of fitted equation, for non-commercial energy in rural areas, follows a nonlinear form

\[ y = \left\{ \frac{a + b}{1 + (x-c)/d} \right\}, \text{ where } x: \text{ year, } y: \text{ fRnce} \]

*Table 4-9: Fraction of Rural Non-Commercial Energy Equation Summary*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Std Error</th>
<th>t-Value</th>
<th>95 per cent Confidence Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>0.753804513145</td>
<td>0.0.28555007</td>
<td>26.39833016</td>
<td>0.638672391 - 0.868936635</td>
</tr>
<tr>
<td>b</td>
<td>0.0909265328106</td>
<td>0.028202351</td>
<td>3.224076334</td>
<td>-0.0227837 - 0.2044636766</td>
</tr>
<tr>
<td>c</td>
<td>1956.55404879</td>
<td>1.28723799</td>
<td>1519.962947</td>
<td>1951.36398 - 1961.744111</td>
</tr>
<tr>
<td>d</td>
<td>28.4575706284</td>
<td>8.112936829</td>
<td>3.507678074</td>
<td>-4.25991689 - 61.16845815</td>
</tr>
</tbody>
</table>
A closer look into the dynamic relationship of non-commercial energy consumption can be obtained if one understands the behavior of fuelwood share in total non-commercial energy consumption. Table 4-6 illustrates largely a constant fuelwood share (65 per cent) in non-commercial energy consumption. In future, the scenario is not likely to change unless energy planners target the needs of rural inhabitants. There has been a slight shift in focus, at least in principle, from the urban energy needs to rural energy needs. The Eighth Five Year Plan emphasizes the role of non-commercial energy. But this semblance may not alter the dynamics of energy structure and its impact on forestry unless a large amount of the allocation is directed to non-commercial energy forms. Currently, the share of non-commercial energy is around 1 per cent of the total energy allocations.

4.4.4 Livestock Dynamics

On one hand pasture and common grazing lands are shrinking in India while on the other hand the livestock number is increasing (Rao 1994). These two processes have significant implications for the forest stocks. The dynamics of decreasing common grazing lands have been modeled indirectly through the dynamics of available cultivable lands, while the interactions due to the increasing number of livestock is modeled through the use of a time function for the livestock number. The past behavior in the livestock number is seen through the behavior of the standard cattle unit (SCU).
Table 4-10: Trends in Animal Populations (millions), India

<table>
<thead>
<tr>
<th>Year</th>
<th>Cattle</th>
<th>Buffalo</th>
<th>Sheep</th>
<th>Goat</th>
<th>Total</th>
<th>SCU</th>
</tr>
</thead>
<tbody>
<tr>
<td>1951</td>
<td>155.239</td>
<td>43.401</td>
<td>38.96</td>
<td>47</td>
<td>284.6</td>
<td>226.862</td>
</tr>
<tr>
<td>1956</td>
<td>158.669</td>
<td>44.916</td>
<td>39.25</td>
<td>55</td>
<td>297.835</td>
<td>234.1682</td>
</tr>
<tr>
<td>1961</td>
<td>175.557</td>
<td>51.21</td>
<td>40.22</td>
<td>60.8</td>
<td>327.787</td>
<td>260.253</td>
</tr>
<tr>
<td>1966</td>
<td>176.182</td>
<td>52.955</td>
<td>40.01</td>
<td>64.6</td>
<td>335.747</td>
<td>264.28</td>
</tr>
<tr>
<td>1972</td>
<td>178.865</td>
<td>57.941</td>
<td>40.39</td>
<td>68</td>
<td>345.196</td>
<td>273.4722</td>
</tr>
<tr>
<td>1977</td>
<td>180.14</td>
<td>62.029</td>
<td>40.907</td>
<td>75.62</td>
<td>358.696</td>
<td>281.6612</td>
</tr>
<tr>
<td>1983</td>
<td>192.45</td>
<td>69.78</td>
<td>48.77</td>
<td>95.26</td>
<td>406.26</td>
<td>309.755</td>
</tr>
<tr>
<td>1987</td>
<td>198.189</td>
<td>69.784</td>
<td>48.764</td>
<td>95.253</td>
<td>411.99</td>
<td>315.4959</td>
</tr>
<tr>
<td>1991</td>
<td>192.8</td>
<td>79.1</td>
<td>44.9</td>
<td>100</td>
<td>416.8</td>
<td>321.7</td>
</tr>
</tbody>
</table>

Source: Cited in Rao, 1994

Table 4-10 gives the standard cattle unit data number in India for the forty year period 1951-91, and clearly illustrates that SCU is increasing. The fitted trend equation indicates that the livestock number will increase into the future, and consequently, the pressure on forests from grazing will increase unless policy measures are taken to control grazing and/or livestock numbers. The equation is fitted using Table 4-10, and assuming that the government will control the livestock population at least by 2100 to 500 million SCU. The best fitted dynamic function to be used in the model is of the Lorenzian form (Table 4-11). Theoretically, the rationale for adopting this peak functional form is that at least by the end of next century, oxen plowed farms may be replaced, and the number of livestock may decline because draft power may be substituted in agriculture and rural transport. The best fitted dynamic equation:

\[ y = \left\{ a + \frac{b}{1 + ((x-c)/d)} \right\}, \text{ where } x: \text{ year}, \ y: \text{ SCU} \]
The past trend of livestock illustrates that the SCU number will increase in the future if a "business as usual" approach is followed with regard to livestock population. And consequently, the forest grazing will increase if grazing restrictions fail to be implemented. The need is to limit the livestock number to the ecological carrying limits of the forestry grazing grounds. A strict grazing policy may be reinforced by increasing grazing penalties for defaulters. However, these policies are not included in the dynamic function estimated above.

### 4.4.5 Agriculture Dynamics

India’s forests have a significant relationship with the agriculture sector, in particular with agriculture food productivity (hereafter referred to as agricultural productivity). Rising agricultural productivity reduces the pressure to bring in more land area under agriculture production, and consequently diminishes the land use competition between agriculture and forests. Technology has positively changed the agriculture productivity scenario in India. The past behavior of agriculture productivity in India shows a remarkable rising trend in production per hectare per year.

Table 4-12 supports this argument. Optimistically, one can assume that agriculture productivity will also rise in the future. The dynamic behavior of agriculture productivity...
has been accounted in the model by fitting a time trend to the data in Table 4-12. The historical behavior in agriculture productivity indicates that agriculture productivity has risen at a declining rate. The use of the estimated dynamic function in the model projects this behavior into the future (see Table 4-13). It assumes that technological change continues but is subject to diminishing returns. The behavior of agriculture yield is relevant to forestry because the trend in agricultural productivity suggests that the rate of land releases from agriculture to forestry made possible by the agricultural productivity gains may possibly diminish in the future.
### Table 4-12: Agriculture Productivity (Kg/ha), India

<table>
<thead>
<tr>
<th>Year</th>
<th>Agy (Kg/ha)</th>
<th>Growth (Per Cent/Year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1951</td>
<td>522</td>
<td></td>
</tr>
<tr>
<td>1952</td>
<td>536</td>
<td>2.681992</td>
</tr>
<tr>
<td>1953</td>
<td>580</td>
<td>8.208955</td>
</tr>
<tr>
<td>1954</td>
<td>640</td>
<td>10.34483</td>
</tr>
<tr>
<td>1955</td>
<td>631</td>
<td>-1.40625</td>
</tr>
<tr>
<td>1956</td>
<td>605</td>
<td>-4.12044</td>
</tr>
<tr>
<td>1957</td>
<td>629</td>
<td>3.966942</td>
</tr>
<tr>
<td>1958</td>
<td>587</td>
<td>-6.67727</td>
</tr>
<tr>
<td>1959</td>
<td>672</td>
<td>14.48041</td>
</tr>
<tr>
<td>1960</td>
<td>662</td>
<td>-1.4881</td>
</tr>
<tr>
<td>1961</td>
<td>710</td>
<td>7.250755</td>
</tr>
<tr>
<td>1962</td>
<td>705</td>
<td>-0.70423</td>
</tr>
<tr>
<td>1963</td>
<td>680</td>
<td>-3.5461</td>
</tr>
<tr>
<td>1964</td>
<td>687</td>
<td>1.029412</td>
</tr>
<tr>
<td>1965</td>
<td>757</td>
<td>10.18923</td>
</tr>
<tr>
<td>1966</td>
<td>629</td>
<td>-16.9089</td>
</tr>
<tr>
<td>1967</td>
<td>644</td>
<td>2.384738</td>
</tr>
<tr>
<td>1968</td>
<td>783</td>
<td>21.58385</td>
</tr>
<tr>
<td>1969</td>
<td>781</td>
<td>-0.25543</td>
</tr>
<tr>
<td>1970</td>
<td>805</td>
<td>3.072983</td>
</tr>
<tr>
<td>1971</td>
<td>872</td>
<td>8.322981</td>
</tr>
<tr>
<td>1972</td>
<td>858</td>
<td>-1.6055</td>
</tr>
<tr>
<td>1973</td>
<td>813</td>
<td>-5.24476</td>
</tr>
<tr>
<td>1974</td>
<td>827</td>
<td>1.722017</td>
</tr>
<tr>
<td>1975</td>
<td>824</td>
<td>-0.36276</td>
</tr>
<tr>
<td>1976</td>
<td>944</td>
<td>14.56311</td>
</tr>
<tr>
<td>1977</td>
<td>894</td>
<td>-5.29661</td>
</tr>
<tr>
<td>1978</td>
<td>991</td>
<td>10.85011</td>
</tr>
<tr>
<td>1979</td>
<td>1022</td>
<td>3.128153</td>
</tr>
<tr>
<td>1980</td>
<td>876</td>
<td>-14.2857</td>
</tr>
<tr>
<td>1981</td>
<td>1023</td>
<td>16.78082</td>
</tr>
<tr>
<td>1982</td>
<td>1032</td>
<td>0.879765</td>
</tr>
<tr>
<td>1983</td>
<td>1035</td>
<td>0.290698</td>
</tr>
<tr>
<td>1984</td>
<td>1162</td>
<td>12.27053</td>
</tr>
<tr>
<td>1985</td>
<td>1149</td>
<td>-1.11876</td>
</tr>
<tr>
<td>1986</td>
<td>1175</td>
<td>2.262837</td>
</tr>
<tr>
<td>1987</td>
<td>1128</td>
<td>-4</td>
</tr>
<tr>
<td>1988</td>
<td>1173</td>
<td>3.989362</td>
</tr>
<tr>
<td>1989</td>
<td>1331</td>
<td>13.46974</td>
</tr>
<tr>
<td>1990</td>
<td>1349</td>
<td>1.352367</td>
</tr>
<tr>
<td>1991</td>
<td>1380</td>
<td>2.297999</td>
</tr>
<tr>
<td>1992</td>
<td>1382</td>
<td>0.144928</td>
</tr>
<tr>
<td>1993</td>
<td>1445</td>
<td>4.558611</td>
</tr>
</tbody>
</table>

Source: Agriculture at a Glance (Government of India 1994 A)
The best fitted equation:

\[ y = \left( a + \frac{b}{1 + \exp(-(x-c)/d)} \right), \text{ where } x : \text{year}, y: \text{Agriculture Productivity} \]

Table 4-13: Agriculture Productivity Equation Summary

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Std Error</th>
<th>t-Value</th>
<th>95 per cent Confidence Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>500.6984933</td>
<td>25.89116555</td>
<td>19.33858452</td>
<td>431.0700329 - 570.3269536</td>
</tr>
<tr>
<td>b</td>
<td>2723.716449</td>
<td>47.73280105</td>
<td>57.06173509</td>
<td>2595.349827 - 2852.08307</td>
</tr>
<tr>
<td>c</td>
<td>2002.783489</td>
<td>0.746824555</td>
<td>2681.732241</td>
<td>2000.775072 - 2004.791905</td>
</tr>
<tr>
<td>d</td>
<td>15.01653358</td>
<td>0.717697275</td>
<td>20.92321388</td>
<td>13.08644835 - 16.94661881</td>
</tr>
</tbody>
</table>

Table 4-14: Per Capita Net Availability of Food Grains (Gm/Day), India

<table>
<thead>
<tr>
<th>Year</th>
<th>Grams Per Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>405.5</td>
</tr>
<tr>
<td>1976</td>
<td>424.3</td>
</tr>
<tr>
<td>1977</td>
<td>429.6</td>
</tr>
<tr>
<td>1978</td>
<td>468</td>
</tr>
<tr>
<td>1979</td>
<td>476.5</td>
</tr>
<tr>
<td>1980</td>
<td>410.4</td>
</tr>
<tr>
<td>1981</td>
<td>454.8</td>
</tr>
<tr>
<td>1982</td>
<td>454.8</td>
</tr>
<tr>
<td>1983</td>
<td>437.3</td>
</tr>
<tr>
<td>1984</td>
<td>479.7</td>
</tr>
<tr>
<td>1985</td>
<td>454</td>
</tr>
<tr>
<td>1986</td>
<td>478.1</td>
</tr>
<tr>
<td>1987</td>
<td>471.8</td>
</tr>
<tr>
<td>1988</td>
<td>448.5</td>
</tr>
<tr>
<td>1989</td>
<td>494.5</td>
</tr>
<tr>
<td>1990</td>
<td>476.4</td>
</tr>
<tr>
<td>1991</td>
<td>510.1</td>
</tr>
<tr>
<td>1992</td>
<td>469.9</td>
</tr>
<tr>
<td>1993</td>
<td>465.6</td>
</tr>
</tbody>
</table>

Source: Agriculture at a glance (GOI, 1994 A)

Table 4-14, illustrates the behavior of net food per capita availability in India.

Despite rising food productivity, food production has had difficulty keeping pace with the increasing population in India. This is evident from examining the net per capita availability of food grains. The availability of food grains generally increased during 1975-
1991, but in recent years it has declined. This declining behavior is because the increased population has outstripped the increased agricultural production. However, theoretically for the long run, it is reasonable to assume an asymptotic relationships between net availability of food and time. Accordingly, the dynamic behavior of net per capita availability of food grain per day was accounted in the model by incorporating a sigmoid equation. The equation used in the model of net per capita availability of food grain is given below (Table 4-15).

\[ y = a + \frac{b}{1 + e^{-(x-c)/d}} \]  
\( x: \) year \( y: \) net availability of food

**Table 4-15: Net Availability of Food Equation Summary**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Std Error</th>
<th>t-Value</th>
<th>95 per Cent Confidence Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>-4080.88244</td>
<td>1.74076e+06</td>
<td>-0.00234431</td>
<td>-5.1334e+06 5.1252e+06</td>
</tr>
<tr>
<td>b</td>
<td>4567.29533</td>
<td>1.74083e+06</td>
<td>0.002623638</td>
<td>-5.1249e+06 5.13405e+06</td>
</tr>
<tr>
<td>c</td>
<td>1942.673993</td>
<td>3165.267828</td>
<td>0.613747114</td>
<td>-7384.04564 11269.39363</td>
</tr>
<tr>
<td>d</td>
<td>7.763661484</td>
<td>41.05548992</td>
<td>0.189101665</td>
<td>-113.209686 128.7370087</td>
</tr>
</tbody>
</table>

To increase net availability of food grain per-capita per day, it will be necessary to increase the agricultural output at a rate faster than the rate of increase in population. Consequently, pressure to increase the area under food production will increase in the future, and the competition between forestry and agriculture for land use will intensify. Thus, it is observed that increasing agricultural productivity is reducing the intensity of land competition while for even maintaining the net per capita availability of food grain the competition is increasing. The outcome of the agricultural interaction with forestry will be influenced by the net strengths of these relationships.
All of these elements interact to effect the dynamic profile of forestry sector. Therefore, analyses which have ignored the interactions of these dynamic elements may fail to capture sufficient insight into the dynamic process. In order to fully appreciate the role of dynamic interactions between elements, the Model C incorporates the dynamic behavior of its interacting elements.
CHAPTER FIVE

5. Model Validation

5.1 Introduction

The purpose of this Chapter is to examine the validity of the dynamic simulation model of deforestation developed in this thesis. If the model, approximates the historical behavior of the important elements, especially the barometric stocks of forestry sector, it may be expected to yield reasonable and reliable forecasts in the future. The focus is primarily on the behavioral patterns of forest area and forest biomass, because the dynamics of these two crucial stocks provide insight into explaining the deforestation process. The behavior of other elements are also presented to strengthen the model validation results.

However, the validation is limited by the absence of reliable estimates of some forestry sector data. There are few estimates for forest area and hardly any reliable estimates for forest biomass. Unfortunately, different agencies have provided different estimates. For example, in 1991 the estimates of forest area in India is estimated by FAO (1993) at 55 million hectares, at 64.01 million hectares by the forest department, and at 67.8 million hectares by the land use statistics of Ministry of Agriculture (GOI, 1994). Moreover, except for the Ministry of Agriculture’s land use statistics (GOI, 1994 p. 79), it is not possible to obtain land use estimates for past years. Therefore, for past behavior of

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12 A Portion of this Chapter is presented in Saxena et al (1997 B).
the total forest area, the land use statistics of the Ministry of Agriculture (GOI, 1994 p 79) have been used.

Nevertheless, for India there are more reliable estimates of population, population distribution, area in food production, agriculture yield, and livestock units. The behavior of population and percentage of rural population are recorded by Registrar General of India during censuses. Livestock behavior is recorded during livestock census by Animal Husbandry Department, and behaviors of area in food production and productivity per hectare are recorded during the agriculture census by Agriculture Ministry. The simulated behaviors of these elements are compared with their behaviors as recorded by the above different agencies. Every dynamic function, which includes a number of historical data points, are used as additional validation of the model results. If the historical behaviors generated by the model are to the behaviors actually observed for these elements, then confidence in the accuracy of the model structure is reinforced. To reproduce the historical behavior over 1951-1991, the model (Model C) uses initial values for 1951 and generates results for each year over the period and into the future to enable an understanding of the underlying dynamics.

5.2 Total Forest Area Validation

The simulated behavior of TFA is given in the Figure 5-1. It illustrates non-linear behavior of TFA. There is an increase in forest area during 1951-2005, when it reaches a level of 71 million and then TFA declines slightly. This pattern of behavior is consistent with the past land use estimates. The Ministry of Agriculture land use records reveal that in 1951, TFA was 40.4 million hectares. This continued to increase to 67.99 million
hectares by 1991 (GOI, 1994). The model generates an increase in TFA from its initial 40.4 million hectares in 1951 to 70.2 million hectares in 1991 which is only 3.3 per cent above the observed value. The models indicates an increasing trend for nearly five and half decades (1951-2005), but also suggests a caution that this trend will not be a lasting behavior. The results indicate that current behavior in forest area is only likely to continue for one more decade, that is, until 2005. Thereafter, the total forest area will start declining. Thus, the non-linear behavior of TFA arises because the positive impact of increasing forest area due to plantation will eventually be offset by negative impacts of increasing encroachments and forest diversions.

Figure 5-1: Simulated FBM and TFA Behaviors$^{12a}$

$^{12a}$The numbers on the vertical axis show the scales for the two chosen elements(1:FBM-Forest Biomass, 2:TFA-Total Forest Area) in their respective units, and horizontal axis shows the simulation time displayed in years. The two curves show the behavioral patterns of the two chosen elements as projected by the Model C.
During the last 40 years (see Table 5-1 and Figure 5-2) TFA behavior, as simulated by the model, closely resembles 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. However, India has so far witnessed only the rising segment of TFA behavior but soon India will face the declining segment of TFA behavior. So, if India intends to sustain its forests, a change in forest policy direction is warranted (see Chapter 6).

Table 5-1: TFA: Actual and Simulated Values

<table>
<thead>
<tr>
<th>Year</th>
<th>Total forest area (TFA) recorded by Government of India (1994) in million hectare (mha) - Series 1</th>
<th>Simulated values of Total forest area (wuzzu TFA) by the Model in million hectare (mha) - Series 2</th>
<th>Error (per cent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1951</td>
<td>40.4</td>
<td>40.4</td>
<td>0</td>
</tr>
<tr>
<td>1961</td>
<td>54.0</td>
<td>51.1</td>
<td>+5.3</td>
</tr>
<tr>
<td>1971</td>
<td>63.9</td>
<td>62.9</td>
<td>+1.0</td>
</tr>
<tr>
<td>1981</td>
<td>67.4</td>
<td>68.4</td>
<td>-1.4</td>
</tr>
<tr>
<td>1991</td>
<td>67.9</td>
<td>70.2</td>
<td>-3.3</td>
</tr>
</tbody>
</table>

Figure 5-2: TFA: Actual and Simulated Values

This result underscores the anomaly in the conceptualization of deforestation (see Section 1.2). Currently, deforestation is considered as a problem of reduction in forest
area only. As a result, deforestation is said to occur only when there is a reduction in recorded forest area. In India, the land use records show increases in forest area between 1951 and 1991. Therefore, existing records do not reveal any deforestation. This reporting anomaly is much the same for many of the industrializing countries in the world (see FAO 1993, WRI 1993, WRI 1994). Consequently, the actual process of deforestation remains hidden. Ironically, researchers are still attempting to understand the deforestation problem by focusing only on forest area dynamics which does not provide sufficient insight into the deforestation problem because history has not yet provided sufficient data to reveal the dynamic behavior of forest biomass.

The behavior of TFA also points to another challenge that Indian forestry policy planners will face; that is, the goal to increase the forest area to 33 per cent of its geographical area or to 109 million ha (GOI, 1988) by the end of 9th Five Year Plan (2000). The systems model suggests that this goal is far too ambitious and is not attainable given existing polices. The model suggests that forest area can increase only up to 71 million hectares by 2005. In summary, TFA behavior as simulated by the model is validated by the historical behavior, but historical behavior provides no indication of the impending deforestation revealed by the model.

5.3 Forest Biomass Validation

The recent definition of deforestation by the FAO (1993) is broad enough to include two types of deforestation: (1) “Deforestation to other wooded land” where the forest is lost but a certain woody biomass remains; (2) “Deforestation to non-wooded area” where forest is lost and no woody biomass remains (FAO, 1993 p37). Nevertheless,
deforestation is still recorded in terms of area only (see WB 1992, WRI 1992, WRI 1993, WRI 1994) and the reduction in forest biomass is included in the degradation of forests. With this linguistic maneuvering, the focus remains on the dynamics of forest area while the dynamics of forest biomass is neglected to a minor position. But since the forests can not be sustained without understanding the dynamics of both the forest area and the forest biomass, the dynamics of forest biomass also needs the attention of forest policy planners.

Table 5-2: FBM: Actual and Simulated Values

<table>
<thead>
<tr>
<th>Year</th>
<th>FBM as estimated by FAO in Kilogram</th>
<th>FBM as estimated by Model in Kilogram</th>
<th>Error percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>4.805690*10^{12}</td>
<td>5.1*only 10^{12}</td>
<td>6.2</td>
</tr>
</tbody>
</table>

Figure 5-3: FBM: Actual and Simulated Values

The model has been used to generate FBM behavior for 1951-1990, and the simulated values has been compared with available estimates (Table 5-2). Figure 5-3, shows a continuing decline in the stock of forest biomass from 1951 onwards, and given existing policies the FBM projection into the future suggests that by 2015 it will virtually vanish. This model projects a strange scenario for forests: forest area exists but without
forest on it. This is likely to happen because the current rate of forest biomass removal is about five to six times the current rate of forest biomass production (Saxena and Nautiyal 1997).

There are hardly any reliable estimates of FBM for the past years. However, FAO has estimated FBM for 1990. The model estimate of FBM for 1990 is close to the independent FAO estimates of FBM. The deviation between the two estimates is 4 per cent (see Table 5-2). The declining behavior of FBM is consistent with the expectations of previous researchers. For example: Mathur (1976), Tiwari (1983), Khator (1989), Shukal et al (1989), Haeuber (1993), Chaturvedi (1994), Dwivedi (1994), and Khoshoo (1994) have suggested a decline in forest vegetation in India. This consistency of the dynamics behavior of FBM with the findings of these researchers provides additional evidence of the model validation. Further, the simulated FBM behavior indicates that deforestation cannot be ameliorated by policy packages such as the Forest Conservation Act (1980) which addresses only the dynamics of TFA behavior and neglects the dynamics of FBM behavior.

5.4 Agriculture Validation

5.4.1 Area in Food Production

The Ministry of Agriculture has regularly monitored data for area under food production. These data show an increasing behavior of area in food production (Table 5-3). The model correctly simulates an increasing behavior for area in food production in general, which is consistent with the recorded behavior as reported by Ministry similar of Agriculture (GOI 1994), but the recorded behavior for 1961-1971 differ from simulated behavior by slightly over 10 per cent. However, for 1981-1991, and onwards the
simulated behavior is very close to the recorded behaviors. It is difficult to explain these variations in general behavior of area in food. This may be because the area in the model has incorporated average values such as the average rate of forest encroachments conversion to agriculture and the average land development rate.

The increase for "area in food production" has been significant from 1966 to 1988, but after 1988 the increase in area of food production has slowed. In 1966, India did witness a "Green revolution" where marginal lands came under plow by increasing use of water, better seed and fertilizer inputs. The area under food production, as recorded by the ministry also shows a rising trend and lend supports to the general behavior of area under food production generated by the model. During the 1990s the increases in the "area in food production" are slower than in the previous decades. The model also foresees that during 1990s the increases will be much smaller than the previous decades and the area will increase to only about 133 million hectare by 2025 (see Chapter 6). The model suggests that now, India can significantly step up its agriculture production by land augmenting technology and not by the land using technologies. The model foresees that Indian agriculture faces an increasing physical (area) constraint and the area under food production cannot be increased forever. Therefore, the emphasis should be given to yield increasing technologies. Fortunately, this scenario has been visualized by many experts in the agriculture sector as well. Figure 5-4 presents the actual and simulated behaviors.
Table 5-3: Area in Food: Actual and Simulated Values

<table>
<thead>
<tr>
<th>Year</th>
<th>Area in food as recorded by Government of India (1994) in million hectare (mha) - Series 1</th>
<th>Simulated values of area in food by the Model in million hectare (mha) - Series 2</th>
<th>Error percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1951</td>
<td>97.32</td>
<td>97.32</td>
<td>0</td>
</tr>
<tr>
<td>1961</td>
<td>115.58</td>
<td>97.85</td>
<td>+15.34</td>
</tr>
<tr>
<td>1971</td>
<td>124.32</td>
<td>110.41</td>
<td>+11.18</td>
</tr>
<tr>
<td>1981</td>
<td>126.67</td>
<td>126.65</td>
<td>+.01</td>
</tr>
<tr>
<td>1991</td>
<td>127.84</td>
<td>129.00</td>
<td>-.01</td>
</tr>
</tbody>
</table>

Figure 5-4: Area in Food: Actual and Simulated Values

In addition, to the area in food production, the value of agriculture productivity and the quantity of food production were generated by using the dynamic model.

5.4.2 Agriculture Productivity

The historical behavior of agriculture productivity, shows an increasing (Table 5-4 and Figure 5-5) which is closely simulated by the model, especially in the recent years (1981-1991). However, the increment in productivity diminishes over time. Therefore, in the future the agriculture sector is likely to face constraints both from the area under agriculture and from slower growing agriculture productivity. Thus the forests are likely to face severe land competition from agriculture which constrains the increase in the area under forests.
Table 5-4: Food Productivity: Actual and Simulated Values

<table>
<thead>
<tr>
<th>Year</th>
<th>Food Productivity per hectare as recorded by Government of India (1994) in kg/ha</th>
<th>Simulated values of Food productivity per hectare in kg/ha by the Model</th>
<th>Error percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1951</td>
<td>522</td>
<td>580.90</td>
<td>-11.28</td>
</tr>
<tr>
<td>1961</td>
<td>710</td>
<td>646.78</td>
<td>+8.9</td>
</tr>
<tr>
<td>1971</td>
<td>872</td>
<td>798.13</td>
<td>+8.47</td>
</tr>
<tr>
<td>1981</td>
<td>1023</td>
<td>1033.51</td>
<td>+0.98</td>
</tr>
<tr>
<td>1991</td>
<td>1380</td>
<td>1351.48</td>
<td>+2.06</td>
</tr>
</tbody>
</table>

Figure 5-5: Food Productivity: Actual and Simulated Values

5.4.3 Agriculture Food Production

Agriculture food production is obtained by multiplying agriculture productivity by area in food production so the previous two results (Sections 5.4.1 and 5.4.2) feed directly into the results for agriculture food production. These results are presented in Table 5-5 and Figure 5-6. Not surprisingly, there are noticeable deviations between simulated and recorded values of food production for 1961 and 1971 and the two most recent points (1981 and 1991) have very small errors. This is because the deviations in simulated area and simulated productivity values from their recorded values feed directly into food production. However, the model reproduces the general behavior in food production,
showing an increase in food production over the historical period (1951-1991) which is what actually happened.

Table 5-5: Food Production: Actual and Simulated Values

<table>
<thead>
<tr>
<th>Year</th>
<th>Food Production as recorded by Government of India (1994)</th>
<th>Simulated values of Food production by the Model</th>
<th>Error percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1951</td>
<td>50.82</td>
<td>56.53</td>
<td>-11.23</td>
</tr>
<tr>
<td>1961</td>
<td>82.02</td>
<td>63.29</td>
<td>+22.82</td>
</tr>
<tr>
<td>1971</td>
<td>108.42</td>
<td>88.19</td>
<td>+22.83</td>
</tr>
<tr>
<td>1981</td>
<td>129.59</td>
<td>130.89</td>
<td>-0.22</td>
</tr>
<tr>
<td>1991</td>
<td>176.39</td>
<td>174.35</td>
<td>+1.09</td>
</tr>
</tbody>
</table>

Figure 5-6: Food Production: Actual and Simulated Values

In the future the model suggests that the agriculture food production will rise because of increasing area in food production and growing agriculture food productivity. However, the increase in area is constrained by the size of country; therefore, to obtain more food production, agricultural productivity must rise.

5.5 Population Validation

5.5.1 Total Population

The historical behavior of population is recorded by the various population censuses. The model reproduces the historical behavior of population very closely, showing an increasing population with an increasing growth rate during period 1951-
1981, and thereafter the growth rate declines. The extremely close correspondence of the simulated and the observed behavior provides credibility for the dynamic function used for the population element (see Table 5-6, and Figure 5-7).

Table 5-6: Population: Actual and Simulated Values

<table>
<thead>
<tr>
<th>Year</th>
<th>Population as recorded by Government of India (1994) in million persons Series 1</th>
<th>Simulated values of Population by the Model in million persons- Series 2</th>
<th>Error percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950</td>
<td>361.1</td>
<td>364.2</td>
<td>-.008</td>
</tr>
<tr>
<td>1960</td>
<td>439.2</td>
<td>442.8</td>
<td>-.008</td>
</tr>
<tr>
<td>1970</td>
<td>548.2</td>
<td>547.4</td>
<td>+.001</td>
</tr>
<tr>
<td>1980</td>
<td>685.2</td>
<td>680.9</td>
<td>+.006</td>
</tr>
<tr>
<td>1990</td>
<td>846.3</td>
<td>846.2</td>
<td>+.0001</td>
</tr>
</tbody>
</table>

Figure 5-7: Population: Actual and Simulated Values

5.5.2 Rural Population

Historical data for the percentage of the population residing in rural areas is also collected in the decennial censuses over 1951-1991. As shown in Table 5-7, historical data show a declining trend in this percentage. The model also forecasts declining behavior in the rural population percentage over the same period with considerable accuracy (see Table 5-7 and Figure 5-8).

However, the number of rural population shows no signs of declining because the decline in percentage of rural population is more than offset by the rising total population.
(see Table 5-8 and Figure 5-9). Figure 5-9 clearly shows that despite the decline in the percentage of rural population, the actual number of people living in rural areas has risen in the past (1951-1991). Furthermore, as shown in Table 5-8, the model tracks the historical data very closely, especially in the two most recent years (1981 and 1991).

Table 5-7: Percentage of Rural Population: Actual and Simulated Values

<table>
<thead>
<tr>
<th>Year</th>
<th>Percentage of rural population as recorded by Government of India (1994)</th>
<th>Simulated values of Percentage of rural population by the Model</th>
<th>Error percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1951</td>
<td>82.7</td>
<td>84</td>
<td>-1.5</td>
</tr>
<tr>
<td>1961</td>
<td>82.0</td>
<td>82.0</td>
<td>0</td>
</tr>
<tr>
<td>1971</td>
<td>80.1</td>
<td>79</td>
<td>+1.3</td>
</tr>
<tr>
<td>1981</td>
<td>76.7</td>
<td>77</td>
<td>-.003</td>
</tr>
<tr>
<td>1991</td>
<td>74.3</td>
<td>74</td>
<td>+.003</td>
</tr>
</tbody>
</table>

Figure 5-8: Percentage of Rural Population: Actual and Simulated Values
Table 5-8: Rural Population: Actual and Simulated Values

<table>
<thead>
<tr>
<th>Year</th>
<th>Rural population as recorded by Government of India (1994) in Millions</th>
<th>Simulated values of Rural population by the Model in Millions</th>
<th>Error percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1951</td>
<td>298.6</td>
<td>305.7</td>
<td>-2.3</td>
</tr>
<tr>
<td>1961</td>
<td>360.3</td>
<td>361.6</td>
<td>-0.36</td>
</tr>
<tr>
<td>1971</td>
<td>439.1</td>
<td>434.0</td>
<td>1.16</td>
</tr>
<tr>
<td>1981</td>
<td>525.1</td>
<td>523.4</td>
<td>0.32</td>
</tr>
<tr>
<td>1991</td>
<td>628.7</td>
<td>630.4</td>
<td>-0.27</td>
</tr>
</tbody>
</table>

Figure 5-9: Rural Population: Actual and Simulated Values

The rising rural population scenario along with the corresponding rise in the numbers of rural poor and the unemployed population suggests a difficult forest protection problem resulting from increased fuelwood needs for this population.

5.6 Energy Validation

In addition to addressing the issue of population, the issue of energy consumption particularly in rural areas, is of significant importance for deforestation. This calls for monitoring the behavior of non-commercial energy consumption because primarily non-commercial energy is consumed in rural areas. The total energy consumption has increased over the year (1951-1991), and the fraction of non-commercial energy consumption has also declined over the same period. However, the total quantity of non-commercial energy consumption has increased (see Section 4.4.3). The model simulation also suggests an
increase in the consumption of non-commercial energy with considerable accuracy (see Table 5-9 and Figure 5-9).

Table 5-9: Non-Commercial Energy Consumption: Actual and Simulated Values

<table>
<thead>
<tr>
<th>Year</th>
<th>Non commercial energy consumption in India in million tons of oil equivalent as per World Energy Council (1990)</th>
<th>Non commercial energy consumption in India in million tons of oil equivalent as per the Model</th>
<th>Error percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>84</td>
<td>87.98</td>
<td>-4.73</td>
</tr>
<tr>
<td>1973</td>
<td>90</td>
<td>91.88</td>
<td>-0.02</td>
</tr>
<tr>
<td>1979</td>
<td>102</td>
<td>98.73</td>
<td>-3.20</td>
</tr>
<tr>
<td>1980</td>
<td>103</td>
<td>99.76</td>
<td>-3.14</td>
</tr>
<tr>
<td>1984</td>
<td>103</td>
<td>103.57</td>
<td>+0.05</td>
</tr>
<tr>
<td>1985</td>
<td>105</td>
<td>104.45</td>
<td>+0.0009</td>
</tr>
<tr>
<td>1986</td>
<td>107</td>
<td>105.30</td>
<td>+1.58</td>
</tr>
<tr>
<td>1987</td>
<td>109</td>
<td>106.12</td>
<td>+2.64</td>
</tr>
</tbody>
</table>

Figure 5-10: Non-Commercial Energy Consumption: Actual and Simulated Values

Unless the rural energy needs become the focus of energy planners, the non-commercial energy consumption is not likely to diminish in near future. As a result, the fuelwood consumption is not likely to decrease and so forest biomass depletion is projected to continue. Therefore, the forest biomass will not be sustainable with current energy policies. The close tracking of non-commercial consumption (see Figure 5-10) reinforces the results of the model.
5.7 Livestock Validation

Figure 5-11 demonstrates that the rising behavior of livestock units, as suggested by the model, supports the recorded past behavior. Simulated errors of less than one percent are recorded for few of the six data points including the two most recent observations (1987 and 1991).

Table 5-10: Standard Livestock: Actual and Simulated Values

<table>
<thead>
<tr>
<th>Year</th>
<th>Standard livestock units in millions as per Government of India (Rao, 1994)</th>
<th>Simulated values of Standard livestock units in millions by the Model</th>
<th>Error percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>1951</td>
<td>226.8</td>
<td>227.2</td>
<td>0.17</td>
</tr>
<tr>
<td>1961</td>
<td>260.2</td>
<td>250.9</td>
<td>3.57</td>
</tr>
<tr>
<td>1972</td>
<td>273.4</td>
<td>272.3</td>
<td>0.01</td>
</tr>
<tr>
<td>1983</td>
<td>309.7</td>
<td>303.8</td>
<td>1.90</td>
</tr>
<tr>
<td>1987</td>
<td>315.4</td>
<td>313.6</td>
<td>0.57</td>
</tr>
<tr>
<td>1991</td>
<td>321.7</td>
<td>323.3</td>
<td>-0.49</td>
</tr>
</tbody>
</table>

Figure 5-11: Standard Livestock: Actual and Simulated Values

The model indicates that in future too, grazing pressure will not diminish, but rather will increase (see Table 5-10 and Figure 5-11). The policy decision to reduce the grazing animals per hectares of forests is urgently required. Simultaneously, the pasture productivity will have to be increased if forests are to be sustained.
5.8 Conclusion

The model closely reproduces the behavior of forest stocks and the behaviors of the driving elements in the model such as population, agriculture productivity, energy consumption, and livestock units in India. This provides a validation of the model structure and the estimated relationships. Therefore, the future behavior as suggested by the model can be expected to provide a good foundation to review the future for the forest sector. The preliminary findings indicated in this Chapter suggest that this should be a matter of extreme concern for the forest policy planners. These issues and possible alternative policies for ameliorating and/or halting the process of deforestation are examined in the following Chapters.
CHAPTER SIX

6. Results And Discussion

6.1 Introduction

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 of Model A, Model B, and Model C are presented and compared. These results show the dynamic outcome of current policies assuming no new policy interventions. Second, the results of “forest only” policy interventions, which show the impacts of forest conservation and development policies in isolation from other policy initiatives, are examined. As a logical extension of forestry interventions, the conventionally emphasized policy impact of agro-forestry is also discussed. Third, the results of “non-forest” policy initiatives in the four other sectors of the model are discussed. These results provide essential insights into how other sectors impinge on the deforestation process. Finally, results for a combination of the forest and non-forest polices are presented and discussed. These results strongly indicate that if Indian forests are to be sustained, policies within the forestry sector alone will not be sufficient to sustain the forests. They will have to be designed in combination with polices in other sectors. Foresters have no choice but to look beyond the forest sector to sustain forests.

13 A substantial portion of this Chapter is presented in Saxena et al. (1997 A).
6.2 The Base Case Scenarios

The base case scenario, or the "business as usual" approach, reveals the outcome of the continuation of existing policies on forests. It not only demonstrates the results of the existing policies, but also provides a reference scenario for comparing the impacts of various new alternative policy interventions on forests. The base case 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 the 1990 level of 828 million. It is known that the population will rise in the future. Therefore, the expected impacts of an increase in population on deforestation can be examined by sensitivity analyses; that is, by comparing model results for the base case scenario, with those containing higher population inputs. Similarly, an insight into the impacts of other policies can also be appreciated by using a base case scenario in this manner.

6.2.1 Model A

The base case scenario results for Model A concentrates on the impacts of biophysical interactions on deforestation. The base case scenario results of Model B show the additional impacts of market linkages on deforestation. The base case scenario results of Model C show the cumulative impacts of biophysical and market linkages along with the impacts of dynamic functions on deforestation. The initialization values\(^\text{14}\) and sources of some of the important elements are given in Table 6-1; other values can be obtained from the dynamic equations (presented in Appendix II).

\(^{14}\)In the base case scenario, the Model A and Model B use the values of the system's elements set at the 1990 levels while Model C uses initialization values set at 1951 levels so as to generate the historical behavior.
Table 6-1: Initialization Values and Sources

<table>
<thead>
<tr>
<th>Element</th>
<th>Initialization values for Models A &amp; B (1990)</th>
<th>Initialization values for Model C (1951)</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Total Forest Area</td>
<td>64.01 million hectare.</td>
<td>40.48 million hectare.</td>
<td>Munkerji (1994), GOI (1994)</td>
</tr>
<tr>
<td>2. Forest biomass</td>
<td>$4.09 \times 10^{12}$ kg</td>
<td>$11 \times 10^{12}$ kg</td>
<td>FAO (1993)</td>
</tr>
<tr>
<td>3. Area in Food</td>
<td>127.8 million hectare</td>
<td>97.32 million hectare</td>
<td>GOI (1994)</td>
</tr>
<tr>
<td>5 Cultivable land (cultivable waste + fallow other than current fallow land)</td>
<td>24.5 million hectare</td>
<td>60.2 million hectare</td>
<td>GOI (1994)</td>
</tr>
<tr>
<td>7 Total energy consumed</td>
<td>199 mtoe in million tons of oil equivalent</td>
<td>Dynamic Function generates initial value</td>
<td>Estimated from Mehetre (1990), see Chapter 4</td>
</tr>
<tr>
<td>8 Fraction of non-commercial energy in mtoe</td>
<td>0.53</td>
<td>Dynamic Function generates initial value</td>
<td>Mehetre (1990), World Energy Council 1992, see Chapter 5</td>
</tr>
<tr>
<td>9 Fraction of non-commercial energy consumed in rural areas</td>
<td>0.79</td>
<td>Dynamic Function generates initial value</td>
<td>Mehetre (1990), Khoshoo (1994), see Chapter 4</td>
</tr>
<tr>
<td>10 Fraction of rural population dependent on fuelwood area</td>
<td>0.8</td>
<td>0.8 *</td>
<td>Khoshoo (1994)</td>
</tr>
<tr>
<td>11 Fraction of dense forest area</td>
<td>0.60</td>
<td>System internally determines</td>
<td>FSI (1993)</td>
</tr>
<tr>
<td>12. Fraction of open forest area</td>
<td>0.39</td>
<td>System internally determines</td>
<td>FSI (1993)</td>
</tr>
<tr>
<td>14 Agriculture food productivity per hectare in 1990</td>
<td>1382 kg</td>
<td>Dynamic Function generates initial value</td>
<td>GOI (1994)</td>
</tr>
<tr>
<td>15. Fodder required per unit per day for a standard livestock unit</td>
<td>5 kg</td>
<td>5 kg</td>
<td>Rao (1994)</td>
</tr>
</tbody>
</table>

* Assumed values

The results of the base case scenario of Model A are presented in Figure 6-1. The numbers on vertical axis show the 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, on the vertical axis “area in food” lies in the range 128 million hectares to 142 million hectares. Other elements are interpreted similarly.

**Figure 6-1: Base Case Scenario of Model A**

![Graph showing simulation of elements over years](image)

In this Figure 6-1, 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

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14 The numbers on vertical axis show the 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. The five curves show the behavioral patterns of the five chosen elements as projected by Model A.
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 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 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. 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 Forest Survey of India (FSI 1991, 1993) reports compiled using satellite images of forest areas during 1989-1993 support this explanation of increases in forest area. 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.

The area planted per year (curve marked 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.

6.2.2 Model B

It is important to note that the Model A shows that without any new policy interventions India will be depleted of its forest biomass by 2015. However, this rapidly increasing scarcity of a natural resource can be expected to result in some responses. The market responses suggested in Section 4.3 are now incorporated into the model to assess their effectiveness in ameliorating the projected rapid deforestation.

The results of the Model B are shown in the Figure 6-2. By comparing these results with the results of the Model A (Figure 6-1), it is possible to assess the impacts of price loops in the deforestation process of India. This offers an opportunity to reflect on the efficacy of market institutions in alleviating deforestation especially in India, but also in developing countries in general. In Model B (see Figure 6-2), the rising behavior of area in food (curve marked 1) and the declining behaviors of the cultivable lands (curve 2) and the area under plantations (curve 5), show no change. This is because shifting cultivators
primarily convert the forest for food production, and these forest encroachments are driven by the survival rather commercial needs. The total forest area (curve 4) indicates a non-linear behavior as in Model A. The area increases from its 1990 level of 64 million hectares to about 73 million hectares in 2025. Thereafter, TFA declines. This is because the dynamics of forest area is significantly affected by encroachments and diversions, and the behaviors of encroachments and diversions do not substantially change. These are primarily driven by the survival needs rather than the commercial needs. However, the stock of forest biomass (curve 3) declines from the outset but does not completely vanish. This reflects the impact of the market mechanisms since continuous investments do not allow the total depletion of FBM stock.

Figure 6-2: Base Case Scenario of Model B$^{46}$

The numbers on vertical axis show the 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. The five curves show the behavioral patterns of the five chosen elements as projected by Model B.
The net outcome of responses affecting the relationships between the market and biomass scarcity is positive but is of a limited significance. Even with market mechanisms in place, FBM still declines and hence, deforestation continues. Throughout the projection period the rate of forest biomass removal continues to exceed the production rate. As suggested in Section 4.3, a market mechanism in forestry resources has little impact on the deforestation process in India and in most developing countries. In developing countries in general and India in particular, a very large amount of forestry products are removed through non-market channels, and this not only reduces the efficacy of market mechanisms, but also introduces processes that speeds up the deforestation process. However, the ongoing investments in forestry plantations does stop FBM from its complete depletion, but the declining behavior of FBM does not change and the model suggests that FBM level will be reduced to a negligible level of about 3.3 per cent of 1990 stock by 2065. Thus, the impact of market mechanism, while useful is minimal on the dynamics of the forest biomass in India. A comparison of the results of the two models yield the following important observations:

- the time profiles of the important forestry stocks: Total Forest Area (TFA), Forest Biomass (FBM) remain almost unchanged, although forest biomass does not vanish completely when price mechanisms are working.

- the time profiles of important interacting elements including the area in food, cultivable lands, and area planted per year also remain almost unchanged.
This comparison of results clearly reveals that markets have a limited role in alleviating the deforestation problem in India, and, most likely, in most developing nations. The outcome of the relationship between forest biomass scarcity and price increases is limited because of the long gestation period of forest investments, the need for a large inventory, apathetic public ownership, and the existence of poverty and unemployment in rural areas. The positive feedback loops counteract the negative feedback loops of economic theory (see Section 4.3). It seems clear that policy planners cannot just rely on market place policies to control deforestation.

6.2.3 Model C

The results of the Model C are shown in the Figure 6-3. By comparing these results with the results of Model B (Figure 6-2), it is possible to gain insights into the impacts of dynamics functions in the model. Comparisons of Figure 6-3 with Figures 6-1 and 6-2 reveal that even with dynamic functions the results of Model C are not very different behaviorally from the previous base case outcomes.

Model C projects an increase in TFA (curve 4) from its 1951 level of 40 million hectares to 70.5 million hectares in 2005 and declines thereafter. It shows that the dynamic behavior of the interacting elements has resulted in a quicker buildup of TFA, but to a lower level. Nevertheless, the decline thereafter is similar to the previous results. This is because although the population is increasing and driving both the poverty and the process of forest encroachment, the improvements in technology are offsetting, although not completely, their negative impacts. The technology is increasing productivity in agriculture and in the forest plantations thereby decreasing the pressures on land.
Model C further indicates that despite the increasing of TFA in initial years, the stock of forest biomass (curve 3) continues to decline be from its 1951 level. This occurs because development polices in the other sectors (agriculture, socio-economic, energy, and livestock) have contributed to continuing depletion of forests. This is evident from Figure 6-4, where the behavior of FBM is shown under five different situations.

\[^{14c}\] The numbers on vertical axis show the 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. The five curves show the behavioral patterns of the five chosen elements as projected by Model C.
First, the forestry sector is considered in isolation (FBM:1), and then with increasing sectoral interactions from agriculture (FBM:2), socioeconomic (FBM:3), energy (FBM:4), and livestock (FBM:5) sectors. It is interesting to note the changing profile of FBM on increasing sectoral interactions (see Figure 6-4). In its forestry sector only run (curve 1) the simulation results indicate no concern for FBM as after the first decade of the 21st century there would be a continuous build up of the stock. This is a hypothetical situation because it is not possible to insulate forests from the interactions of other sectors. However, to understand the impacts of the intersectoral interactions, it is useful to consider this hypothetical situation as a base case. In this case, the FBM dynamics is primarily influenced by the dynamics of TFA alone. TFA continues to increase.

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14d The numbers on vertical axis shows the scale for FBM (forest biomass) in kilograms, and the horizontal axis shows simulation time displayed in years. The five curves show the behavioral patterns of the FBM under five different sectoral interaction situations.
because of increasing plantations (178 million hectares during 1951-2065). As a result, the forest biomass production rate soon exceeds its removal rate turning the declining behavior of FBM into an increasing behavior.

However, this unconstrained opportunity of increasing forest area is not available when agriculture interactions are incorporated. In most of the developing countries, and especially in India the need to produce food takes a priority. As a result, a major share of cultivable lands, and even forests lands are encroached for food production. Therefore, TFA can not increase continuously and reaches a peak at much lower level (73 million hectares). This change in TFA behavior is an outcome of the intersectoral interaction, and accordingly influences the behavior of FBM. Similarly, when the socio-economic, energy and livestock interactions are incorporated, the dynamics of FBM changes. For example, poverty of the people increases the forest lands encroachments and intensifies the land competition further. Poverty acts not only on the input side of FBM production by negatively influencing TFA, but also negatively influences the forest biomass stock by increasing the removals. The poor people depend heavily on forests for their immediate needs of food, housing and energy. Moreover, in the absence of alternative sources of energy, fuelwood remains the major source of energy in the rural housing sector and the energy planners do not assess its impact on forest sustainability. In fact, the interactions between the forest and energy sectors are overlooked, and the rural energy needs are neglected. Similarly, the interactions between the forest and livestock sectors are frequently overlooked and the fodder needs of increasing livestock are neglected. The result is acceleration in the rate of FBM decline.
In summary, when the forest sector is viewed in isolation of intersectoral interactions, forestry planners may be satisfied with FBM behavior and expect an increase in FBM over time due to plantations. They detect no deforestation. However, with the progressive addition of sectors that have linkages with the forestry sector, deforestation sets in and becomes increasingly grave. The agriculture sector competes with forests for land, thus reducing TFA; increasing population and rural poverty results in additional invasions of forest lands as the landless need land for food production and use fuelwood for energy; the low provisions of energy for rural masses further compound the depletion; and finally, the livestock sector competes with forests for pasture lands, withdraws a substantial amount of fodder from forests and damages the young forest plantations. These results suggest that part of the reason for deforestation is attributable to the failure of policy planners to explicitly recognize the intersectoral linkages. In India, forest policy documents (for example, GOI 1952, MEF 1988, 1994) have overwhelmingly emphasized the efforts to increase forest productivity without any mention of the need to consider effects of policies in other sectors.

In addition to the behavior of key forestry elements, Model C also reinforces the results of behavior of elements in the other sectors. For example, Model C suggests increasing area under food production (see Figure 6-3, curve 1), declining behavior of cultivable lands production (curve 2), and declining forestry plantations outside forests (curve 3). However, while similar behaviors of elements are suggested by the three Models, there are subtle but important differences. To appreciate the resemblance and differences in the patterns of behaviors, it is essential to understand the interactions in the
system. For example, increasing the size of the population (Model C) impacts the total forest area and forest biomass negatively, while increasing agriculture productivity ameliorates the negative effects of population. This is similar to a “tug of war”, when the forces are opposing and the outcome depends on which force is dominant at any point in time. In general, while on the one hand investments and technology help in increasing agriculture productivity, the area in forestry plantations, and the productivity of forestry plantations, on the other hand increasing human population, livestock numbers, numbers of rural and urban poor people, and energy demands can offset the gains of technology and investments. This suggests that while on one hand investments in increasing yields in agriculture and forestry plantations are needed to reverse the process of deforestation, planners should not ignore policies to control population, poverty, livestock numbers, and to increase environmentally benign rural energy to maintain and strengthen the gains from technology and investments. The results of Model C do not deny the operational importance of dynamic elements, but they draw into focus that it is not the elements but the interactions among elements that are more important in understanding and explaining the complex process such as deforestation. Moreover, Model C results reinforce the results of the previous models, and introduce important new considerations in understanding the complex process of deforestation. The “bottom line” of all results is that without any new policy initiatives, deforestation will continue in India and the forests may be completely destroyed within the near future. Therefore, the next two Sections are devoted to analysis of new policy initiatives that could be used in an attempt to sustain the forests of India.
6.3 Impacts of Forest Conservation Policies

The attempt to control and if possible reverse, deforestation has three foci within forestry sector policies. They are: (1) increasing plantations, (2) increasing protection of the existing forests, and (3) increasing the productivity of plantations. Is it possible that focusing only on these policies of forest plantation and forest conservation that forests be sustained?

To examine the impacts of forest sector conservation policies in isolation from the development policies of other interacting sectors Model A is used for simulating FBM and TFA behaviors. By eliminating the impacts of prices and dynamic functions, Model A facilitates a clearer understanding on the impacts of these policies. Moreover, the similarity of behavioral profiles between Models A, B and C lends credibility to sensitivity results obtained from Model A.

The efforts of forest conservation policies are incorporated by incrementally changing the fraction of dense forest area from the current 60 per cent to 100 per cent (the theoretical upper limit of forest conservation). The density of forest can be increased by (1) under-planting existing forests, and raising new plantations in very sparse forest areas, (2) increasing forest protection of the existing forests by increasing the protection staff and increasing penalties for forest removals, and (3) improving the productivity of forest areas. The increases in productivity of forest can be brought about by planting genetically improved material, improving other input levels such as fertilizers and water at early stages of plantation establishment, and reducing damages to plantation from incidence of forest fires, diseases, and insects. All of these activities demand increased investment on
forest research and on enhanced protection of plantations. Increases in productivity of the forest area are assumed to rise from the present level of 1000 kg per hectare to 1500 kg per hectare (see Table 6-2).

The increased plantation efforts are introduced by relaxing the financial constraints in the model; that is by increasing the value of investment for plantation from 8000 million rupees to 10000 million rupees, and reducing the cost of plantation from 6000 rupees per hectare per year to 4000 rupees per hectare per year. These effects are incorporated by incrementally changing the values of two converters: (1) investment allocated for plantation, and (2) cost of plantations. The efforts of agro-forestry plantations were also incorporated. Operationally agro-forestry is equivalent to an 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 6-5.

These forest conservation policy measures indicate that improving forest protection, increasing the financial flow for forest plantations and improving the productivity of dense forest do have a significant positive effect on the stock of FBM. But despite these measures, the essential dynamic behavior of the FBM does not change. FBM remains a declining stock. 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.
Table 6-2: Forest Conservation Policy Variables

<table>
<thead>
<tr>
<th>Setup</th>
<th>Input variables</th>
<th>Cost of planting (Rs/ha/yr.)</th>
<th>inv. allocated (Rs/yr.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run</td>
<td>Fr. DFA</td>
<td>ainc DFA</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>0.603</td>
<td>1000</td>
<td>6000</td>
</tr>
<tr>
<td>2</td>
<td>0.802</td>
<td>1250</td>
<td>5000</td>
</tr>
<tr>
<td>3</td>
<td>1.00</td>
<td>1500</td>
<td>4000</td>
</tr>
</tbody>
</table>

The Forest Conservation Act (1980) in India was an important step to control and addresses the issue of forest area dynamics. Its impact goes beyond the conventional boundary of the forestry sector, by regulating and monitoring forest diversions and encroachments triggered by the other economic and demographic policies. When “forest only” interventions include the effects of the Forest Conservation Act (1980), that is, by assuming a reduction in the average encroachment from 12500 hectares to 6000 hectare

15 The numbers on vertical axis shows the scale for FBM (forest biomass) in kilograms, and the horizontal axis shows simulation time displayed in years. The three curves show the behavioral patterns of the FBM under impacts of three different sensitivity setups of forest conservation policy variables (see Table 6-2). Curve 3 is higher than curve 2 and curve 1, indicating the positive influence of the improved efforts in forest conservation.
per annum, a reduction in the average diversion of 12000 hectare to 6000 hectare per annum, and a reduction in the percentage of rural population engaged in encroaching the forest from its present level of 0.2 per cent to 0.1 per cent, the model suggests a significant impact on TFA peak (see Table 6-3). However, the dynamic behavior of FBM does not change. FBM remains a declining stock so deforestation continues. Its sustainability is marginally improved by only two more years, that is, until 2028.

Moreover, the behavior of TFA does not change (see Table 6-3). The TFA peak moves further into the future and the value at the end of simulation period (2065) improves from 70.4 million hectares to 81.2 million hectares. Nonetheless the dynamic profile does not change. The explanation of this behavior lies in understanding the dynamics of area change; the forest area change is governed mainly by policies in 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 significantly.

With all its good intentions the Forest Conservation Act is not sufficient to arrest the decline of TFA. It is not possible to isolate the forest sector from the effects of policies in other sectors. Policies related to agricultural yield and population growth in rural areas affect TFA because these policies effect the land competition between the forest and the other sectors, while the policies addressing the issues of population control, rural energy consumption and livestock grazing may effect FBM because these policies impact on the dynamics of forest biomass; that is, forest production and forest biomass removals.
Table 6-3: The Delay Impact of “Forestry-Only” Interventions

<table>
<thead>
<tr>
<th>Policy scenario</th>
<th>Year at which FBM vanishes</th>
<th>TFA in million hectares at the end of simulation period (2065)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Base case scenario</td>
<td>2015</td>
<td>70.4</td>
</tr>
<tr>
<td>2. “Forest-only” interventions</td>
<td>2026</td>
<td>70.4</td>
</tr>
<tr>
<td>3. “Forest-only” interventions with emphasis on Forest Conservation Act (1980)</td>
<td>2028</td>
<td>81.2</td>
</tr>
</tbody>
</table>

Two important results emerge from the forest conservation policy simulations.

- First, 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 (unless the Forest Conservation Act (1980) is enforced) because these polices affect primarily the production flows and do not address the dynamics of forest areas.

- Second, forest conservation policies in isolation are ineffective in sustaining the stock of the forest biomass (FBM). The “forest only” interventions can significantly affect the biophysical production flow, but these interventions are primarily based on technological aspects in isolation from the use of forest resources in other sectors, 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 of other development policies are ineffective in sustaining the forest biomass in India.
Consequently, it is necessary to look to new policies in these sectors if forest sustainability is to be achieved.

Once again Model A is used for simulations since the addition of the price system was found to be an insignificant complicating influence and the new policy initiatives examined in this Chapter are designed to the change historically determined dynamic functions.

6.4 Impacts of Non-Forest Policies

Given the apparent lack of success in forest conservation policies in maintaining forest sustainability, alternative development policy interventions to sustain forests in India are investigated. These policy alternatives focus on such important interactions in the model as the negative influence of population growth on forest biomass, the positive relationship between poverty alleviation and forest biomass, the positive relationship between energy planning and rural fuelwood consumption, the positive relationship between control on livestock grazing and the forest biomass, and the positive relationship between trade promoting policies such as devaluation and the forest biomass.

To examine the roles of policies in non-forestry agriculture, energy, socio-economic or livestock sectors on total forest area (TFA) and forest biomass (FBM), the analysis has been conducted in two steps. First, the value of only one element—population—is incrementally increased, keeping the values of all the other elements at their original levels (see Table 6-1). This is selected first because the population of India has been increasing and will be increasing in the future. After having examined the impacts of incrementally changing population on deforestation, the values of number of other
important policy elements such as the poverty ratio, the percentage of population in rural areas, energy consumption and the fraction of livestock grazing in forest areas are incrementally changed. Each element is introduced one at a time. Using sensitivity analyses, this enables the impacts of these additional variables on deforestation to be measured as a change from the previous policy package. The results of these sensitivity analyses (see Table 6-3) provide additional insights into the effectiveness of alternative development policy interventions for controlling deforestation.

6.4.1 Population Policies

Population is often mentioned as an important causal factor in deforestation (see Chapter 2). The impacts of hypothetical population increases are examined in two separate simulations over the period 1990-2065. The population totals considered are 1.0 billion, and 1.2 billion in place of 828 million (population value used in the base case). The results are shown in Table 6-4.

With each increase in population the FBM curve shifts downward (see Figure 6-6). This demonstrates the negative impact of population on FBM. Increases in the 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 affect 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.
### Table 6-4: Impacts of non-forest Development Policy Interventions

<table>
<thead>
<tr>
<th>Policy Scenario</th>
<th>Year at which FBM vanishes</th>
<th>Value of TFA at the end of simulation period (2065)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Base case scenario (Figure 6-1)</td>
<td>2015</td>
<td>70.4 million hectares</td>
</tr>
<tr>
<td>2. Population increase</td>
<td>2012</td>
<td>40.4 million hectares</td>
</tr>
<tr>
<td>3. Urban Poverty amelioration with population increase</td>
<td>2013</td>
<td>40.4 million hectares</td>
</tr>
<tr>
<td>4. Reduction in fraction of rural population along with poverty but population increase</td>
<td>2012</td>
<td>48.1 million hectares</td>
</tr>
<tr>
<td>5. Reduction in fuelwood dependence along with scenario 4 measures</td>
<td>2018</td>
<td>48.1 million hectares</td>
</tr>
<tr>
<td>6. Change in energy consumption structure expressed by a reduction in fraction of non-commercial energy consumption along with scenario 5 measures</td>
<td>2024</td>
<td>48.1 million hectares</td>
</tr>
<tr>
<td>7. Change in energy structure with focus on rural areas along with scenario 6 measures</td>
<td>2026</td>
<td>48.1 million hectares</td>
</tr>
<tr>
<td>8. Increased investment on alternate energy, and reduction in their cost along with scenario 7 measures</td>
<td>2032</td>
<td>48.1 million hectares</td>
</tr>
<tr>
<td>9. Agriculture productivity increase impact along with policy measures of scenario 8</td>
<td>2037</td>
<td>70.9 million hectares</td>
</tr>
<tr>
<td>10. Decrease in fraction of forest grazing from 30 per cent to 20 per cent along with scenario 9 measures</td>
<td>2115</td>
<td>70.9 million hectares</td>
</tr>
</tbody>
</table>

The effect of an increase in population is also visible on TFA (see Figure 6-7). The stock of total forest area shrinks at a faster rate than in a “no population” increase situation. With an increase in population the TFA curve no longer experiences a rising Section for the first 20 years and instead slopes downwards from the beginning of the simulation. This confirms that increases in population in India on their own reduce both the stock of forest biomass and the stock of forest area. Increased population contributes to deforestation. Therefore, policies aimed at reducing population growth will positively affect the levels of both forest stocks.
Figure 6-6: Impact of Population Increases on FBM

Table 6-5: non-forest Policy Variable

<table>
<thead>
<tr>
<th>Setup #1</th>
<th>Variable</th>
<th>Run</th>
<th>Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>1</td>
<td>8.28e+008</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>2e+009</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>1.2e+009</td>
<td></td>
</tr>
</tbody>
</table>

In order to examine whether the negative impacts of increased population on forest sustainability can be overcome, a variety of other policies variables are considered involving such elements as the urban poverty ratio, the percentage of rural population, and non-commercial energy consumption. Since there is no doubt that population will increase

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16 The numbers on vertical axis shows the scale for FBM (forest biomass) in kilograms, and the horizontal axis shows simulation time displayed in years. The three curves show the behavioral patterns of the FBM under impacts of three different sensitivity setup of a population variable (see Table 6-5). Curve 1 is higher than curve 2, and curve 2 is higher than curve 3, indicating a negative impact of two increases in population from 828 million to 1.0 billion, and to 1.2 billion persons in India in 1990.
in future years, the results with a population of 1.2 billion is now used as the base case against which the additional new non-forest policies are compared.

*Figure 6-7: Impact of Population on TFA*

6.4.2 Poverty Policies

In order to examine the effect of urban poverty on forests, the urban poverty ratios were assumed to decline from 40.1 per cent to 30.1 and 20.1 per cent 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 does not change the dynamic behavior. Forest sustainability while improved is not achieved with this policy.

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17 The numbers on vertical axis shows the scale for TFA (Total Forest Area) in hectares, and the horizontal axis shows simulation time displayed in years. The three curves show the behavioral patterns of TFA under impacts of three different sensitivity setup of a population variable (see Table 6-5).
It is interesting to observe that a reduction in the urban poverty fraction from 30.1 to 20 per cent 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 confirms 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 should be targeted as a priority if forests sustainability is to be a goal.

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 for by varying the fraction of rural people dependent on fuelwood (see Section 6.4.3).

The results of the impact of urban poverty on the total forest area (TFA) are shown in Table 6-4. 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 via their numbers and production because their economic activities affects
the forest area. A change in the consumption of the urban poor simply affects the forest biomass depletion rate, and the forest area is not affected by decreasing the urban poverty ratio. This suggests that forest area is largely independent of urban poverty variations. However, programs directed towards the amelioration of rural poverty (which affect both area and forest biomass) may be of greater policy significance than those directed at the urban poverty amelioration.

6.4.3 Rural-Urban Distribution Policies

In addition to the impact of a reduction in the urban poverty ratio, reducing the percentage of the rural population from 70 per cent to 60 and 50 per cent improves the TFA stock but does not change the behavior of the FBM stock (see Table 6-3) because the rural migration swells the urban population and the number of urban poor. Consequently, the number of forest encroachers is reduced, and forest encroachments are reduced. As a result, a small positive boost is observed in forest area. However, the impact of reduction in urban poverty on FBM is nullified by a swelling number of slum dwellers. This finding further 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. In addition, these results demonstrate that the sum of the positive effects of the reduction in urban poverty and the reduction in the fraction of rural population compensate to a large extent for the negative effect of increased population. In total, 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 considered in these simulation results.
6.4.4 Rural Energy Policies

Another policy initiative that can impact on forest sustainability is 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 per cent of the rural population is dependent on fuelwood for their cooking energy needs. If that fraction can be reduced to 50 per cent by the enhancement of biogas and other energy sources the FBM sustainability will further improve and FBM will last longer (see Table 6-4). This suggests that the 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, in these simulations there is still a decline in FBM throughout the projection period (Table 6-3). FBM now disappears in 2018. The policy changes of a reduction in fuelwood dependence does not have any significant 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 forestry stocks.

6.4.5 General Energy Policies

Improvements to the forests are possible when changes in the population and population structure as (the rural-urban distribution) and the energy sector are considered simultaneously. Currently in India, about 53 per cent 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 1990). If the fraction of non-commercial energy can be brought down to 30 per cent from its current level of 53
per cent, it is possible to decrease the rate of depletion of the FBM stock and increase the level.

If the alternative set of development 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 more than compensate for the negative effect of a population increase. However, the impact is minor. These policy interventions can sustain the FBM stock for a further three years (up to 2018). 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 per cent. With these changed policy measures combined the stock of FBM will not be depleted until 2026.

The positive effect of energy changes on FBM will be enhanced (see Table 6-4) by reducing the cost of supplying alternate energy, say hypothetically from 26700 to 20000 rupees millions/Mtoe, and increasing the investment from the hypothetical value of 800000 to 1200000 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 change of 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 impacts, other policy measures that affected FBM have not affected TFA. This strengthens the policy conclusion that different policy measures are required to change the behavior of the two forestry stocks of TFA and FBM.

6.4.6 Agriculture Policies

If the combination of socio-economic interventions are enlarged to include the agriculture sector policies, a significant change in the rate of FBM decline is possible (see Table 6-4). If the 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. However, the FBM remains a declining stock. The increase in agriculture productivity increases the agriculture production and reduces the demand for land. 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. This finding reinforces the finding of Southgate (1994) that suggests that increase in agriculture productivity will help ameliorate deforestation. However, the results also provide an additional insight that by increasing agricultural productivity alone the forests can not be sustained.

6.4.7 Livestock Grazing Policies

A noticeable change in the rate of FBM decline is possible if the grazing fraction is reduced from its present level of 30 to 20 per cent. Instead of earlier depletion, the FBM lasts throughout 21st century when combined with the previous policies. The reduction in grazing impacts both removal and the 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 6-4).

### 6.4.8 Trade policies

The impact of trade policies was measured by devaluing the domestic currency, (that is, changing the exchange rate: 1$ = .057 Rs. to 1$ = .03 Rs.) and observing the simulated behavior of FBM. There was no perceptible change in behavior of FBM, suggesting that there was no direct impact of devaluation on the forest sector. Another policy instrument: relaxing the ban on the import of industrial wood, also does not change the behavior of FBM. Although, increasing the industrial wood imports from the 1990 level of 0.5 million ton to 4.0 million ton, reduces the industrial wood removals from the nation’s forests, the overall rate of FBM decline is not significantly affected. FBM vanishes in year 2015. This is because (1) the total industrial wood removals are very small percentage (8-10 per cent) of total forest biomass removals, and (2) on the top of that the forest trade, particularly industrial wood trade is small in relation to the total industrial wood removals in India. The impact is therefore negligible on the overall behavior of FBM.

Further, the impact via intersectoral land competition is also low. The areas in agriculture nonfood items such as cotton or jute are a very small percentage of total area in agriculture production (about 1 per cent), and currently additional forest areas are not diverted for increasing their production because of the Forest Conservation Act. So, the impact from trade in the agriculture sector is also insignificant. This result is not to deny the significance of a devaluation or import substitution in explaining the deforestation,
especially for those developing countries where the trading volumes are significant percentage of total industrial wood removals such as Malaysia or Indonesia. However, for the majority of developing countries where the trading volumes are low, the direct impact of these trading instruments will be small on deforestation. In summary, for countries where the timber trading volumes are low in relation to total domestic consumption, the exchange rate policy plays an insignificant role in ameliorating the deforestation problem. Moreover, relaxing the ban on the import of industrial wood eases the industrial wood supply position, but because of foreign exchange scarcity in most of the developing countries and especially in India, it will be difficult to increase the imports and change the deforestation scene. The trading policies are therefore not included in the combination of the alternative non-forest policy package to ameliorate deforestation.

A combination of the alternative development interventions do significantly impact the FBM, yet these policies are unable to change the declining behavior of FBM. In summary, like the "forest-only" interventions, the set of alternative non-forest development policy interventions in isolation of forest sector policies can not sustain the forest biomass. This is demonstrated in Figure 6-8. While these policies together result in a significant upward shift in the FBM curve, and FBM will last much longer (until 2115) than in the base case or in the only forest policy intervention cases, the declining behavior of FBM stock is not altered even by the impacts of the combination of these non-forest development policy interventions. For forest sustainability - it is still necessary to find a set of policy measures that could possibly change the behavior of FBM from a declining to at least stable behavior.
Figure 6-8: Impact of Alternative Development Policy Interventions on FBM

Table 6-6: Non-Forest Development Policy Variables

<table>
<thead>
<tr>
<th>Run</th>
<th>Population</th>
<th>Urban Poverty Ratio (U pov ratio)</th>
<th>Fraction of Rural Population (fr pop R)</th>
<th>Fraction of rural pop dependent on fuelwood</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>8.5e+008</td>
<td>0.401</td>
<td>0.7</td>
<td>0.8</td>
</tr>
<tr>
<td>2</td>
<td>1e+009</td>
<td>0.301</td>
<td>0.6</td>
<td>0.65</td>
</tr>
<tr>
<td>3</td>
<td>1.2e+009</td>
<td>0.2</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Run</th>
<th>fraction of livestock grazing</th>
<th>Agriculture productivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.3</td>
<td>1380</td>
</tr>
<tr>
<td>2</td>
<td>0.25</td>
<td>1800</td>
</tr>
<tr>
<td>3</td>
<td>0.2</td>
<td>2500</td>
</tr>
</tbody>
</table>

18 The numbers on vertical axis shows the scale for FBM (forest biomass) in kilograms, and the horizontal axis shows simulation time displayed in years. The three curves show the behavioral patterns of the FBM under impacts of three different sensitivity setup of Non-Forest Development Policy variables (see Table 6-6).
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 “non-forest” Development policy interventions strengthens the results of “forest-only” policy interventions (see Section 6.2). (1) By altering the non-forest development policy interventions the process of deforestation can be delayed. These policy interventions play a dominant role in impacting the behavior of the forest biomass. However, non-forest development interventions in isolation of forest sector interventions fail to change the declining behavior of the forest biomass. The development policies in isolation do not sustain the stock of forest biomass and the forest area; and (2) once again TFA and FBM are subject to different policy influences. Therefore, different policy measures are called for to sustain the two stocks.

The result 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 but do not eliminate it.
6.5 Combination of Forest Conservation and Non-Forest Development Policies

A combination of Forest conservation (see Section 6.3) and non-forest development policy interventions (see Section 6.4) provides hope to forest planners. A radical change in the 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 (Figure 6-9).

A combination of forest conservation and non-forest development policies, if implemented together can result in sustainable FBM. 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. Simulation results (see Table 6-4) demonstrate that the result of a population increase on FBM can be mollified if adequate attention is given to ameliorating poverty, to undertaking structural changes in energy consumption (so as to reduce the fraction of non-commercial energy particularly in rural areas), and to significantly reducing the fraction of livestock grazing in forest areas. In isolation, neither forest conservation policy interventions nor non-forest development policy interventions can significantly effect the dynamics of both forest biomass and forest area. For forest sustainability, it is essential to implement both the forest conservation and the non-forest development policies together. Forest conservation policies that effectively use the Forest Conservation Act (1980) can significantly impact the TFA dynamics but only marginally effect the FBM dynamics because these policies only effect the FBM inflow, while the non-forest development polices significantly impact the dynamics of FBM outflow, and the dynamics of TFA by effecting the land use
competition between forests and other land using sectors. It is only the combinations of polices that addresses the core issue of forest interactions with other sectors, including both its biophysical nature (productivity inflows to the forest) and its (FBM outflow) socio-economic uses.

Figure 6-9: Impact of Combination of Forest Conservation and Development Policies on Forest

Table 6-7 illustrates the general impacts of various policies. Although the table shows the impacts of policies in terms of numbers, it will be useful to understand the numbers in the context of the overall behavioral pattern of the forest stocks. At the risk of repetition, it is worth reminding that sustainable policies require gaining insight into the behavior patterns of FBM and TFA and not on their "snapshot values". While non-forest

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19 The numbers on vertical axis shows the scale for FBM (forest biomass) in kilograms, and the horizontal axis shows simulation time displayed in years. The three curves show the behavioral patterns of the FBM under impacts of three different sensitivity setup of a combination of Forest and Non-Forest Development Policy variables (see Table 6-2 and Table 6-6)
development policy plays an important role in determining the dynamics of forestry sector, it is the combination of forest and non-forest development policies that ensure forest sustainability. Following a combination of the forest conservation and non-forest development policies, India can move to the path of forest sustainability (see Table 6-7).

Table 6-7: Impacts of Various Policy Interventions

<table>
<thead>
<tr>
<th>Policy Scenario</th>
<th>Year at which FBM vanishes</th>
<th>TFA value at the end of simulation period (2065)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Base case scenario</td>
<td>2015</td>
<td>70.4 million hectares</td>
</tr>
<tr>
<td>2. Forest-alone interventions</td>
<td>2026</td>
<td>70.4 million hectares</td>
</tr>
<tr>
<td>3. Forest interventions with emphasis on Forest Conservation Act(1980)</td>
<td>2028</td>
<td>81.2 million hectares</td>
</tr>
<tr>
<td>4. Alternative Non-Forest Development policy alone interventions</td>
<td>2115</td>
<td>70.9 million hectares</td>
</tr>
<tr>
<td>5. A Combination of Forest Conservation and Non-Forest Development Policies with emphasis on Forest Conservation Act(1980)</td>
<td>FBM level improves and sustained at a improved level</td>
<td>81.6 million hectares</td>
</tr>
</tbody>
</table>

These results should be understood by the current policy planners who are attempting to develop policies that could stabilize FBM by focusing on the stock of TFA alone. For example, the Indian Forest Conservation Act of 1980 simply focuses on the stock of forest area. It prescribes stringent rules for forest encroachments and diversion, but does not spell out any enforceable action to control the forest biomass flow resulting from the inter-sectoral policy links. Similarly, the Indian "Forest Policy" of 1988 is not clear about distinct policy measures for the stocks of FBM and TFA. This is not surprising. In past policy studies the distinct behavior of the two stocks, FBM and TFA was not appreciated (for example, Allen and Barnes 1985, Grainger 1986, Palo et al. 1987, Khator 1989, Repetto and Gillis 1988, Reis and Guzman 1989, Scotti 1990,
Kummer 1992, Chakraborty 1994, Kummer and Sham 1994), and uniform policy measures were called for to control deforestation. Therefore, results of past analyses of deforestation are of limited use for developing the policy package to ameliorate the process of deforestation, and bring about sustainable forest management.

6.6 Reflections on Conventionally Emphasized Policies

Conventionally, it is suggested that focus on agro-forestry, and finding substitutes for fuelwood may ameliorate the problems of deforestation (Nair, 1991). By using sensitivity analyses, it is possible to reflect on their strengths and limitations.

6.6.1 Sensitivity Effect of Agro-forestry on Forest Biomass

The strengths and limits of agro-forestry in combating deforestation problem is explored by using sensitivity analyses. Operationally, the concept of agro-forestry is tantamount to enhancing the land available for forestry plantations. Therefore, agro-forestry (a complementary use of land for agriculture and forestry) could relax the constraint of physical area on plantations. However, over the projection period (1990-2065), the on-going competition between forestry and agriculture will also simultaneously intensify the pressures on agro-forestry. Agro-forestry, operationally increases the potential for forest planting by increasing the availability of agriculture land. However, its impact is likely to be marginal only because the increase in availability of agriculture lands for agro-forestry will only be marginal. The increase in land may be 10-15 per cent of the land under current (1990) agriculture use (127 million ha.). On increasing the stock of available cultivable land by approximately that magnitude, that is, from 25 million hectares
(1990) to 40 million hectares, the behavior of FBM does not change. FBM remains a
decreasing stock, and lasts until 2016 instead of 2015 (see Figure 6-10).

Figure 6-10: Sensitivity Effect of Agro-forestry on FBM

This is not deny the importance of agro-forestry initiatives, but it does illustrate that a
policy advocating simply agro-forestry solutions, falls short of achieving the forest policy
goal of sustainable forestry.

6.6.2 Sensitivity Effect of Fuelwood Substitution by Biogas and Natural gas

In order to understand the implications of energy policy for sustainable
forestry, a sensitivity analysis with the different fractions of currently available natural gas
and biogas potential was undertaken. Natural gas instead of being burnt is supplied to
rural areas to replace their fuelwood consumption, and also the available biogas potential

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The numbers on vertical axis shows the scale for FBM (forest biomass) in kilograms, and the horizontal axis shows simulation time displayed in years. The three curves show the behavioral patterns of the FBM under impacts of three different sensitivity setup of changes in agro-forestry variable (cultivable land).
is realized and is made available to fuelwood consumers. Under these conditions the rate of loss in forest biomass is delayed.

*Figure 6-11: Sensitivity Effect Of Fuelwood Substitution on FBM Stock*  

Figure 6-11 presents five curves (1, 2, 3, 4, and 5) indicating five substitution levels, that is 20 per cent, 40 per cent, 60 per cent, 80 per cent, and 100 per cent of the available biogas and natural gas potential of India. Under maximum substitution (curve 5) FBM depletes in 2050 instead of 2015. Nonetheless, the declining behavior of forest biomass does not change highlighting once again that energy policy alone will not be a

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21 The numbers on vertical axis shows the scale for FBM (forest biomass) in kilograms, and the horizontal axis shows simulation time displayed in years. The five curves show the behavioral patterns of the FBM under five substitution levels, that is 20 per cent, 40 per cent, 60 per cent, 80 per cent, and 100 per cent of the available biogas and natural gas potential of India.
sustaining forestry policy; additional supporting policies to achieve sustainability will be required.

Unfortunately, India is on the “hard energy path” but needs a “soft energy path” (Reddy and Prasad 1977, Goldenberg et al 1988). The soft energy path (earlier suggested by Lovin 1979, Reddy and Prasad 1980, Goldenberg et al 1988) focuses on *inter-linkages of energy* planning with other sectors and also considers the issue of “energy from what and energy for whom?”, as contrast to hard path-path which is concerned with the engineering aspects of increasing energy and focuses on the energy needs of urban elite. In the current pattern of energy investment the share of investment on non-commercial energy is of token nature only (Mehta 1992), and was less than one per cent even in the Eighth Five year plan of Government of India (1992-1997). The simulation results with Model C suggest that altering the current pattern of energy investment from the total focus on commercial energy to enhancing availability of non-commercial forms of energy is an appropriate direction for ameliorating deforestation. Less than 1 per cent of total energy sector investment allocations are available for non-commercial forms of energy (Eighth FYP, p164-168) such as biogasification, solar thermal, solar photo-voltaic, wind, geothermal and ocean energy. If the currently available natural gas, and biogas potential is to be utilized for replacing fuelwood consumption, a quantum jump in the allocation of non-commercial energy is required. This should be in the range of 10-15 per cent of the total investment on energy instead of the present one per cent. The model estimates that India has the potential for about 3.7 million biogas plants per year, and requires investment, in the range of Rs. 22500 millions per year just for making biogas plants.
Ironically, the five year allocation for the total non-conventional forms of energy which includes the biogas, solar, wind and tidal is only Rs. 11000 millions. This suggest that at least a 10 to 11 times jump in the allocation of non-commercial energy allocations should be given to utilize the potential for biogas alone, and thereby reduce fuelwood dependence.

The changing profiles of FBM are obtained under the assumption that the fuelwood substitution policy was implemented in 1951. However, ruefully it may be mentioned that it has not been fully implemented until now. If the implementation of biogas program in achieving its potential is further delayed, it is possible that Indian forests may become history. Time is of the essence, and India needs to immediately switch its energy allocation pattern in favor of non-commercial energy-which are the energy sources for an average rural Indian. However, the results of sensitivity analyses of conventional policies suggest and reinforce that these policies alone are not sufficient to sustain forests in India.

The only way which may have a reasonable chance of arresting deforestation in India is taking an integrated systemic view of the problem. A joint effort in the forestry, agriculture, livestock, energy and socio-economic sectors if undertaken simultaneously and immediately, has the potential to keep the forests sustainable in the country. More specifically if the objectives of government policy is: (a) to increase the productivity both in dense and open forests from its 1990 level of 1000 kg/ha/year to 1500 kg/ha/year, and 500 kg/ha/year to 1000 kg/ha/year respectively by 2001 in the forestry sector; (b) to utilize the biogas and natural gas to 80 per cent of their known potential for substituting
fuelwood energy consumption by 2001 in the energy sector; (c) to reduce land inequality and generate rural employment so as to reduce the fraction of forest encroachments from 0.1 per cent of the rural households to 0.05 per cent by 2001, in the socio-economic sector; (d) to increase fodder availability and reinforce by grazing penalty so as to reduce fraction of livestock grazing in forests from 30 per cent level to 20 per cent by 2001 in the livestock sector; (e) to continue with the trend in increasing agriculture productivity and reach the goals of increasing agriculture productivity from its 1990 level of about 1380 kg/ha to about 2400 ha/year by 2011, and further to about 3200 kg/ha by 2050 in agriculture sector; and (f) to reinforce all these policies, control population to 1.1 billion level by 2010 and thereafter; then the FBM and TFA can be sustained at a level higher than the 1990 level. In 1990, FBM and TFA are at 45 per cent and 190 per cent of their 1951 levels. With the achievement of these inter-sectoral policy goals FBM in contrast to the present declining behavior, can be made to change its behavior and may rise to 52 per cent of the 1951 level (that is, \(5.7\times10^{12}\) kg), while TFA may be sustained at 236 per cent (that is, 94 million hectares) by the year 2065. These simulation results indicate that the process of deforestation can be arrested, and even reversed on implementation of a multi-sector policy package of the type outlined above.
CHAPTER SEVEN

7. Conclusions

7.1 Introduction

The thesis demonstrates that the vision of analyzing forestry problems, particularly deforestation in an isolated sectoral framework needs to change. A systems thinking approach that transcends the boundaries of the forest sector is required for sustainable forestry development. A system that views the process of deforestation in terms of the interrelationships between the forest sector and other interacting sectors is necessary to capture sufficient insight for developing policies to ameliorate deforestation and establishing a sustainable development approach to forest management. A number of components are necessary to effect this change in orientation.

7.2 Conceptual Conclusions

The process of deforestation can be fully understood and captured only if the dynamics of its both dimensions: the geophysical and the biophysical are monitored and analyzed. This calls for the explicit inclusion of the two distinct elements: the total forest area (geophysical), and the forest biomass (biophysical), into the definition of deforestation, and captioning the decline in either of them as deforestation.

The nature of these two elements is different (see Section 1.2), and so these two elements are influenced differently by different factors and hence by different policies. Accordingly, an insight into the impacts of different policies on deforestation can only be examined by the changed dynamic behaviors of both the forest area and the forest biomass. Since sustainable forestry development requires that both measures be non-
declining, this conceptual conclusion suggests that *a policy package approach* is required to ameliorate deforestation, and to achieve sustainable forestry development.

### 7.3 Modeling Conclusions

A model that recognizes that process of deforestation is a complex and dynamic process is essential if sustainable policies are to be developed and implemented. Partial linear and static analyses fail to provide the needed insight into the process of deforestation. The simulations presented in this thesis clearly show that the process of deforestation is affected by the web of relationships between the forest, agriculture, socio-economic, energy and livestock sectors. The strengths of impacts depend on the strengths of these relationships between and within sectors. These can vary over time depending upon the values of elements in the system 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 another over time. As a result, the causes of deforestation shift over time. The need is to understand why one relationship dominates over another, and why the dominance varies over time in a given setting.

The model simulations also reconcile the two views in the population debate. They demonstrate that an increase in population increases deforestation, but the issue of population is not just about numbers but also about the socio-economic context within which the population lives. A small population can be as much or even more damaging than a large population depending on their interactive behavior with the forests. The same
is true for the agriculture, energy and livestock sectors. Obviously, these interactions will vary from country to country and within country over time.

From these results it follows that focusing exclusively on one set of factors (such as population or international trade) or one set of activities (such as shifting cultivation, diversions for infrastructure or logging) are not sufficient to address the deforestation question. It is too simplistic to identify the causation of deforestation at an isolated factor level such as the growth of population (for example, by the advocates from Northern countries at Rio) or the growth of forest trade (for example, by the advocates of Southern countries at Rio). 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.

The results also suggest that the scarcity debate in the forestry context may be misguided. A multifaceted approach that combines the biophysical with the neoclassical economic relationships is essential to understand the strength and weakness of these different arguments. The efficacy of the argument will vary from country to country depending upon the strength and nature of interactions within the country. Nonetheless, the simulations presented in this thesis suggest that a complete reliance on market mechanisms to control deforestation may be misguided, especially in a developing economy where markets are nonexistent or incomplete.

The model simulations show that technological gains made in the forestry, agriculture and energy sectors are not completely sufficient to match the forest based
needs of an increasing population and livestock numbers. Moreover, the needs are compounded by the existing poverty structure, the energy consumption structure, and fodder source structure.

The model simulations clearly show that if the current vision of analyzing deforestation and policies to ameliorate deforestation remain unchanged the depletion of forests in India will continue and the forests of India will vanish within two decades. It is likely that the general conclusion that current analyses and policies will not lead to sustainable forestry development have universal applicability.

7.4 Policy Conclusions

The model results strongly indicate that if forests are to be sustained, policies within the forestry sector alone will not be sufficient to sustain forests. They will have to be designed in combinations with policies in other sectors. Foresters have no choice but to look beyond the forest sector to sustain forests. This conclusion is likely to be true for most countries.

Within the forestry sector, policies to control and if possible reverse deforestation by focusing on (1) increasing plantations, (2) increasing protection of existing forests, and (3) increasing productivity of plantation are necessary but are not sufficient. This is because forest polices especially impact the supply side of forest product flows while the policies of the other sectors primarily impact the demand side of the forest products flows. As a result, both: “forest only” and the “other sectors” policies must be combined for forest sustainability. This means that broad-based multi-sectoral policy combination is required to ameliorate deforestation.
7.5 Forest Policies in India

In a general way Indian forestry planners seems to be aware of the gravity of the situation but a clear vision of the impending forestry disaster does not seem to be present as yet. The usual response to the deforestation issue has been to concentrate on the maintenance of total forest area (TFA) with little attention being given to forest biomass (FBM) (GOI 1952, GOI 1988, MEF 1994). For example, the Forest Conservation Act (1988) focuses on the maintenance of forest area (the legally mapped surface area with forest department) but little attention has paid on the maintenance of forest biomass (organic biomass on the surface of forest area). The results of this thesis suggest that this response to forest conservation will be ineffective.

Indian forestry planners tend to take the official position that there is “no deforestation problem in India”. This delusion occurs because forest planners have focused exclusively on the behavior of forest area. The forest area has increased from 40 million hectares to 67.9 million hectares during 1951-1991, but the model results suggest that by 2005 forest area will have reached a peak and then start declining because of severe land competition from the agriculture sector. The thesis demonstrates that the policy goal of increasing forest area to 33% of geographical area in India is a far fetched goal and cannot be achieved under current policies. It may, however, be possible to increase the forest area to a range of 25 to 30% of geographical area depending upon the interacting sectors policies. Of special importance in this matter is (1) the agriculture sector policy enhancing agriculture productivity, together with (2) rural development policies addressing rural poverty, unemployment and agriculture land inequality so as to reduce the encroachments
on forests and (4) population control policies to reinforce the impacts of these above policies.

The "no deforestation problem" response of Indian forestry planners to the deforestation problem seems to be based on a familiar approach generally adopted with regard to environmental problems that disguise, deny, or confuse the signals of the problem (Meadows et al 1992). They disguise by focusing attention on total forest area and by overlooking the state of forestry biomass. They deny by ignoring the research results of many past authors and by focusing on past behavior of forest area. They confuse the signals by focusing on plantation drives and other technological improvements. These misleading of signals represent refusals to deal with the problems induced by systemic interactions and they guarantee even worse problems in the future.

A somewhat more sophisticated response has been to focus on technological or market solutions such as increasing productivity, increasing area in forestry plantations, using resources more efficiently, and substituting for wood uses. Though definitely better than the previous approach, this approach is only capable of slowing the total depletion of forests by another decade. By themselves these measures will not be able to sustain forests. Without addressing the issues of population growth, poverty alleviation, and the reduction in unemployment, the poor people will not be able to implement technological solutions or have purchasing power to make markets work efficiently.

The only way that may have a reasonable chance of arresting deforestation in India is by taking an integrated systemic view of the problem. A joint effort in the forestry, agriculture, livestock, energy and socio-economic sectors, if undertaken simultaneously
and immediately, has the potential to keep the forests sustainable in the country. More specifically, to sustain Indian forests a government policy package that for example, (1) increases the productivity both in dense and open forests from its 1990 level of 1000 kg/ha/year to 1500 kg/ha/year, and 500 kg/ha/year to 1000 kg/ha/year, respectively, by 2001 in the forestry sector; (2) utilizes biogas and natural gas to 80% of their known potential to substitute for fuelwood energy consumption by 2001 in the energy sector; (3) reduces land inequality and generates rural employment so as to reduce the fraction of forest encroachments from 0.1% of the rural households to 0.05% by 2001 in the socio-economic sector; (4) increases fodder availability reinforced by grazing penalties so as to reduce fraction of livestock grazing in forests from 30% level to 20% by 2001 in the livestock sector; (5) continues the trend in increasing agriculture productivity and reach the goals of increasing agriculture productivity from its 1990 level of about 1380 kg/ha to about 2400 kg/ha/year by 2011, and further to about 3200 kg/ha by 2050 in agriculture sector; and (6) reinforces all these policies with controlled population growth; must be implemented. With the achievement of these multi-sectoral policies the decline in FBM can be reversed and TFA can be sustained. In summary, the process of deforestation can be arrested, and even reversed if a multi-sectoral policy approach is adopted.

The most important insight obtained from this thesis is that a policy approach that focuses exclusively on the forestry sector will not be able to sustain forests. This means that the current National Forestry Action Plan (1996) which focuses only on forestry sector elements such as increasing forest productivity and the protection of the forests will not be able to sustain forests in India.
Another important insight obtained from the model results is that too much reliance on the market forces to attract investment in the forestry sector are likely to be ineffective in influencing deforestation in India and in many other developing countries because markets are not well developed since the rural sector is not well integrated into the national economy. Under these conditions the biophysical linkages tend to dominate the interrelationships between and within the interacting sectors and these point to the continuation of deforestation without broad-based and immediate policy interventions.

7.6 Future Research Frontiers

Although the dynamic model developed in this thesis reproduces the behavior of total forest area and other elements to a great extent, further advances can enhance the understanding of deforestation and many other related processes.

It is well known that policy planning, and implementation have time lags. In the model presented in this thesis, delay functions have been used to incorporate these time lags. If a plantation area of different tree crops is available, then different delay functions can be utilized for each species. Most of the fast growing species take 8-10 years of rotation. Also the model structure offers the opportunity to use different delay functions for different policy affects. There is a need to determine the various policy planning delay functions. Incorporation of these relevant realities can further advance the model and therefore, its results.

Another important advance from a forestry perspective is to differentiate forests by forest types and include various productivity delays in the model. Although, these
relationships have been incorporated indirectly into the model developed in this thesis, there is scope for further improvements utilizing additional information on differential productivity responses.

The livestock sector of the model could be expanded. Research on the number of livestock units and the total farming land of a nation, which in turn are influenced by the farm sizes and their distribution, is important in determining the state of forests. This research could provide insights into why people keep a given number of livestock units, and provide some operational elements that can be inserted between the livestock, forestry, and agricultural sectors. The dynamics of the livestock sector, including the livestock structure, birth rate, and the death rate of various livestock units in different age classes, and other elements that determine these stocks and flows, may be useful in providing a better understanding of livestock growth.

The same is true for human population. In this model, a sample population trend function has been used to incorporate the impacts of population. Alternatively, a complete demographic sector could be developed for inclusion in the model. This would be useful in including more feedback relationships between the economic and socio-economic system as, for example, births, deaths and migration respond to the state of socio-economic system.

The model is primarily suited for industrializing nations where the fuelwood flow is major form of wood removal from forests. However, to make it suitable to industrialized nations the incorporation of a detailed structure of industrial wood flow into various uses could be an important addition. Industrial wood is primarily used as sawn wood and as
pulp wood. Both of these uses, in turn, depends on the state of forest based
industrialization and the industrial wood trade. For example, the number of saw mills, pulp
and paper mills and their production capacities influence the production for domestic
consumption and for trade. Similarly, although the general impacts of exports and imports
on the forestry sector have been incorporated into the model in this thesis, detailed
impacts of exports and imports in terms of land requirements might be important for those
nations where relationships emanating from forest products trade could play a dominant
role in the economy.

Finally, beyond the structure of this model, the incorporation of a soil science
system into the model could be an important extension. This addition could link forest
biomass depletion with the forest biomass productivity via an element reflecting soil
quality. Unfortunately, given the current state of knowledge, there are no direct data on a
national scale that could connect the forest biomass removal rate with rate of forest
biomass production. The linkage between forest biomass depletion with the forest biomass
productivity theoretically emanates from the relationship between the removal rate and the
soil erosion rate, which in turn can be linked to the forest biomass production rate.
Besides the removal rate, the rate of forest biomass production is affected by the
biological, physical, and chemical characteristics of the soil stock. In the absence of these
detailed elements of the soil science system, these theoretical linkages are incorporated by
using average productivity values of different class of forests (for example, closed and
open). Identifying the soil system relationships with the production and removal rates
could enhance the model and provide further understanding of the process of deforestation and provide additional policy considerations.

While these future research initiatives could enhance the model presented in this thesis, both in terms of its real world applicability and in terms of additional policy instruments that could be used to ameliorate or reverse the process of deforestation, it is very unlikely that they would reverse the conclusions of this thesis. It remains essential to distinguish TFA and FBM and to realize that sustainable forestry development requires that both be non-declining. It is essential that a multi-sectoral, systems approach be adopted if the process of deforestation is to be properly understood. And it seems very unlikely that deforestation can be arrested by focusing on "forest only" policy initiatives. A multi-sectoral policy approach is necessary if the process of deforestation is to be halted and reversed. Moreover, such an approach is urgently needed if forests are to be saved in India and, most likely, in other countries as well. The continuation of partial one sector analyses and current policies towards forests result in misguided efforts to conserve forests. A new approach is required if forest sustainability is to be achieved and this thesis provides a framework as to how this can be achieved.
Literature Cited


Chowdhary, K. 1994. Forestry: Reconciling Poverty and Equity Concerns. Discussion paper prepared for International Workshop on India’s Forest Management and


Appendix I

Equations for Simple Model

\[ FBM(t) = wmtu FBM(t - dt) + (Production - Removal) \bullet dt \]  \text{Equation S-1}

\[ INIT FBM = 4196000000 \]  \text{Equation S-2}

DOCUMENT: This is in cubic meters and the data has been taken from (FSI, 1987).

\[ Production = TFA \times productivity_\text{per_hectare} \]  \text{Equation S-3}

\[ Removal = FBM \times fraction_\text{removed} \]  \text{Equation S-4}

\[ TFA(t) = TFA(t - dt) + (-Ch_FA) \bullet dt \]  \text{Equation S-5}

\[ INIT TFA = 64010000 \]  \text{Equation S-6}

DOCUMENT: This is in hectare (FSI 1987, FSI 1989, FSI 1991, FSI 1993)

\[ Ch_FA = \text{Division} + \text{enc_of_FA} - \text{area_planted} \]  \text{Equation S-7}

DOCUMENT: The total forest area can be changed by the encroachment or by the diversion of forest land.

\[ \text{Division} = div_{\text{for_infra}} + otherdiv \]  \text{Equation S-8}

DOCUMENT: The diversion figures are actual diversion figures from 1981-1994 (MEF Report 1994). They are in hectares.

\[ enc_{\text{of_FA}} = TFA \times ffaenc \]  \text{Equation S-9}

\[ ffaenc = .011 \]  \text{Equation S-10}

per DOCUMENT: 700,000 ha. are encroached. This is about 1.1% of the total forest area (FSI 1987, Mukerji 1994)

\[ fraction_\text{removed} = \frac{\text{total_rempyr}}{FBM} \]  \text{Equation S-11}

DOCUMENT: Fraction of biomass removed is sum of fraction of fuelwood removed as biomass, fraction of biomass removed as industrial timber and fraction of fodder removed

\[ \text{productivity_\text{per_hectare}} = 0.8 \]  \text{Equation S-12}

DOCUMENT: This is assumed that the current forest productivity per hectare (0.8 cubic meter/ha/year) (Mukerji, 1994)

\[ total_{\text{rempyr}} = 315000000 \]  \text{Equation S-13}


\[ area_{\text{planted}} = \text{GRAPH(TIME)} \]  \text{Equation S-14}
In 1990, the average rate of plantation was 1.441 million ha. (Mukerji, 1994), about 1 million ha. were in existing forest area and 0.441 million hectare were on lands other than forest area. The plantation outside forests when classified as forests brings change in forest area. For simplicity, assume that this pattern of plantations continue for further 25 years.

\[ \text{div}_{\text{for infra}} = \text{GRAPH}(\text{TIME}) \text{ Equation S-15} \]


\[ \text{otherdiv} = \text{GRAPH}(\text{TIME}) \text{ Equation S-16} \]

Appendix II

Equations for Model C (including Model A and B)

\[ A_{enc}(t) = A_{enc}(t - dt) + (A\_enc\_yr - A_{enc\_ag}) \times dt \]  Equation C- 1

\[ \text{INIT } A_{enc} = 700000 \]  Equation C- 2

DOCUMENT: This is the INITIAL forest area encroached. It is expressed in hectares (FSI 1987, Mukerjee, 1994)

\[ A\_enc\_yr = \text{av_size_of_encroachment} \times \text{no_encroachers} \_yr \]  Equation C- 3

\[ A_{enc\_ag} = \frac{(Fr\_Aenc\_C\_Agfp \times A_{enc})}{\text{shifting_cycle}} \]  Equation C- 4

\[ A_{planted}(t) = A_{planted}(t - dt) + (A_{planted\_yr} - FAjr) \times dt \]  Equation C- 5

\[ \text{INIT } A_{planted} = 300000 \]  Equation C- 6

DOCUMENT: This is the area under plantations in year 1951 (FAO 1993).

\[ A_{planted\_yr} = \text{MIN}(\text{cultivable} \_\text{lands/} \text{plantation} \_\text{time} \_\text{goal,} \text{inv} \_\text{allocated/} \text{cost} \_\text{rural of} \text{planting} \_\text{ha} \_\text{yr}) \]  Equation C- 7

\[ FAjr = A_{planted\_yr} \times 0.8 \]  Equation C- 8

DOCUMENT: 80% of the plantations done on road, canal and other 6 wastelands have been designated as protected forests

\[ \text{area\_in\_food}(t) = \text{area\_in\_food}(t - dt) + (l\_dr + A_{enc\_ag}) \times dt \]  Equation C- 9

\[ \text{INIT } \text{area\_in\_food} = 97.32 \times 10^6 \]  Equation C- 10

DOCUMENT: In 1990-91, 127.84 million hectares of area was under agricultural productions (GOI 1994, p8 table 2.2(a)), and in 1950-51 it was 97.32. While attempting to mimic the 1951-1991 scenario, 1951 value is used.

\[ l\_dr = \frac{(Fpgoal\_Qtcp)/(agfY\_DevTime)} \]  Equation C- 11

\[ A_{enc\_ag} = \frac{(Fr\_Aenc\_C\_Agfp \times A_{enc})}{\text{shifting_cycle}} \]  Equation C- 12

\[ A_{div}(t) = A_{div}(t - dt) + (A\_div\_yr) \times dt \]  Equation C- 13

\[ \text{INIT } A_{div} = 0.045 \times 1000000 \]  Equation C- 14

DOCUMENT: About 1.5 million hectares of forest land is diverted during 1951-1990 (MEF, 1994). Intially, 0.045 mha of land is assumed to be under encroachment
A_{\text{div yr}} = \text{div for infrastructure} + \text{other diversions} \quad \text{Equation C-15}

cultivable\_lands(t) = \text{cultivable}\_lands(t - dt) + (\text{roin} - l_{dr} - A_{\text{planted yr}}) \times dt \quad \text{Equation C-16}

\text{INIT cultivable}\_lands = 60.2 \times 10^6 \text{Equation C-17}

\text{DOCUMENT: There are 19.83 million ha. of miscellaneous tree crops and land under groves, 22.94 million of "cultivable waste" and 17.44 mha of fallow lands "other than current fallow" lands (GOI 1994, p79 table 9.1) in 1951, that is, 60.2 mha in 1951}

\text{roin = CONVEYOR OUTFLOW} \quad \text{Equation C-18}

l_{dr} = (F_{\text{goal}} - q_{\text{cfs}}) / (a_{gf} * \text{DevTime}) \quad \text{Equation C-19}

A_{\text{planted yr}} = \text{MIN(cultivable}\_lands/\text{plantation}\_time\_goal, \text{inv}\_\text{allocated}/\text{cost of planting ha yr}) \quad \text{Equation C-20}

FBM(t) = FBM(t - dt) + (\text{Prod yr} - \text{Rem yr}) \times dt \quad \text{Equation C-21}

\text{INIT FBM = 11} \times 10^4 \times 12 \text{Equation C-22}

\text{DOCUMENT: Biomass is defined as the amount of above-ground organic matter present. There is no data for FBM (1951), therefore 1951 figure is a just an assumed estimate only: 11} \times 10^4 \times 12 \text{ kg of FBM.}

\text{Prod yr = (TFA}\_r \times w_{\text{prod ha yr}} + \text{DELAY}((A_{\text{planted}} \times \text{plantation productivity}).10.18900000*4000) \quad \text{Equation C-23}

\text{Rem yr = Rem}_W\_yr + \text{Rem}_NW\_yr \quad \text{Equation C-24}

\text{Reporting_area change(t) = Reporting_area change(t - dt) + (roin) \times dt} \quad \text{Equation C-25}

\text{INIT Reporting_area change = 2.07e+007} \quad \text{Equation C-26}

\text{TRANSIT TIME = 10}
\text{INFLOW LIMIT = INF}
\text{CAPACITY = INF}

\text{DOCUMENT: There has been an increase in reporting area of about 21 million hectares for reasons unknown from the land use statistic of India. This increase is assumed to have added to the size of culturable lands}

\text{roin = CONVEYOR OUTFLOW} \quad \text{Equation C-27}

TFA(t) = TFA(t - dt) + (FA_{lyr} - A_{\text{enc yr}} - A_{\text{div yr}}) \times dt \quad \text{Equation C-28}

\text{INIT TFA = 40.04} \times 10^4 \times 6 \text{Equation C-29}

\text{DOCUMENT: TFA: Area under legal classification of forests. Total Forest Area, was 40.04 in 1951 (GOI, 1994A).}
\[ FA\text{yr} = A\text{planted yr} \times 0.8 \quad \text{Equation C-30} \]

**DOCUMENT:** Assumed that 80% of the plantation on road, canal and other wastelands have been declared as protected forests.

\[ A\_\text{enc yr} = \text{av size of encroachment} \times \text{no encroachers yr} \quad \text{Equation C-31} \]

\[ A\_\text{div yr} = \text{div for infrastructure + other diversions} \quad \text{Equation C-32} \]

\[ \text{value of this burnt fertilizer} = \text{total fertilizer equi burnt} \times \text{fertilizer price} \times \text{Exc Rate} \quad \text{Equation C-33} \]

\[ \text{worth nonfood} = \text{nonfood} \times \text{world nonfood price} \times \text{Exc Rate} \quad \text{Equation C-34} \]

\[ \text{worth of food} = \text{food} \times \text{world food price} \times \text{Exc Rate} \quad \text{Equation C-35} \]

\[ \text{worth of IW} = \text{Rs worth of IW M} \times \text{Exc Rate} \quad \text{Equation C-36} \]

\[ \text{worth of IX} = \text{Rs worth of IX X} \times \text{Exc Rate} \quad \text{Equation C-37} \]

\[ \text{agY} = 500.6984933 + 2723.716449/(1+\text{EXP}(-\text{TIME}-2002.01653358)/15.01653358)) \quad \text{Equation C-38} \]

**DOCUMENT:** This is the trend function value expressed in kg/ha. The data source: Agricultural statistics at a glance 1994. p8. GOI.

\[ \text{Agpgoal} = \text{Fpgoal} + \text{nonfoodgoal} \quad \text{Equation C-39} \]

\[ \text{ainc 0fa} = 500 \quad \text{Equation C-40} \]

**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 Cell, Ministry of Environment and Forests) (Srivastava 1994).

\[ \text{ainc Dfa} = 1000 \quad \text{Equation C-41} \]

**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 Cell, Ministry of Environment and Forests) (Srivastava 1994).

\[ \text{ainc Mnfa} = 700 \quad \text{Equation C-42} \]

**DOCUMENT:** This is in kg/hectare/year based on the average mean increment of mangrove forest areas of different states. This average is the weighted average of the mangrove forest areas of different states in India (National Forest action Plan Cell, Ministry of Environment and Forests) Srivastava (1994).

\[ \text{area in ag} = \text{area in food} + \text{area in non food} \quad \text{Equation C-43} \]

\[ \text{area in non food} = 20 \times 10^6 \quad \text{Equation C-44} \]

**DOCUMENT:** This is in hectares. This figure has been estimated from using the area in agriculture and area in food production in 1991 (MOA, 1994).
On average the usable dry dung required per day to run a family biogas plan is 10 kg. (Tyner, 1978 p121). Therefore, per year requirement of dry dung for a family biogas unit is taken as 365*10 kg.

\[ \text{av\_size\_of\_encroachment} = 0.15 \ \text{Equation C-46} \]

This is in hectares.

\[ bgascon = 1.06 \ \text{Equation C-47} \]

This is the 1.06 cubic meter of gas available from 1 kg of cow dung. In (p 18, Chatterji, M. 1991)

\[ bgas\_burnt = bgascon*total\_dung\_burnt\_yr \ \text{Equation C-48} \]

\[ bgcuft\_available = total\_dung\_available*yield\_perkg\_of\_bg \ \text{Equation C-49} \]

This is the total biogas in cubic feet available from total dry dung in the country produced by the total standard livestock units per year. Bufferstock = 20*10^6*10^3 \ \text{Equation C-50} \]

About 20 million tons of buffer stock is maintained per annum.

\[ cost\_of\_planting\_ha\_yr = 5000 \ \text{Equation C-51} \]

This is the average cost of planting per hectare per year in Indian Rupees (Mukerji 1994).

\[ cost\_per\_plant = 6000 \ \text{Equation C-52} \]

On average the cost of a family biogas plant is in the range of Rs 5000-7000 in 1995. To have an approximate idea for investment on biogas in present times, Rs 6000 figure is used.

\[ CpcFW = (\text{Size}\_\text{R}\_\text{pop}\times RpcfWcons+\text{size}\_\text{U}\_\text{pop}\times UpcfWcons)/(\text{Size}\_\text{R}\_\text{pop}+\text{size}\_\text{U}\_\text{pop}) \ \text{Equation C-53} \]

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.

\[ div\_for\_infrastructure = 100000 \ \text{Equation C-55} \]

This is the average forest area diverted per year during the period 1981-1994 (Ministry of Environment And Forests, personnel communication by Mishra, 1994)

\[ dom\_food\_Xprice = 4.61 \ \text{Equation C-56} \]

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 (personnel communication by Bhatiya, 1994)

\[ dung\_fr\_burnt = 0.6 \ \text{Equation C-57} \]

60% of the collected is burnt (Singh, 1994)

\[ dung\_per\_lstk\_unit\_yr = 3\times 365 \ \text{Equation C-58} \]

This is the fresh manure production per head in kg/year (Chatterji, M. 1981 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 500BTU/ft^3. The maximum amount of biogas in case of cow manure is 1.06m^3/kg. Tyner (1978) observed that in India, per day dry dung is 3kg (Tyner, 1978, p 117).
\[ D_{FA} = TFA \times Fr_{D_{FA}} \text{ Equation C- 59} \]

\[ \text{equi}_{FW}\text{ waste} = \text{natural gas burnt and wasted} \times \text{FW per unit equivalent of nat gas} \text{ Equation C- 60} \]

\[ \text{Exc Rate} = 0.057 \text{ Equation C- 61} \]

**DOCUMENT:** The exchange rate of Indian 1RS=0.057US$ in 1990.(FAO,1992 pxli).

\[ fbmtocinibm = (FBM/INIT(FBM)) \times 100 \text{ Equation C- 62} \]

\[ \text{fertilizer eq of brunt dung} = 0.2 \]

**DOCUMENT:** 1 kg of dung = 0.2 kg of fertilizer. It is assumed that at least 20% of the total weight of dung can provide 1 unit weight of fertilizer (Singh 1988).

\[ \text{fertilizer price} = 4.843 \text{ Equation C- 63} \]

**DOCUMENT:** In 1990-91 Indian government imported 2.758 mton worth 13358.2 million Rs. The average price estimated is 4843 Rs per tonne. This is price in Rs/kg.

\[ \text{fodderreaper unit per yr} = 5 \times 365 \text{ Equation C- 64} \]

**DOCUMENT:** Rao(1994) estimated that 5kg of fodder is required per unit of standard livestock per day.

\[ \text{foodpc cons} = \text{net food available} \text{ Equation C- 65} \]

**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).

\[ \text{foodtrade} = (food_X \cdot food_M) \text{ Equation C- 66} \]

\[ \text{food}_M = 1000000000 \text{ Equation C- 67} \]

**DOCUMENT:** On an average about 1 million ton of food was imported per year during 1981-1993. This is expressed here in units kilograms(GOI, p 71, table 7.1 (a)).

\[ \text{food}_X = Q_{cef} \times fr \cdot \text{food}_XQ \text{ Equation C- 68} \]

\[ \text{food}_X \cdot \text{price ratio} = \text{world food}_X \cdot \text{price} / \text{dom food}_X \cdot \text{price} \text{ Equation C- 69} \]

\[ \text{Fgoal} = Q\text{food cons} + \text{foodtrade} + \text{Bufferstock} \text{ Equation C- 70} \]

\[ \text{FrFW subst} = 0 \text{ Equation C- 71} \]

**DOCUMENT:** Assumed that no fuel food substitution policy was implemented initially in 1951.

\[ \text{frncemtoe} = 2063.018239 + 1.538407196 \times \text{SQRT(TIME)} \times \text{LOGN(TIME)} - (-340.15252) \times \text{LOGN(TIME)} \text{ Equation C- 72} \]

**DOCUMENT:** The source of data has been Mehetre (1990).
This is observed that about 80% of the non commercial energy (NCE) is used in rural areas. The estimated value of this fraction has been obtained after fitting a trend function for the fraction of NCE in rural areas. The source of data has been Mehetre (1990).

\[ Fr_{\text{Aenc}_C\text{Agfp}} = .8 \]  Equation C- 74

DOCUMENT: About 80% of the forest area encroached is converted to agricultural farm lands, rest is for housing, village and farm paths. total

\[ \text{fr}_dung\_collected = .80 \]

DOCUMENT: 80% of the dung is collected (Tyner 1978, Singh 1980)

\[ \text{fr}_\text{lstk\_grazing\_in\_forests} = .3 \]  Equation C- 76

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

\[ Fr_{\text{Mn\_FA}} = .01 \]  Equation C- 77

DOCUMENT: Fraction value is estimated from the data given by the report on state of forest (FSI,1993).

\[ fr_{\text{ne\_mkt}} = 1- fr_{\text{mkt}} \]  Equation C- 78

DOCUMENT: 90% of the wood (Fuelwood and Industrial wood) is removed through non market channels (Dwivedi 1994, Khoshoo 1994). And including fodder, which is also mostly removed through non-market channels, therefore, the maximum fraction that enters market is taken as 10% of total removals.

\[ Fr_{\text{O\_FA}} = 1- Fr_{\text{D\_FA}}- Fr_{\text{Mn\_FA}} \]  Equation C- 79

\[ fr_{\text{pop\_R}} = \frac{46.5781936+43.44851635/(1+((\text{TIME}-1906.465094)/-116.333527)^2))/100 \]  Equation C- 80

DOCUMENT: 74% of the population is living in rural areas. A trend function of this fraction has be taken using historical data.

\[ fr_{\text{R\_Penitroching}} = .0017 \]

DOCUMENT: This is assumed that about 0.2% of the population flows to neighbouring forests and encroach forests (FSI 1987).

\[ fr_{\text{R\_pop\_dep\_fw}} = .80 \]  Equation C- 81

DOCUMENT: 80% of the rural population is dependent on fuel wood for their energy needs (Khoshoo, 1994)

\[ FWF_{\text{r\_ncecons}} = -5731778.1 +(-660.34748)*\text{SQR}(\text{TIME})*\text{LOGN}(\text{TIME})+462690.2968*\text{LOGN}(\text{TIME})+18541504/\text{LOGN}(\text{TIME}) \]  Equation C- 82

DOCUMENT: In general about 2/3 is the share of fuel wood in NCE expressed in Mtoe (Mehetre, 1990). 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.
2.1 million ton of Fuel wood is equivalent to 1 mtoc. 1111 million cubic meter of natural gas is also equivalent to 1 mtoc. Therefore, 1 cm3 of natural gas is equivalent to 2100/1111 kg of fuel wood (Mehetre, 1990, p 26, Table3.2).

\[ f_w \text{ equivalent of dung burnt} = 0.27392 \] Equation C- 84

DOCUMENT: 20 million tons of fuel wood would be needed to replace 73 million tons of air dry cow dung (Singh, 1988, p 91)

\[ IW_{cons} = IF((1.91607 \times 10^8 - 1.976 \times 10^7 \times \text{LOGn(TIME)}) + (-1.850993 \times 10^9) / \text{SQRT(TIME)}) \times 10^{-3} < 500000) \text{THEN}(500000) \text{ELSE}(1.91607 \times 10^8 - 1.976 \times 10^7 \times \text{LOGn(TIME)}) + (-1.850993 \times 10^9) / \text{SQRT(TIME)}) \times 10^{-3} \] Equation C- 85

DOCUMENT: A trend function for IW has been fitted by using data in Dileep (1994) The figures are expressed in metric tons.

\[ IW_M = 0.35 \times 10^6 \] Equation C- 86

DOCUMENT: The industrial wood imports are convrtd from their volume units into weight units by using a conversion factor of 1.38cum/MT. The values have been obtained from FAO(1992) and averaged over 1981-1992.

\[ IW_{traded} = (IW_X - IW_M) \] Equation C- 87

\[ IW_X = 1.3 \times 10^6 \] Equation C- 88

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 (thousand cubic meter)FAO Year Book(1992). These have been converted to weight units of metric ton by using a conversion factor of 1.38cum/mt and a average value has been used for simplicity

\[ \text{lstk}_no = (-268.83669 + 769.0181848 / (1 + ((\text{TIME} - 2103.119944) / 205.1950893)^2)) \times 10^6 \] Equation C- 89

DOCUMENT: This is the the fitted function for the standard livestock number in India. Data source: Rao (1994)

\[ Mn_FA = TFA \times Fr_{Mn_FA} \] Equation C- 90

\[ MtoeCMTfw = 2.16845 \times 10^6 \times 10^3 \] Equation C- 91

DOCUMENT: This conversion factor converts the value of fuel wood energy in terms of fuel wood weight in kg (Mehetre 1990,p26 Table 3.2). This is estimated using data from the National Energy Data Profile 1989. In World Energy Council (1990). London. U.K.

\[ \text{natural gas burnt and wasted} = 20 \times 10^6 \times 10^3 \] Equation C- 92

DOCUMENT: 19.27 cubic meter of natural gas is flared (GOI 1992, VIII FYP, p 168)
nbgppossible = bgcuf available/avbgreq family Equation C-93

NCEmtoe = TEMtoe *frncemtoe Equation C-94

netfoodavailable = IF(4080.88244+4567/(1+EXP(-(TIME-1942.673993)/7.763661484))*(365/1000)<75 THEN(75) ELSE(4080.88244+4567/(1+EXP(-(TIME-1942.673993)/7.763661484)))*(365/1000) Equation C-95

DOCUMENT: It is assumed that net per capita available food is consumed. This is in kg/year, so multiplied by 365 and divided by 1000.

nonfM = 50000*170 Equation C-96

DOCUMENT: About 50000 bales of 170 kg of cotton is imported (GOI, 1994A)

nonfoodgoal = nonfrade+ Qnonfcons Equation C-97

nonfcons = 50Equation C-98

DOCUMENT: It is assumed that about 50 kg of nonfood items are consumed per capita for example jute, cotton, rubber, and other fibres

nonfrade = (nonF-nonfM) Equation C-99

NonfXdom_price = 12.42Equation C-100

DOCUMENT: This is the price of cotton in Indian currency (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 Equation C-101

no_encroachers_yr = fr_RPen croching*Size_R_pop Equation C-102

no_FWdep_pop = (fr_R_pop_dep_fw*Size_R_pop+size_U_poor) Equation C-103

no_urban_that_could_replacefcons = equi_FW_waste/Upcfsfcons Equation C-104

other_diversions = 10000

DOCUMENT: This is the average value of diversion during 1980-1994 (MEF, 1994).

O_FA = TFA*Fr_O_FA Equation C-105

percchirrmtosbm = DERIVN(rrmtofbm,1)*100 Equation C-106

plantation_productivity = 4000 Equation C-107

DOCUMENT: Here, the unit is kg/ha/year. The estimated 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 in India.

plantation_time_goal = 30 Equation C-108

DOCUMENT: This is in years. The goal is to plant all available cultivable lands within 30 years.
planting_inv_yr = cost_ofplanting_ha_yr*Aplanted_yr  Equation C- 109

pop = (244.4955805+1091.685676/(1+EXP(-(TIME-1987.534894)/17.17780982)))*10^6  Equation C- 110

DOCUMENT: A trend was obtained using historical data, and was used to realistically account for the change in population. This has been done to demonstrate the affect of growing population on FBM&TFA over time.

POPG = (DERIVN(pop,1)/pop)*100  Equation C- 111

Qfood_cons = pop*foodpc_cons  Equation C- 112

Qnonfcons = nonfpcons*pop  Equation C- 113

Qtcsp = area_in_food*agfY  Equation C- 114

remfodder_yr = fodderreaper_unit_per_yr*fr_lstk_grazing_in_forests*lstk_no  Equation C- 115

Rem_FW_yr = (CpcFW)*(no_FWdep_pop)-(FrFWsubst)*(equi_FW_waste+total_equi_FW_burnt)  Equation C- 116

Rem_IW_yr = IWcons+IW_traded  Equation C- 117

Rem_NW_yr = remfodder_yr  Equation C- 118

Rem_W_yr = Rem_FW_yr+Rem_IW_yr  Equation C- 119

RnceCons = fnce_rural*NCEmtoe  Equation C- 120

DOCUMENT: This element is the product of fraction of nce used in rural areas and the total non commercial energy used in the country.

Rpcfcons = (TRFWC)/(Size_R_pop)  Equation C- 121

rrntoFbm = IF(FBM>0)THEN(Rem_yr/FBM)ELSE(1)  Equation C- 122

Rs_worth_of_IW_M = IW_M*Unit_value_of_IW_M_in_Rs  Equation C- 123

Rs_worth_of_IW_X = IW_X*Unit_value_of_IWX_in_Rs  Equation C- 124

shifting_cycle = 10  Equation C- 125

DOCUMENT: It assumed that average shifting cycle for forest encroachment is 10 years. This assumption is based on the observation of FSI in different states.
Size_R_pop = \text{fr}_\text{pop}_R \cdot \text{pop}\quad\text{Equation C- 126}

size_U_poor = (\text{U}_\text{pov}_\text{ratio}) \cdot (\text{size}_U_\text{pop})\quad\text{Equation C- 127}

size_U_pop = \text{pop} \cdot \text{Size}_R_\text{pop}\quad\text{Equation C- 128}

TE_{\text{mtoe}} = -6453.9132 + 3.343386432 \cdot \text{TIME}\quad\text{Equation C- 129}

DOCUMENT: This is the estimated trend function of total energy consumption. Total Energy is measured in million tonnes of oil equivalent. The value has been estimated by using data from Mehetre (1990).

\text{TFA}_{\text{tija}} = \text{TFA}_{\text{INIT}}(\text{TFA})\quad\text{Equation C- 130}

\text{thermal}_\text{energyeq} = \text{bgas}_\text{burnt} \cdot (500) \cdot (9)\quad\text{Equation C- 131}

\text{DOCUMENT:} 500 \text{ btu} of energy is obtained from 1 cubic feet of gas. It is converted to cubic meter by multiplying by 9.

\text{total}_\text{dung}_\text{available} = \text{dung}_\text{per lstk}_\text{unit}_\text{yr} \cdot \text{fr}_\text{dung}_\text{collected} \cdot \text{lstk}_\text{no}\quad\text{Equation C- 132}

\text{total}_\text{dung}_\text{burnt}_\text{yr} = \text{dung}_\text{fr}_\text{burnt} \cdot \text{total}_\text{dung}_\text{available}\quad\text{Equation C- 133}

\text{total}_\text{equi}_\text{FW}_\text{burnt} = \text{fw}_\text{equivalent}_\text{of}_\text{dung}_\text{burnt} \cdot \text{total}_\text{dung}_\text{burnt}_\text{yr}\quad\text{Equation C- 134}

\text{total}_\text{fertilizer}_\text{equi}_\text{burnt} = \text{fertilizer}_\text{eq}_\text{of}_\text{brunt}_\text{dung} \cdot \text{total}_\text{dung}_\text{burnt}_\text{yr}\quad\text{Equation C- 135}

\text{total}_\text{yearly}_\text{required}_\text{inv} = \text{cost}_\text{perfplant} \cdot \text{yearly}_\text{increment}_\text{in}_\text{no}\quad\text{Equation C- 136}

\text{TFRWC} = (\text{FWFr}_\text{ncecons}) \cdot (\text{rnceCons}) \cdot \text{MtoeCMTFw}\quad\text{Equation C- 137}

\text{Unit value of JWX in RS} = 2500\quad\text{Equation C- 138}

\text{DOCUMENT:} This is the 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 1992).

\text{Unit value of JW M in Rs} = 1800\quad\text{Equation C- 139}

\text{DOCUMENT:} The Rs values have been estimated from FAO (1992) Unit value estimates. A unit value of Industrial round wood imports has been given in $. Average value in Rs per cubic meter is taken to understand the interactive role of industrial imports and the exchange rate.

\text{Upcfwcons} = (0.384/1.38) \cdot 1000\quad\text{Equation C- 140}

\text{DOCUMENT:} Per capita consumption in Urban areas is expressed in kg per year. It has been estimated from the figures of National Forestry Action Plan (Ministry of Environment and Forests, NFAP Cell, India). Conversion factor is 1.38 cum/mt (FAO 1992, p xvii).

\text{U_pov_ratio} = (-541760.87 + 62899.488 \cdot \text{LOGN(TIME)} + 1.2740347 \cdot 10^8 \cdot \text{TIME}) / 100\quad\text{Equation C- 141}

\text{DOCUMENT:} This is the trend in urban poverty ratio and is estimated by the planning commission report figures on proportion and number of poor (GOI,1993,pp 54-58). The equation expresses the trend in percentages. Therefore, to express as a fraction the equation is divided by 100.
**worldnonfXprice = 38.53 Equation C- 142**

**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 Equation C- 143**

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

\[ w_{t\_prod\_ha\_yr} = (a_{inc}\_D\_fa*D\_FA + a_{inc}\_0\_fa*O\_FA + a_{inc}\_Mn\_fa*Mn\_FA)/(D\_FA + Mn\_FA + O\_FA) \]

*Equation C- 144*

\[ \text{yearly\_increment\_in\_no} = \text{DERIVN}(\text{nbgpsposible,1}) \]

*Equation C- 145*

**yield\_perkg\_of\_bg = 6.4**

**DOCUMENT:** This is the yield of biogas in cubic feet per kg. of dry dung Tyner (1978, P121).

\[ \text{fremkt} = \text{GRAPH}(\text{percen chin\_av\_fbmprice}) \]

*Equation C- 147*

\[(0.00, 0.115), (10.0, 0.09), (20.0, 0.075), (30.0, 0.07), (40.0, 0.065), (50.0, 0.065), (60.0, 0.06), (70.0, 0.06), (80.0, 0.055), (90.0, 0.05), (100, 0.05)\]

**DOCUMENT:** This is observed that with the percentage increase in average FBM price, the offences increases. And therefore, the fraction of FBM not entering market channel also increases, resulting in a reduction of the fraction entering through legal market channel. More than 90% of FBM in India is removed through non-market channels.

\[ \text{Fr\_D\_FA} = \text{GRAPH}(\text{fr\_ne\_mkt}) \]

*Equation C- 148*

\[(0.00, 0.99), (0.1, 0.96), (0.2, 0.93), (0.3, 0.89), (0.4, 0.855), (0.5, 0.82), (0.6, 0.78), (0.7, 0.73), (0.8, 0.675), (0.9, 0.615), (1, 0.585) \]

**DOCUMENT:** It is assumed that when FBM flow through only market channels there is no illegal cutting of forests, and the dense forest fraction is well protected to an extent of 99% of total dense forests. However, with the increase in flow of FBM through non-market channels, the fraction reduces. However the present fraction of dense forest is 60% FSI (1993), and the present outflow through non-market channel is 90%, so if 100% of FBM flows through non-market channel, the fraction of dense forest value can be assumed to be less than 60%, here 58% is assumed.

\[ \text{fr\_food\_XQ} = \text{GRAPH}(\text{food\_X\_price\_ratio}) \]

*Equation C- 149*

\[(0.00, 0.0015), (0.2, 0.0025), (0.4, 0.003), (0.6, 0.004), (0.8, 0.005), (1, 0.005), (1.2, 0.0055), (1.4, 0.0055), (1.6, 0.0055), (1.8, 0.006), (2.0, 0.0065)\]

**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 to a maximum value of 2. This means that due to trade the world price just can be double of the domestic prices. This range was assumed on basis of the historical price ratio of the major food items such as rice and wheat.

\[ \text{inv\_allocated} = \text{GRAPH}(\text{percen chin\_av\_fbmprice}) \]

*Equation C- 150*

\[(0.00, 8e+009), (10.0, 8.7e+009), (20.0, 9.4e+009), (30.0, 1e+010), (40.0, 1.1e+010), (50.0, 1.2e+010), (60.0, 1.2e+010), (70.0, 1.3e+010), (80.0, 1.4e+010), (90.0, 1.4e+010), (100, 1.5e+010)\]

**DOCUMENT:** In India, a positive relationship between the average FBM price changes and the investment allocated to the forestry sector is not observed. However, to incorporate neoclassical
conventional negative loop argument, it is assumed that with the increase in average price, the allocation of investment for forest plantation increases. The range of allocation is 8 billion to 15 billion Rs. Alternatively an average value for the planting investment per year can be used.

\[
\text{nonFX} = \text{GRAPH(nonFXprice\_ratio)}
\]
\[
(0.00, 8.5e+006), (0.2, 1.1e+007), (0.4, 1.3e+007), (0.6, 1.5e+007), (0.8, 1.7e+007), (1, 1.9e+007), (1.20, 2e+007), (1.40, 2.1e+007), (1.60, 2.3e+007), (1.80, 2.4e+007), (2.00, 2.5e+007) \text{ Equation C-151}
\]

\[
\text{percentin\textunderscore av\textunderscore fbmprice} = \text{GRAPH(percentinrmtofbm)}
\]
\[
(0.00, 0.00), (10.0, 10.0), (20.0, 20.0), (30.0, 30.0), (40.0, 40.0), (50.0, 50.0), (60.0, 60.0), (70.0, 70.0), (80.0, 80.0), (90.0, 90.0), (100, 100) \text{ Equation C-152}
\]
Appendix III

Elements of Forest Sector with Symbols

Area diverted (A div.)
Area diverted per year (A div. yr)
Area planted per year (A planted yr)
Area encroached (Aenc)
Area encroached per year (A enc yr)
Area planted (Aplanted)
Average size of encroachment (av. size of encroachment)
Change in Forest Area (CF FA)
Dense Forest Area (DFA)
Diversion for infrastructure (div. for infrastructure)
Forest area increase (FAI)
Forest Biomass (FBM)
Fraction of Open Forest Area (Fr OFA)
Fraction of Dense Forest Area (Fr DFA)
Fraction of FBM entering market (Fr emkt)
Fraction of FBM not entering market (Fr nemkt)
Total forest area to initial forest area (TFA ini)
Ratio of removal to FBM (rmtofbm)
Percentage of change in ratio of removal to FBM (pechsrmtolfbm)
Plantation Productivity
Fraction of Mangrove Forest Area (Fr MnFA)
Mangrove Forest Area (MnFA)
Mean annual increment of dense forest area (ainc DFA)
Mean annual increment of Mangrove forest area (wazzu ainc Mnfa)
Mean annual increment of open forest area (ainc Ofa)
No. Of encroachers per year (no encroacher yr)
Open Forest Area (OFA)
Other diversions (other diversions)
Production per year (Prod yr)
Removal of Non wood per year (Rem NW YR)
Removal of wood per year (Rem W YR)
Removal per year (Rem yr)
Total Forest Area (TFA)
Weighted productivity per year (wt prod ha yr)

of Agriculture Sector with Symbols

Agricultural food production yield
Agriculture production goal (Agpgoa1)
Area encroached converted for agriculture (Aenc cag)
Area in agriculture production (area in ag)
Area in food production (area in food)
Area in non food production (area in nonfood)
Area planted per year (A planted yr)
Buffer stock of food (Buffer stock)
Cost of planting ha/year (cost of planting ha yr)
Cultivable Lands (Cultivable lands)
Development time (Dev time)
Dollar worth of food exports ($worth of food X)
Dollar worth of nonfood exports ($worth nonfood X) Elements
Domestic Food Exports price (dom food X price)
Domestic Non-food Exports price (non f food price wazzu)
Exchange rate of Indian Rs in US $ (Exc. rate)
Food consumption per capita (food pc cons)
Food Exports price ratio(food X price ratio)
Food exports quantity (food X)
Food imports quantity (food M)
Food production goal (Fpg goal)
Food Trade (food trade)
Fraction of encroached area converted for agricultural food production (Fr Aenc C Agfp)
Fraction of food quantity exported (fr food XQ)
Increase in Reported area (rein)
Investment allocated for forest plantation (inv allocated)
Land development rate (l/yr)
Net food available
Non Food exports quantity (nonfood X)
Non food per capita consumption (nonfood cons)
Non food production goal (nonfood goal)
Non- Food Trade (nonfood trade)
Non-Food Exports price ratio (nonfood X price ratio)
Non-food imports quantity (non food M)
Plantation time goal (plantation time goal)
Planting investment /year (planting inv /yr)
Population (Pop)
Quantity of current food production (Qfood)
Quantity of food consumption (Qfood cons)
Quantity of nonfood consumption (Qnonfood cons)
Shifting cycle
World Food Exports price (world food X price)
World nonfood Exports price (world non X price)

Elements of Socio-Economic Sector with Symbols

Consumption per capita of fuelwood (CpcFW)
Converter for million tons of oil equivalent to million tons of fuel wood (Mtoe C MTFw)
Dollar worth of industrial wood exports (Swroth of IWX)
Dollar worth of industrial wood imports (Swroth of IWM)
Fraction of Fuelwood Substitution (Fr FW Subs)
Fraction of population residing in rural areas (fr pop R)
Fraction of rural Population encroaching forests (fr RP encroaching)
Industrial wood Consumption per year (IWCons)
Industrial wood Export Quantity (IW X)
Industrial wood Import Quantity (IWM)
Industrial wood trade (IW trade)
Number of Fuelwood dependent population (no FW dep pop)
Population growth (POPGR)
Fraction of Rural Population dependent on fuelwood (fr Rpop dep fw)
Removal of Fuel wood per year (Rem FW yr)
Removal of Industrial wood per year (Rem IW YR)
Rupees worth of industrial wood exports (Rs worth of IWX)
Rupees worth of industrial wood imports (Rs worth of IWM)
Size of Rural Population (Size R pop)
Size of Urban Poor (size U poor)
Size of Urban Population (size of Upop)
Unit value of industrial wood exports in Rs
Unit value of industrial wood imports in Rs.
Urban poverty ratio (U pov ratio)

Elements of Energy Sector with Symbols

Average Cost per million tons of alternate energies (cost per mtoe alt energy)
Average family biogas dugh requirement (avbregp/family)
Cost per family biogas plant (cost perfplant)
Equivalent fuel wood wasted (equi FW waste)
Equivalent of fw wasted by flaring natural gas (equi FW waste)
Fraction of total energy consumed as non-commercial energy(fncc mtoe)
Fraction of non commercial energy consumed in rural areas (fncc rural)
Fraction of non-commercial energy in MTOE (fnccmtoe)
Fuelwood as fraction of non-commercial energy consumption (FWFr ncc cons)
Fuelwood perunit equivalent of natural gas (Fwperunit equivalent of nat gas)
Investment on alternate energies for rural areas (inv on alt energy for rural area)
Million tons of oil equivalent converted in million tons of FW (MtoeCMTFw)
Natural gas burnt and wasted
No of urban people that could replace their FW Consumption..
Non commercial energy consumption in million tons of oil equivalent (NCEmtoe)
Number of biogas possible (nhbpossible)
Rural consumption of non commercial energy (RcncConsumption)
Rural per capita fuelwood consumption (Rpcmfwcons)
Total biogas available per year in cubic feet (buccf available)
Total consumption of fuelwood in rural areas (TRFWC)
Total energy consumption in million tons (TE mtoe)
Urban per capita fuelwood consumption (Upcmfwcons)
**Elements of Livestock Sector with Symbols**

- Biogas burnt (bgas burnt)
- Biogas conversion of dung (bgascon)
- Biogas conversion value of one kilogram of cow dung
- Dollar value of burnt fertilizer ($value of burnt fertilizer)
- Dung fraction burnt (dung fr burnt)
- Dung per unit of live stock per year (dung per lstock per yr)
- Exchange rate
- Fertilizer equivalent of burnt dung (fertilizer equiv burnt fertilizer)
- Fertilizer price in Rs (fertilizer price)
- Fodder required perunit of livestock per year (fodder req per unit yr)
- Fraction of dung collected (fr dung collected)
- Fraction of live stock grazing in forests (fr lstock grazing in forests)
- Fuel wood equivalent of dung burnt (fw equivalent of dung burnt)
- Livestock number (lstock no)
- Removal of fodder per year (remfodder yr)
- Thermal energy equivalent of biogas (thermal energy eq)
- Total dung available
- Total dung burnt per year (total dung burnt yr)
- Total equivalent fuelwood burnt (total equi FW burnt)
- Total equivalent of fuelwood burnt
- Total fertilizer equivalent burnt (total fertilizer equiv burnt)

**Elements of the System with Symbols**

- Agricultural food production yield
- Agriculture production goal (Agpgoyal)
- Area diverted (A div.)
- Area diverted per year (A div. yr)
- Area planted per year (A planted yr)
- Area encroached (Aenc)
- Area encroached converted for agriculture (Aenc cag)
- Area encroached per year (A enc yr)
- Area in agriculture production (area in ag)
- Area in food production (area in food)
- Area in non food production (area in nonfood)
- Area planted (Aplanted)
- Area planted per year (A planted yr)
- Average Cost per million tons of alternate energies (cost per mtce alt energy)
- Average family biogas dung requirement (avbgreq/family)
- Average size of encroachment (av. size of encroachment)
- Biogas burnt (bgas burnt)
- Biogas conversion of dung (bgascon)
- Biogas conversion value of one kilogram of cow dung
- Buffer stock of food (Buffer stock)
- Change in Forest Area (CH FA)
- Consumption per capita of fuelwood (CpcFW)
- Converter for million tons of oil equivalent to million tons of fuel wood (Mtoe C MTfw)
- Cost of planting ha./year (cost of planting ha yr)
- Cost per family biogas plant (cost periplant)
- Cultivable Lands (Cultivable lands)
- Dense Forest Area (DFA)
- Development time (Dev time)
- Diversion for infrastructure (div. for infrastructure)
- Dollar value of burnt fertilizer ($value of burnt fertilizer)
- Dollar worth of food exports ($worth of Food X)
- Dollar worth of industrial wood exports ($worth of IWX)
- Dollar worth of industrial wood imports ($worth of IWM)
- Dollar worth of nonfood exports ($worth nonfood X)
- Domestic Food Exports price (dom food X price)
- Domestic Non-food Exports price (nonf X dom price)
- Dung fraction burnt (dung fr burnt)
- Dung per unit of live stock per year (dung per lstock per yr)
- Equivalent fuel wood wasted (equi FW waste)
- Equivalent of fw wasted by flaring natural gas (equi FW waste)
- Exchange rate
- Exchange rate of Indian Rs in US $ (Exc. rate)
- Fertilizer equivalent of burnt dung (fertilizer equiv burnt fertilizer)
- Fertilizer price in Rs (fertilizer price)
Fodder required per unit of livestock per year (fodder reaper unit yr)
Food consumption per capita (food pc cons)
Food Exports price ratio(food X price ratio)
Food exports quantity (food X)
Food imports quantity (food M)
Food production goal (Fpggoal)
Food Trade (food trade)
Forest area increase (FAl)
Forest Biomass (FBM)
Fraction of Open Forest Area (Fr OFA)
Fraction of Fuelwood Substitution (Fr FW Subs)
Fraction of total energy consumed as non-commercial energy(frome mtoe)
Fraction of Dense Forest Area (FrDFA)
Fraction of dung collected (fr dung collected)
Fraction of encroached area converted for agricultural food production(Fr Aenc C Agfp)
Fraction of FBM entering market (fr emkt)
Fraction of FBM not entering market (fr nemkt)
Fraction of food quantity exported (fr food XQ)
Fraction of livestock grazing in forests (fr livestock grazing in forests)
Fraction of Mangrove Forest Area (Fr MnFA)
Fraction of non-commercial energy consumed in rural areas (frnce rural)
Fraction of non-commercial energy in MTOE (frncemtoe)
Fraction of population residing in rural areas (fr pop R)
Fraction of rural Population encroaching forests (fr RP encroaching)
Fuel wood equivalent of dung burnt (fw equivalent of dung burnt)
Fuelwood as fraction of non-commercial energy consumption (FWFr rce cons)
Fuelwood per unit equivalent of natural gas (Fwperunit equivalent of nat gas)
Increase in Reported area (roin)
Industrial wood Consumption per year (IWCons)
Industrial wood Export Quantity (IW X)
Industrial wood Import Quantity (IWM)
Industrial wood trade (IW trade)
Investment allocated for forest plantation (inv allocated)
Investment on alternate energies for rural areas (inv on alt energy for rural area)
Land development rate (l dr)
Livestock number (lakd no)
Mangrove Forest Area (MnFA)
Mean annual increment of dense forest area (ainc Dfa)
Mean annual increment of Mangrove forest area (ainc Mnfa)
Mean annual increment of open forest area (ainc Ofa)
Million tons of oil equivalent converted in million tons of FW (MtoeCMTfw)
Natural gas burnt and wasted
Net food available
No of urban people that could replace their FW Consumption.
No. Of encroachers per year (no encroacher yr)
Non commercial energy consumption in million tons of oil equivalent (NCEmtoe)
Non Food exports quantity (nonfood X)
Non food per capita consumption (nonpcons)
Non food production goal (nonfood goal)
Non- Food Trade (nonfood trade)
Non-Food Exports price ratio( nonfood X price ratio)
Nonfood imports quantity (non food M)
Number of biogas possible (mbgpossible)
Number of Fuelwood dependent population (no FW dep pop)
Open Forest Area (OFA)
Other diversions (other diversions)
Percentage of change in ratio of removal to FBM (percchirmrmttofbm)
Plantation Productivity
Plantation time goal (Plantation time goal)
Planting investment /year (planting inv yr)
Population (Pop)
Population growth (POPGR)
Production per year (Prod yr)
Quantity of current food production (Qtofp)
Quantity of food consumption (Qfood cons)
Quantity of nonfood consumption (Qnonfcns)
ration of Rural Population dependent on fuelwood (fr Rpop dep fw)
Ratio of removal to FBM (rmttofbm)
Removal of fodder per year (remfodder yr)
Removal of Fuel wood per year (Rem FW yr)
Removal of Industrial wood per year (Rem IW YR)
<table>
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<tr>
<th>Dataset Description</th>
<th>Unit</th>
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<tbody>
<tr>
<td>Removal of Non wood per year (Rem NW YR)</td>
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<tr>
<td>Removal of wood per year (Rem W YR)</td>
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<tr>
<td>Removal per year (Rem yr)</td>
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<tr>
<td>Rupees worth of industrial wood exports (Rs worth of IWX)</td>
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<tr>
<td>Rupees worth of industrial wood imports (Rs worth of IWM)</td>
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<tr>
<td>Rural consumption of non commercial energy (RnceConsumption)</td>
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<td>Rural per capita fuelwood consumption (Rpcfwcons)</td>
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<tr>
<td>Shifting cycle</td>
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<td>Size of Rural Population (Size R pop)</td>
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<td>Size of Urban Poor (size U poor)</td>
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<td>Size of Urban Population (size of Upop)</td>
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<tr>
<td>Thermal energy equivalent of biogas (thermal energy eq)</td>
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<tr>
<td>Total biogas available per year in cubic feet (bcuft available)</td>
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<tr>
<td>Total consumption of fuelwood in rural areas (TRFWC)</td>
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<tr>
<td>Total dung available</td>
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<td>Total dung burnt per year (total dung burnt yr)</td>
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<tr>
<td>Total energy consumption in million tons (TE mtoe)</td>
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<tr>
<td>Total equivalent fuelwood burnt (total equi FW burnt)</td>
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<tr>
<td>Total equivalent of fuelwood burnt</td>
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<tr>
<td>Total fertilizer equivalent burnt (total fertilizer equi burnt)</td>
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<tr>
<td>Total Forest Area (TFA)</td>
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<tr>
<td>Total forest area to initial forest area (TFAinitfa)</td>
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<tr>
<td>Unit value of industrial wood exports in Rs</td>
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<td></td>
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<tr>
<td>Urban per capita fuelwood consumption (Upcfwcons)</td>
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<tr>
<td>Unit value of industrial wood imports in Rs</td>
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<tr>
<td>Urban poverty ratio (U pov ratio)</td>
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<tr>
<td>Weighted productivity per year (wt prod ha yr)</td>
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</tr>
<tr>
<td>World Food Exports price (world food X price)</td>
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<tr>
<td>World nonfood Exports price (world nonf X price)</td>
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## Appendix IV

### Table A1: Land Use Trend in India (Million Hectares)

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</thead>
<tbody>
<tr>
<td>1. Geographical Area</td>
<td>328.73</td>
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<td>11. Reporting Area</td>
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<tr>
<td>1. Forests</td>
<td>284.32</td>
<td>298.46</td>
<td>303.76</td>
<td>304.15</td>
<td>305.02</td>
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<tr>
<td>2. Not Available for cultivation</td>
<td>40.48</td>
<td>54.05</td>
<td>63.91</td>
<td>67.47</td>
<td>67.99</td>
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<tr>
<td>2a. Area under non agricultural use</td>
<td>47.52</td>
<td>50.75</td>
<td>44.54</td>
<td>39.62</td>
<td>40.88</td>
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<tr>
<td>2b. Barren and Unculturable land</td>
<td>38.16</td>
<td>35.91</td>
<td>28.16</td>
<td>19.96</td>
<td>19.66</td>
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<tr>
<td>3. Other uncultivated land excluding fallow land</td>
<td>49.45</td>
<td>37.64</td>
<td>35.06</td>
<td>32.31</td>
<td>30.51</td>
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<tr>
<td>3b. Miscellaneous tree crops and groves</td>
<td>19.83</td>
<td>4.46</td>
<td>4.30</td>
<td>3.60</td>
<td>3.70</td>
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<tr>
<td>3c. Culturable waste</td>
<td>22.94</td>
<td>19.21</td>
<td>17.50</td>
<td>16.74</td>
<td>15.01</td>
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<tr>
<td>4. Fallow lands</td>
<td>28.12</td>
<td>22.82</td>
<td>19.88</td>
<td>24.75</td>
<td>23.00</td>
</tr>
<tr>
<td>4a. Fallow lands other than current fallow lands</td>
<td>17.44</td>
<td>11.18</td>
<td>8.76</td>
<td>9.92</td>
<td>9.59</td>
</tr>
<tr>
<td>4b. Current Fallows</td>
<td>10.68</td>
<td>11.64</td>
<td>11.12</td>
<td>14.83</td>
<td>13.81</td>
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<tr>
<td>5. Net area sown</td>
<td>118.75</td>
<td>133.20</td>
<td>140.27</td>
<td>140.90</td>
<td>142.24</td>
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Table A2: Elements Of Forest Sector

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<tr>
<th>Stocks</th>
<th>Flows</th>
<th>Converters</th>
</tr>
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<tbody>
<tr>
<td>1.  Total Forest Area (TFA)</td>
<td>1. Change in Forest Area (CH FA)</td>
<td>1. Average size of encroachment (av. size of encroachment)</td>
</tr>
<tr>
<td>2.  Area encroached (Aenc)</td>
<td>2. Area encroached per year (A enc yr)</td>
<td>2. No. Of encroachers per year (no encroacher yr)</td>
</tr>
<tr>
<td>3.  Area diverted (A div.)</td>
<td>3. Area diverted per year (A div. yr)</td>
<td>3. Diversion for infrastructure (div. for infrastructure)</td>
</tr>
<tr>
<td>4.  Area planted (A planted)</td>
<td>4. Area planted per year (A planted yr)</td>
<td>4. Other diversions (other diversions)</td>
</tr>
<tr>
<td>5.  Forest Biomass (FBM)</td>
<td>5. Production per year (Prod yr)</td>
<td>5. Dense Forest Area (DFA)</td>
</tr>
<tr>
<td></td>
<td>6. Removal per year (Rem yr)</td>
<td>6. Open Forest Area (OFA)</td>
</tr>
<tr>
<td></td>
<td>7. Forest area increase (FAI)</td>
<td>7. Mangrove Forest Area (MnFA)</td>
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<tr>
<td></td>
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<td>8. Mean annual increment of dense forest area (inc DFA)</td>
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<td>9. Mean annual increment of open forest area (inc OFA)</td>
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<td></td>
<td></td>
<td>10. Mean annual increment of Mangrove forest area (inc Mnfa)</td>
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<td></td>
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<td>11. Fraction of Dense Forest Area (FrDFA)</td>
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<td>12. Fraction of Open Forest Area (Fr OFA)</td>
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<td>13. Fraction of Mangrove Forest Area (Fr MnFA)</td>
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<td>14. Weighted productivity per year (wt prod ha yr)</td>
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<td>15. Removal of Non wood per year (Rem NW YR)</td>
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<td>16. Removal of wood per year (Rem W YR)</td>
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<td></td>
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<td>17. Fraction of FBM entering market (fr entmk)</td>
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<td>18. Fraction of FBM not entering market (fr nemkt)</td>
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<td>19. Total forest area to initial forest area (TFAinitfa)</td>
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<td></td>
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<td>20. Ratio of removal to FBM (rmttofbm)</td>
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<td></td>
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<td>21. Percentage of change in ratio of removal to FBM (perechinrmttofbm)</td>
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<tr>
<td></td>
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<td>22. Plantation Productivity</td>
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## Table A3: Elements Of Agricultural Sector

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

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<table>
<thead>
<tr>
<th>Table A4: Elements Of Socio-Economic Sector</th>
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</thead>
<tbody>
<tr>
<td><strong>Converters</strong></td>
</tr>
<tr>
<td>1. Removal of Fuel wood per year (Rem FW yr)</td>
</tr>
<tr>
<td>2. Number of Fuelwood dependent population (no FW dep pop)</td>
</tr>
<tr>
<td>3. Size of Urban Poor (size U pop)</td>
</tr>
<tr>
<td>4. Size of Urban Population (size of Upop)</td>
</tr>
<tr>
<td>5. Fraction of Rural Population dependent on fuelwood (fr Rpop dep fw)</td>
</tr>
<tr>
<td>6. Size of Rural Population (Size R pop)</td>
</tr>
<tr>
<td>7. Fraction of population residing in rural areas (fr pop R)</td>
</tr>
<tr>
<td>8. Urban poverty ratio (U pov ratio)</td>
</tr>
<tr>
<td>9. Population growth (POPGR)</td>
</tr>
<tr>
<td>10. Fraction of rural Population encroaching forests (fr RP encroaching)</td>
</tr>
<tr>
<td>11. Fraction of Fuelwood Substitution (Fr FW Subs)</td>
</tr>
<tr>
<td>12. Consumption per capita of fuelwood (CpcFW)</td>
</tr>
<tr>
<td>13. Removal of Industrial wood per year (Rem IW YR)</td>
</tr>
<tr>
<td>14. Industrial wood Consumption per year (IWCons)</td>
</tr>
<tr>
<td>15. Industrial wood trade (IW trade)</td>
</tr>
<tr>
<td>16. Industrial wood Export Quantity (IW X)</td>
</tr>
<tr>
<td>17. Industrial wood Import Quantity (IWM)</td>
</tr>
<tr>
<td>18. Rupees worth of industrial wood exports (Rs worth of IWX)</td>
</tr>
<tr>
<td>19. Dollar worth of industrial wood exports ($worth of IWX)</td>
</tr>
<tr>
<td>20. Rupees worth of industrial wood imports (Rs worth of IWM)</td>
</tr>
<tr>
<td>21. Dollar worth of industrial wood imports ($worth of IWM)</td>
</tr>
<tr>
<td>22. Unit value of industrial wood exports in Rs</td>
</tr>
<tr>
<td>23. Unit value of industrial wood imports in Rs.</td>
</tr>
<tr>
<td>24. Converter for million tons of oil equivalent to million tons of fuel wood (Mtoe C MTFw)</td>
</tr>
</tbody>
</table>
Table A5: Energy Sector

| Converters                                                                                   |
|                                                                                           |
| 1. Average family biogas dung requirement (avbgreq/family)                                  |
| 2. Total biogas available per year in cubic feet (bgcuft available)                         |
| 3. Cost per family biogas plant (cost perplant)                                           |
| 4. Equivalent of fw wasted by flaring natural gas (equi FW waste)                         |
| 5. Fraction of non-commercial energy in MTOE (frncmtoe)                                   |
| 6. Fraction of non commercial energy consumed in rural areas (frnce rural)                  |
| 7. Fuelwood as fraction of non-commercial energy consumption (FWFr nee cons)               |
| 8. Fuelwood perunit equivalent of natural gas (Fwpereunit equivalent of nat gas)          |
| 9. Million tons of oil equivalent converted in million tons of FW (MtoeCMTfw)              |
| 10. Natural gas burnt and wasted                                                          |
| 11. Number of biogas possible (nbgpossible)                                                |
| 12. Non commercial energy consumption in million tons of oil equivalent (NCEmtoe)           |
| 13 No of urban people that could replace their FW Consumption.                              |
| 14. Rural consumption of non commercial energy (RncConsumption)                            |
| 15. Total energy consumption in million tons (TE mtoc)                                      |
| 16. Rural percapita fuelwood consumption (Rpcfwcwons)                                      |
| 17. Urban percapita fuelwood consumption (Upcfwcons)                                       |
| 18. Total consumption of fuelwood in rural areas (TRFWC)                                    |
| 19. Fraction of total energy consumed as non-commercial energy(france mtoc)                |
| 20. Average Cost per million tons of alternate energies (cost per mtoc alt energy)         |
| 21. Investment on alternate energies for rural areas (inv on alt energy for rural area)     |
| 22. Equivalent fuel wood wasted (equi FW waste)                                            |
Table A6: Elements Of Livestock Sector

<table>
<thead>
<tr>
<th>№</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Removal of fodder per year (remfodder yr)</td>
</tr>
<tr>
<td>2.</td>
<td>Fraction of live stock grazing in forests (fr lsk grazing in forests)</td>
</tr>
<tr>
<td>3.</td>
<td>Fodder required per unit of livestock per year (fodder req per unit yr)</td>
</tr>
<tr>
<td>4.</td>
<td>Livestock number (lsk no)</td>
</tr>
<tr>
<td>5.</td>
<td>Dung per unit of live stock per year (dung per lsk per yr)</td>
</tr>
<tr>
<td>6.</td>
<td>Total dung available</td>
</tr>
<tr>
<td>7.</td>
<td>Fraction of dung collected (fr dung collected)</td>
</tr>
<tr>
<td>8.</td>
<td>Dung fraction burnt (dung fr burnt)</td>
</tr>
<tr>
<td>9.</td>
<td>Total dung burnt per year (total dung burnt yr)</td>
</tr>
<tr>
<td>10.</td>
<td>Fuel wood equivalent of dung burnt (fw equivalent of dung burnt)</td>
</tr>
<tr>
<td>11.</td>
<td>Total equivalent fuelwood burnt (total equi FW burnt)</td>
</tr>
<tr>
<td>12.</td>
<td>Biogas conversion of dung (bgascon)</td>
</tr>
<tr>
<td>13.</td>
<td>Biogas burnt (bgas burnt)</td>
</tr>
<tr>
<td>14.</td>
<td>Thermal energy equivalent of biogas (thermal energy eq)</td>
</tr>
<tr>
<td>15.</td>
<td>Total fertilizer equivalent burnt (total fertilizer equi burnt)</td>
</tr>
<tr>
<td>16.</td>
<td>Fertilizer equivalent of burnt dung (fertilizer equi burnt fertilizer)</td>
</tr>
<tr>
<td>17.</td>
<td>Fertilizer price in Rs (fertilizer price)</td>
</tr>
<tr>
<td>18.</td>
<td>Dollar value of burnt fertilizer ($value of burnt fertilizer)</td>
</tr>
<tr>
<td>19.</td>
<td>Biogas conversion value of one kilogram of cow dung</td>
</tr>
<tr>
<td>20.</td>
<td>Exchange rate</td>
</tr>
<tr>
<td>21.</td>
<td>Total equivalent of fuelwood burnt</td>
</tr>
</tbody>
</table>
## Appendix V

**Table A7: Projected Values of Estimated Dynamic Functions**

<table>
<thead>
<tr>
<th>Years</th>
<th>pop,774,200</th>
<th>fr pop R</th>
<th>TE (mtoe)</th>
<th>fnce(mtoe)</th>
<th>fnce rural</th>
<th>lstk</th>
<th>agfY (Kg/ha)</th>
<th>netfood available (Kg/Yearwazzu)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1951</td>
<td>360,774,200</td>
<td>0.84</td>
<td>69.03</td>
<td>0.8</td>
<td>0.84</td>
<td>227,435,522</td>
<td>588.60 98</td>
<td>75</td>
</tr>
<tr>
<td>1956</td>
<td>394,656,584</td>
<td>0.83</td>
<td>85.75</td>
<td>0.76</td>
<td>0.84</td>
<td>239,083,057</td>
<td>622.18  75</td>
<td></td>
</tr>
<tr>
<td>1961</td>
<td>436,468,809</td>
<td>0.82</td>
<td>102.47</td>
<td>0.72</td>
<td>0.84</td>
<td>250,055,873</td>
<td>667.24  75</td>
<td></td>
</tr>
<tr>
<td>1966</td>
<td>486,925,806</td>
<td>0.8</td>
<td>119.18</td>
<td>0.69</td>
<td>0.84</td>
<td>262,786,618</td>
<td>727.56  98.72</td>
<td></td>
</tr>
<tr>
<td>1971</td>
<td>546,197,497</td>
<td>0.79</td>
<td>135.9</td>
<td>0.66</td>
<td>0.83</td>
<td>274,802,443</td>
<td>807.11  135.14</td>
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</tr>
<tr>
<td>1976</td>
<td>613,661,227</td>
<td>0.78</td>
<td>152.62</td>
<td>0.63</td>
<td>0.82</td>
<td>286,896,680</td>
<td>909.98  154.95</td>
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</tr>
<tr>
<td>1981</td>
<td>687,746,204</td>
<td>0.77</td>
<td>169.34</td>
<td>0.6</td>
<td>0.81</td>
<td>299,042,860</td>
<td>1,039.68 165.55</td>
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<tr>
<td>1991</td>
<td>845,206,173</td>
<td>0.74</td>
<td>202.77</td>
<td>0.54</td>
<td>0.79</td>
<td>323,371,683</td>
<td>1,384.27 174.14</td>
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</tr>
<tr>
<td>1996</td>
<td>922,174,957</td>
<td>0.73</td>
<td>219.49</td>
<td>0.51</td>
<td>0.78</td>
<td>335,467,809</td>
<td>1,593.33 175.7</td>
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<tr>
<td>2001</td>
<td>993,951,758</td>
<td>0.72</td>
<td>236.2</td>
<td>0.49</td>
<td>0.78</td>
<td>347,522,870</td>
<td>1,816.48 176.52</td>
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<tr>
<td>2006</td>
<td>1,058,385,606</td>
<td>0.71</td>
<td>252.92</td>
<td>0.46</td>
<td>0.78</td>
<td>359,436,900</td>
<td>2,042.14 176.95</td>
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<tr>
<td>2011</td>
<td>1,114,279,961</td>
<td>0.7</td>
<td>269.64</td>
<td>0.44</td>
<td>0.77</td>
<td>371,187,426</td>
<td>2,258.19 177.18</td>
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<tr>
<td>2016</td>
<td>1,161,343,896</td>
<td>0.69</td>
<td>286.35</td>
<td>0.42</td>
<td>0.77</td>
<td>382,729,639</td>
<td>2,454.47 177.3</td>
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<tr>
<td>2021</td>
<td>1,199,988,848</td>
<td>0.68</td>
<td>303.07</td>
<td>0.4</td>
<td>0.77</td>
<td>394,016,633</td>
<td>2,624.50 177.36</td>
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<tr>
<td>2026</td>
<td>1,231,071,223</td>
<td>0.67</td>
<td>319.79</td>
<td>0.38</td>
<td>0.77</td>
<td>404,999,889</td>
<td>2,765.79 177.4</td>
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<tr>
<td>2031</td>
<td>1,255,657,675</td>
<td>0.66</td>
<td>336.5</td>
<td>0.36</td>
<td>0.77</td>
<td>415,628,837</td>
<td>2,879.21 177.41</td>
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<tr>
<td>2036</td>
<td>1,274,850,587</td>
<td>0.65</td>
<td>353.22</td>
<td>0.35</td>
<td>0.76</td>
<td>425,852,264</td>
<td>2,967.76 177.42</td>
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<tr>
<td>2041</td>
<td>1,299,679,223</td>
<td>0.65</td>
<td>369.94</td>
<td>0.33</td>
<td>0.76</td>
<td>435,618,787</td>
<td>3,035.41 177.43</td>
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<tr>
<td>2046</td>
<td>1,301,044,829</td>
<td>0.64</td>
<td>386.66</td>
<td>0.32</td>
<td>0.76</td>
<td>444,876,383</td>
<td>3,086.22 177.43</td>
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<tr>
<td>2051</td>
<td>1,309,702,930</td>
<td>0.63</td>
<td>403.37</td>
<td>0.31</td>
<td>0.76</td>
<td>453,573,762</td>
<td>3,123.91 177.43</td>
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<tr>
<td>2056</td>
<td>1,316,267,767</td>
<td>0.62</td>
<td>420.09</td>
<td>0.3</td>
<td>0.76</td>
<td>461,660,781</td>
<td>3,151.61 177.43</td>
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<tr>
<td>2061</td>
<td>1,321,227,815</td>
<td>0.62</td>
<td>436.81</td>
<td>0.29</td>
<td>0.76</td>
<td>469,089,089</td>
<td>3,171.83 177.43</td>
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<tr>
<td>Final</td>
<td>1,324,300,353</td>
<td>0.61</td>
<td>450.18</td>
<td>0.28</td>
<td>0.76</td>
<td>474,526,517</td>
<td>3,183.95 177.43</td>
<td></td>
</tr>
</tbody>
</table>
Appendix VI

Projected Behaviors of Estimated Dynamic Functions

Figure 1: Total Population Behavior
\[ y = e^{b(1 + \exp(-a-c))} \] [Sigmoid]
\( r^2 = 0.84947721 \times 1 \)

Figure 2: Percentage of Rural Population Behavior
\[ y = e^{b(1 + (x-c)/d) - d/2} \] [Lorentzian]
\( r^2 = 0.94321739, F \text{ value } 202.364 \)

Figure 3: Total Energy Behavior
\[ y = e^{b(x-z)} \]
\( r^2 = 0.88301734 \)

Figure 4: Fraction of Non-Commercial Energy Behavior

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